Progress at LAMPF

July—December 1981
Clinton P. Anderson Meson Physics Facility

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ABSTRACT

Progress at LAMPF is the semiannual progress report of the MP Division of the Los Alamos National Laboratory. The report includes brief reports on research done at LAMPF by researchers from other institutions and Los Alamos divisions.
Time to Think about the Future:

LAMPF continues to increase its capabilities and productivity. Experimenters are asking ever more sharply defined questions and experiments are becoming increasingly illuminating. The rate of accomplishment is high, but strongly limited by budgets for research and operations. This state of affairs is expected to continue through the rest of this decade.

However, now is the time to start giving serious thought to the direction of nuclear physics generally, and LAMPF activities in particular — during the 1990s. The vast world-wide effort on weak interactions is almost guaranteed to open new doors for pursuing the study of nuclear as well as subnuclear physics. Quark physics appears to be here to stay. Low-energy pion probes are proving extremely powerful, and high-energy ones hold similar promise, as do kaons and antiprotons, for opening new windows on the atomic nucleus. So what shall we do to assure the nation a high level of accomplishment in nuclear physics next decade and perhaps the one beyond that?

A serious effort has commenced to explore the options available to us if we use LAMPF as an injector for a higher energy accelerator. Studies are being pursued, workshops are being held, and attempts are under way to elicit the wishes and enthusiasms of the scientific community, upon whom our nation depends for producing the knowledge and people for coping with all matters nuclear. Your input is urgently required. Without it, nothing will happen.

Louis Rosen
Director, LAMPF
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Experimental Areas

Primary beam lines in experimental areas:

Line A — Main Beam Line for Pion and Muon Channels
Line B — Neutron and Proton Beams and Nuclear Chemistry Facility
Line C — High-Resolution Proton Spectrometer
Line D — Weapons Neutron Research Facility

Experimental beam lines:

Area A:
BSA — Beam Stop A
EPICS — Energetic Pion Channel and Spectrometers
LEP — Low-Energy Pion Channel
P³ — High-Energy Pion Channel
SMC — Stopped Muon Channel
TTA — Thin Target Area

Area B (AB or Nucleon Physics Facility):
BR — Neutrons and Protons
EPB — External Proton Beam
LB-NC — Line B — Nuclear Chemistry

Area C:
CCH — Area C Control and Counting House
HRS — High-Resolution Proton Spectrometer

Area A-East:
Biomedical Pion Channel
TA-5 — Target A-5
ISORAD — Isotope Production and Radiation Effects Facility
Neutrino Area
I. LAMPF NEWS

- Summer brings many visitors to LAMPF. Pictured are some who were present in August: Vernon Hughes (Yale University), Earle Lomon (Massachusetts Institute of Technology), Fred Goldhaber (State University of New York at Stony Brook), Dirk Walecka (Stanford University), and R. R. Wilson, formerly Director of Fermilab, now Pupin Professor of Physics at Columbia University.

Vernon Hughes, Yale University

Fred Goldhaber, State University of New York at Stony Brook
Earle Lomon, Massachusetts Institute of Technology

Dirk Walecka, Stanford University

R. R. Wilson, formerly Director of Fermilab, now Pupin Professor of Physics at Columbia University
Translation:  **FANG YI MEETS U.S. FAMOUS NUCLEAR SCIENTIST, DR. ROSEN**

NewChina News Agency Telegraph, October 10, Peking:
Vice Premier Fang Yi met this afternoon at Tze-Quan (Violet Light) Hall in Zhong-Nan-Hai (Mid-South Sea) with the head of the (medium-energy) physics division of Los Alamos National Laboratory, USA, famous nuclear scientist Dr. Rosen and his wife.

- Louis and Mary Rosen visited China September 25-October 19, 1981. They are shown with Vice Premier Fang Yi (center), whose responsibilities include science, technology, and education. The Rosens renewed friendships with two Chinese physicists who visited LAMPF in May 1980. They are Li Shounan (front row, left) and Ding Dazhao (back row, right).

- Danny Doss and Dick Hutson (both in Group MP-3) have a new algorithm for computing corneal shape. arrived at serendipitously over coffee. A photograph of the corneal reflections of concentric rings can be analyzed to yield information on distortions of the cornea. J. James Rowsey, chief of corneal surgery at the Dean A. McGee Eye Institute and the Department of Ophthalmology at the University of Oklahoma, says the technique is something eye specialists have been seeking without success for the past 100 years. "The Los Alamos technique is a bridge that has filled a gap in ophthalmology." Rowsey concludes. "We can now
Darny Doss and Dick Hutson

monitor patients before and after surgery or corrective lens fitting, to define the success of the therapy and make continuing corrections as needed."

- The voluntary separation program at the Laboratory has caused major changes in the administrative structure at LAMPF. T. M. Putnam, Assistant Division Leader for LAMPF Safety, will retire as of February 1982. Donald R. F. Cochran will exchange his duties as Assistant Division Leader for Experiment Evaluation and LAMPF Users Liaison for those that Tom Putnam relinquishes. James N. Bradbury, on an acting basis, assumes the position vacated by Cochran. The LAMPF organization chart in this issue reflects these changes.

Several other people senior in service at LAMPF also opted for voluntary separation. These include Mary Riggs and Kitty Maraman in the Division Office, Lois Rayburn in the Operations Office, Pauline Ungnade in the Safety Office, Garrison H. French of Group MP-13, and Joe Katcher of Group MP-11.

- Linda Tyra, supervisor of the LAMPF Visitors Center for the past 2 years, married Andrew Bacher on December 20, 1981. The Bachers will make their home in Bloomington where Andy is Professor of Physics at Indiana University.
II. MEETINGS

LAMPF Users Group, Inc.

Fifteenth LAMPF Users Group Annual Meeting

The LAMPF Users Fifteenth Annual Meeting was held in Los Alamos on November 2 and 3 with 216 attendees. Chairman Felix Boehm (California Institute of Technology) presided at the opening session, which included a welcoming address by Donald M. Kerr, Director of the Los Alamos National Laboratory, Clarence R. Richardson, Division of Nuclear Physics, Office of Energy Research of the Department of Energy, presented “A Report from Washington.” A report on the status of LAMPF was given by Louis Rosen, Director of LAMPF, and Donald C. Hagerman, Chief of Operations, reported on LAMPF operations. The second portion of the morning session was devoted to New Directions, with reports by Gerard J. Stephenson entitled “Progress Report on a Proposal for a Los Alamos Neutrino Facility;” Darragh E. Nagle, “Progress Report on a Kaon Factory;” and Henry A. Thiessen, “Embryonic Plans for Kaon Factory Experimental Areas.”

The afternoon session was conducted by incoming Chairman Harold E. Jackson, Argonne National Laboratory, and included the Annual Users Group Report by Felix Boehm. The results of the election were given; George J. Igo, University of California, Los Angeles, is the Chairman elect. Other new members of the Board of Directors are George A. Cowan, Los Alamos, and Norton M. Hintz, University of Minnesota. Members whose terms continue in 1982 are Harold E. Jackson, Argonne National Laboratory, Chairman; Felix H. Boehm, California Institute of Technology, Past Chairman; Ernest J. Moniz, Massachusetts Institute of Technology; and L. Wayne Swenson, Oregon State University. The remainder of the afternoon session was devoted to talks by Jean-Pierre Blaser, Director, Swiss Institute for Nuclear Research, who spoke on “SIN: Status, Future Scientific and Technological Plans;” Milla Baldo Ceolin, University of Padova-CERN, who discussed “Neutron Oscillations;” and Alex Zehnder, ETH-Zurich, who reported on “The Hunting for the Axion.”

The Tuesday morning session, presided over by Robert Eisenstein, Carnegie-Mellon University, was devoted to reports by Robert Redwine, Massachusetts Institute of Technology, who spoke on “Searches for Violation of Muon Number Conservation;” George A. Rinker, Los Alamos, who reported on “Current Problems in Muonic Atom Physics;” and David J. Ernst, Texas A&M University, who discussed “Recent Results in the Pion-Nucleus Interaction.”

The remainder of the day was devoted to working group meetings. A round table discussion of “Planning for a Kaon Factory” was held in the evening.

The 1982 Working Group Chairmen are as follows:

| Stopped Muon Channel (SMC) | Gary Sanders | Los Alamos |
| Solid-State Physics and Materials Science | Robert Brown | Los Alamos |
| Neutrino Facilities | Herbert Chen | University of California, Irvine |
| Muon Spin Rotation | Richard Hutson | Los Alamos |
| Nuclear Chemistry | Bruce Dropesky | Los Alamos |
| Biomed | James Bradbury | Los Alamos |
| Nucleon Physics Laboratory (NPL) | Lawrence Pinsky | University of Houston |
| Polarized Facilities | Michael McNaughton | Los Alamos |
| Energetic Pion Channel and Spectrometer (EPICS) | Donald Geesaman | Argonne |
| Computer Facilities | Michael McNaughton | Los Alamos |
| High-Energy Pion (P') Channel | Hans Plendl | Florida State University |
| Low-Energy Pion (LEP) Channel | Barry Ritchie | University of South Carolina |
| High-Resolution Spectrometer (HRS) | John McGill | Rutgers University |
| Graduate Student/Postdoc | John Faucett | University of Oregon |
| $\pi^0$ Spectrometer | Helmut Baer | Los Alamos |
Technical Advisory Panel

Chairman Felix Bochm, California Institute of Technology, presided at the meeting of the Technical Advisory Panel (TAP) on Wednesday, November 4, 1981. Louis Rosen spoke to the group, expressing cautious optimism regarding the LAMPF budget outlook. Budgetary restrictions continue to be a prime concern. A production schedule of about 24 weeks is still projected if appropriate funding is obtainable. Rosen expressed concern that should a "worst case" budget situation evolve, the resulting limited period of operations might seriously affect the biomedical program. The 6 months' shutdown periods are not regarded with favor by the TAP.

Rosen commented on the developing VAX computer system with its possibility that Users might be able to access the system from their home institutions when it becomes fully operational, possibly within a year. This effort will be reviewed at the next TAP meeting.

Donald C. Hagerman presented an optimistic report on the Proton Storage Ring (PSR) and polarized ion source activities, stating that these activities have the full support of the Laboratory administration and that the new and innovative projects at LAMPF present a challenge to those involved in their development.

Wayne Cornelius and Robbie York reported that a proposal for an optically pumped polarized ion source has been submitted to the LAMPF administration, with a projected cost of $2 million and a completion schedule of 3-4 years. The possibility of a collaboration with KEK (Japan) to develop such a source was investigated. It was learned that the Japanese are not interested in further collaboration other than that already established with Fermilab, Stanford, and Brookhaven National Laboratory. They seem willing to permit observers to share their technology on a reasonable basis. It should be possible to obtain a copy in two or three years at a probable cost of about one million dollars. The TAP feels that liaison with KEK should be maintained and George Igo, UCLA, will investigate the possibility of closer collaboration.

The existing Lamb-shift source is operating reliably with the possibility of a factor of two increase in intensity; however, the polarized-neutron program must be held back because of the inability to achieve a factor of 100 increase in beam current.

Lewis Agnew presented a report of experimental operations and possible future programs. A schedule of anticipated needs for improvements and maintenance for beam lines was outlined, contingent on budgetary restraints. The TAP strongly recommends that LAMPF operations should strive for a 1-mA beam.

Richard Boudrie gave an update on the LEP spectrometer. The TAP still holds the opinion that it is over-designed and asked that a subcommittee be formed to review the proposal. Cyrus Hoffman, Los Alamos, and Wayne Swenson, Oregon State University, will study the proposed design and also look into the possibility of an EPICS II.

Robert Macek and H. A. Thiessen, Los Alamos, discussed the proposal for the development of a dispersed beam for the P3 channel. The TAP requested a clear statement of requirements to be presented at the next Board of Directors/TAP meeting.

David Vieira, Los Alamos, gave a progress report on the Time-of-Flight (TOF) spectrometer, outlining the proposal that it be placed in the present location of the Area A basement shop, which would increase the cost by about $100k. Some optics and design problems remain to be solved. The TAP concurs in this proposal.

Ted Spitzmiller, Los Alamos, discussed the LAMPF Electronics and Equipment Pool (LEEP) and computer maintenance activities. The staff for computer maintenance is limited to ongoing experiments, and the LEEP management continues to need very early input for large and/or unusual requests for equipment. The TAP recognizes the progress LEEP has made, stresses the need for further growth, and deplores the lack of User response to the definition of needs.

A discussion of the neutrino facility was led by Lewis Agnew. Cost estimate for a neutrino tunnel to fit the needs of Proposal 645 was estimated at $500-$600k with a time estimate of about 18 months for construction. Gerard Stephenson, Los Alamos, stated that the Laboratory is preparing a proposal for submission to DOE by January 1982 to accommodate Proposal 638. The BOD/TAP would like to review the proposal before submission but because time will not allow this, Chairman Bochm accepted the responsibility of representing BOD/TAP interests.

H. A. Thiessen, Los Alamos, reported on inputs he had received regarding LAMPF II. The BOD/TAP strongly supports efforts leading to a proposal for LAMPF II and recommends implementation of mechanisms for getting user input and employing user effort.
Board of Directors

The Board of Directors of the LAMPF Users Group, Inc., met on Friday, July 31, 1981, with Chairman Felix Boehm presiding.

Guidelines for the new DOE security procedures for visits and assignments of foreign nationals were discussed; instructions to spokesmen will be sent out. Louis Rosen provided a review of operations and a discussion of future funding possibilities for LAMPF. Several funding options are being investigated which, if approved, would increase LAMPF's running time to 28-30 weeks of production for the year. A collaborative development effort between LAMPF and KEK in Japan for an optically pumped ion source is being studied. The budget for LEEP has been increased to $50-$100k with an additional increase projected for next year. Rosen stressed the need for the establishment of a dedicated constituency in support of a kaon factory, and presented the view formulated by several leaders in this field that there should be one kaon factory in the world and that a world-wide collaboration might be sought.

Felix Boehm reported briefly on the Neutrino Workshop and stated that a full report of the workshop is being prepared. A shop to meet the needs of Users was discussed and the idea was endorsed by the Board. The TAP is charged with addressing the scope of User shop needs.

Length of the terms of office of the Board Chairman and scope of duties of members of the Board of Directors was discussed. Significant effort is involved; this fact should be taken into account by the nominating committee when it selects a slate of candidates.

The following reports were presented:

Lewis Agnew reported on the online research being done at the neutrino facility and the proposed experiments. Problems in connection with the facility will be reviewed again at the next Board meeting.

Richard Boudrie discussed the proposed new LEP Spectrometer and the projected cost of incorporating some new features. He stated that copies of the Spectrometer Workshop meeting are available in the Users Office. The Board decided that the final design should be sent to the Technical Advisory Panel early enough so that it can be discussed at the November meeting.

Wayne Cornelius elaborated on the optically pumped ion source work. The Board feels that the development collaboration with TRIUMF and KEK should be pursued, and that the LAMPF level of effort should be strengthened.

Martin Cooper and Ted Spitzmiller presented a number of proposals for operating procedures at LEEP. The TAP is charged with soliciting responses from its colleagues on these proposals.

The Board expressed pleasure with the progress on the Time-of-Flight Spectrometer reported by David Vieira.

Robert Macck reported on the progress of kaon factory studies. The Board recognizes the need for more dissemination of information and suggested that more input from universities should be solicited.

Board of Directors

The Board of Directors of the LAMPF Users Group, Inc., met on Wednesday, November 4, 1981 with Chairman Felix Boehm, California Institute of Technology, presiding. Seventeen candidates for the Program Advisory Committee (PAC) were selected and their nominations sent to Louis Rosen for consideration. Newly appointed or reappointed members of the TAP are:

Billy E. Bonner (Los Alamos/Rice University)
Thomas J. Bowles (Los Alamos)
Gerald Dugan (Columbia University)
Barry M. Precdom (University of South Carolina).

Other members who will continue to serve during 1982 are:

James F. Amann (Los Alamos)
Herbert H. Chen (University of California, Irvine)
Daniel H. Fitzgerald (University of California, Los Angeles)
Robert Heffner (Los Alamos)
Paul J. Karol (Carnegie-Mellon University)
Michael Paciotti (Los Alamos)
William R. Wharton (Carnegie-Mellon University)
Benjamin Zeidman (Argonne National Laboratory).
Robert Eisenstein agreed to act as Chairman of the Nominating Committee.

The recommendations of the TAP were accepted. The graduate student/postdoc organization remains interested in continuing their own physics seminars and will be supported by LAMPF if they will take the initiative. Student representative John Faucett will be contacted.

The Board of Directors is quite interested in studies for LAMPF expansion and improvement (LAMPF II) and recommends a strong advocacy role from the User community. Additional Board of Directors meetings will be scheduled to monitor LAMPF II progress.
The incoming Chairman, Harold Jackson, will continue to be concerned with long-range plans and will emphasize agenda items such as update of LAMPF II working group reports, review of neutrino facility proposal, discussion of User involvement, initiation of a bulletin-type newsletter to foster awareness of LAMPF in the User community, and continued investigation of the possibility for a social area for LAMPF Users.

Visitors Center

During this report period, 391 research guests working on LAMPF-related activities or participating in experiments visited LAMPF. Eighty-two were foreign visitors. A total of 358 check-ins and 400 check-outs were processed by the Visitors Center. A complete list is attached in Appendix C.

Housing requirements for 1981 decreased approximately 15% over the previous year. Families housed in LAMPF apartments totalled 2. students housed totalled 61 in efficiency units, and townsite sublets totalled 18. The number of Users in LAMPF efficiency (short-term) units was 584 for the year. In addition, miscellaneous apartment rentals totalled 14, and 145 motel reservations were arranged for visitors.

A breakdown of user statistics follows.

—M. M. Eutsler

*MEMBERSHIP*

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<tr>
<th>Institution</th>
<th>Number</th>
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<tr>
<td>Non-Los Alamos National Laboratory</td>
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<tr>
<td>Los Alamos National Laboratory</td>
<td>191</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>955</td>
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*FIELDS OF INTEREST*

<table>
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<th>Field of Interest</th>
<th>Number</th>
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<tr>
<td>Nuclear and Particle Physics</td>
<td>748</td>
</tr>
<tr>
<td>Nuclear Chemistry</td>
<td>141</td>
</tr>
<tr>
<td>Solid-State Physics and Materials Science</td>
<td>185</td>
</tr>
<tr>
<td>Theory</td>
<td>185</td>
</tr>
<tr>
<td>Biomedical and Biological Applications</td>
<td>240</td>
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<tr>
<td>Weapons Neutron Research</td>
<td>98</td>
</tr>
<tr>
<td>Data Acquisition</td>
<td>167</td>
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<tr>
<td>Administration, Coordination, Facilities, Operations, Practical Applications, etc.</td>
<td>156</td>
</tr>
<tr>
<td>Isotope Production</td>
<td>88</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>955</td>
</tr>
</tbody>
</table>

(Note: These numbers do not add to total membership because of multiple interests.)

*REGIONAL BREAKDOWN*

<table>
<thead>
<tr>
<th>Region</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwest (Ohio, Missouri, Kansas, Indiana, Wisconsin, Michigan, Illinois, North Dakota, South Dakota, Nebraska, Iowa, Minnesota)</td>
<td>100</td>
</tr>
<tr>
<td>South (Maryland, Virginia, Tennessee, Arkansas, West Virginia, Kentucky, North Carolina, South Carolina, Alabama, Mississippi, Louisiana, Georgia, Florida)</td>
<td>83</td>
</tr>
<tr>
<td>Southwest, Mountain (Montana, Idaho, Utah, Wyoming, Arizona, Colorado, New Mexico, Oklahoma, Texas) (excluding Los Alamos)</td>
<td>148</td>
</tr>
<tr>
<td>West (Alaska, Hawaii, Nevada, Washington, Oregon, California)</td>
<td>124</td>
</tr>
<tr>
<td>Foreign</td>
<td>174</td>
</tr>
<tr>
<td><em>Los Alamos National Laboratory</em></td>
<td>191</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>955</td>
</tr>
</tbody>
</table>
**H^- Workshop**

A Workshop on the Physics of H^- was held by the University of New Mexico and Los Alamos National Laboratory on November 12, 13, and 14, 1981 at the Los Alamos Linear Accelerator Facility (LAMPF). The organizing committee for the workshop was:

- J. B. Donahue (Los Alamos)
- P. A. M. Gram (Los Alamos)
- D. A. Clark (University of New Mexico)
- W. W. Smith (University of Connecticut)
- H. C. Bryant (University of New Mexico).

Workshop staff were Linda Tyra and Alice Horpedahl of LAMPF. The workshop was supported by the US DOE (Contract DE-AS04-77ERO 3998), Los Alamos National Laboratory, and the University of New Mexico.

The two-day workshop was divided into four main sessions, each focusing on a different aspect of the H^- problem, and included as well a session on related work with the parent H^0 atom. The unifying theme of the workshop was the ongoing experimental work at LAMPF, which, by exploiting the relativistic kinematics of an 800-MeV H^- beam, has made accessible the resonance region of H^- with unprecedented resolution.

The first session, entitled “H^- Resonance Structure,” was chaired by John S. Risley from North Carolina State University, who inaugurated the conference with a brief survey of the energies and widths of the H^- resonances. David A. Clark gave a detailed account of the studies at LAMPF of the photodetachment spectrum of H^-; especially as it bears on the character of the resonances in H^-.

He also described the recent precision measurement of the energy of the 1P Feshbach resonance below the n = 2 threshold in H^0. By arranging for three harmonics of the YAG laser to produce three separate, but carefully synchronized beams to intersect the H^- beam at three different points, it has been possible to measure the energy of this “touchstone” resonance in H^- relative to the very well-known levels in H^0. So far, this technique has yielded a value for the photon energy required to excite this resonance of 10.925 ± 0.002 eV. Experiments planned for the spring of 1982 should reduce the uncertainty of the measurement to 1 meV. Discussion following the talk revealed that this measurement of the Feshbach energy should be sensitive to “mass polarization” effects, in which the energy taken up by the proton’s motion is strongly influenced by the correlation between the two electrons. The second speaker was Chih-Dong Lin, Kansas State University, who discussed the spectroscopy of H^- based on the theoretical approach of the Fano school, development of the Schrödinger equation in hyperspherical coordinates. Dr. Lin reported on detailed studies he has made of the correlation between the two electrons in H^-.

These correlations were presented as three-dimensional plots, shown in perspective, which demonstrated clearly the tendency for the two electrons to reside on opposite sides of the proton, and how this correlation depends upon the “hyperspherical radius” (the square root of the sum of the squares of the individual electron-proton distances). The final paper in the “H^- Resonance Structure” session was by David Herrick, University of Oregon, who presented a group-theoretic approach to the two-electron atom, which compared the structures of helium and H^-.

Using Lie algebra, Herrick and his coworkers have been able to arrange the states of these two atomic systems into supermultiplets according to quantum numbers based on angular momentum and the Lenz vector. Following Herrick’s talk, John Nuttall, University of Western Ontario, called attention to the possibility of large-computer calculations for the exact determination of energy levels by “brute force.”

Gary D. Doolen, Los Alamos, described briefly his computations on the Los Alamos National Laboratory CRAY using 816 basis states.

The Thursday afternoon session, entitled “Threshold Laws for H^-,” chaired by Joe Macek, University of Nebraska, began with a presentation by Joey B. Donahue, Los Alamos, on the experimental measurement at LAMPF of the two-electron photodetachment cross section. The LAMPF group finds results consistent with the Wannier law. However, the possibility of an oscillatory modulation of the cross section near threshold cannot be ruled out, if the amplitude of the oscillations is sufficiently small. Donahue also discussed some of the methodological discoveries made in perfecting these measurements which will be helpful in future work on the H^- structure.

Turning to theoretical methods of treating threshold laws, A. R. P. Rau of Louisiana State University briefly reviewed the evolution of threshold laws in general, and then discussed in detail the Wannier idea of dynamic screening and its quantum mechanical implications. One finds, not unexpectedly, that the situation where both electrons remain equal distances from the proton is favored for the detachment process, but it is rather surprising that although the individual angular momentum states of the electrons must be uniformly distributed up to very large values, the threshold cross-section behavior does not depend upon the total angular momentum, so the fact that the photoabsorption process

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picks out the $L = 1$ state is essentially irrelevant. Aaron Temkin of NASA/Goddard Space Flight Center presented his approach to the two-electron detachment problem. In contrast to the Wannier result championed by Rau, Temkin favors what he terms a “Coulomb-dipole theory” in which the dominant contribution to the process is one where the energy partition between the two escaping electrons is asymmetric. This approach yields a threshold law, which, although it is monotonically increasing with energy above threshold, is subject to possible oscillatory modulations. So far no computations of the specific form of the threshold law have been performed, and although its general behavior can be delineated, there are no estimates of either the size or periodicity of the putative oscillations. The final presentation to the workshop on Thursday was a change in pace going back to a strictly classical treatment of the two-electron ion by Kenneth Butterfield, a graduate student in the LAMPF group from the University of New Mexico. Butterfield discussed some results of a computer code that generates trajectories of two electrons and a proton for various initial conditions. The results were presented in a series of binocular colored slides which the audience viewed through special “3-D” glasses. (Most people were actually able to fuse the binocular view into one three-dimensional image.) Butterfield has found that for certain highly symmetrical initial conditions he can get “quasi-stationary” states in which the two electrons remain in the vicinity of the proton. However, for all other initial conditions he has tried, the atom “autoionizes,” with one electron picking up escape velocity from the other, so that one electron spirals in as the other spirals out. The “mathematical experiment” leads to the conjecture that, even without radiation, the classical multielectron atom is, in principle, unstable.

The third session, on Friday morning, entitled “H" in Strong Electric Fields,” was chaired by P. A. M. Gram. According to the customs of this workshop, the first talk was a presentation of LAMPF results for H" in strong fields by H. C. Bryant. Bryant charted the changes in the photodetachment spectrum in the vicinity of the $n = 2$ H" resonances as a function of electric field. The phenomena evidently involve four resonant structures, two seen in the zero field spectrum because they are $^1P_g$, and two unseen, because they cannot be excited in a one-photon process. These four seem to form two pairs that dominate the response in separate regimes of electric-field strength. When small fields are applied, the narrow $^1P$ Feshbach resonance evidently mixes strongly with a nearly degenerate $^1S$ state to give a “linear Stark effect” behavior. As the effective field is increased above 400 kV/cm, these narrow states evidently quench, and noticeable structural changes occur in the $^1P$ shape resonance. Also beginning with field values above 400 kV/cm, a structure appears in the vicinity of a $^1D$ resonance lying some 100 meV below the shape resonance. The systematics of these measurements were compared with a simple perturbation theory. The second talk, by William Reinhardt, JILA, University of Colorado, dealt with theoretical methods of treating the H" ion in strong electric fields. Reinhardt presented the “complex rotation” method for dealing with perturbations by external fields. He went on to discuss recent semiclassical work in which one quantizes line integrals around an “invariant torus.” Joe Macek, University of Nebraska, the next speaker, remarked on the possible implications H" work might have for other three-body problems. An inverse square potential apparently plays a role in the binding of quarks at short ranges and of course is operative in such objects as the H$_2^+$. Macek discussed the hyperspherical approach to the three-body problem, in which he was a pioneer, and the problems involved in the treatment of long-range Coulomb interactions. An extensive discussion concerning three-body effects followed. K. T. Chung, North Carolina State University, next spoke briefly on his work on the formation of low-lying doubly and triply excited He" states.

Peter M. Koch, Yale University, introduced the final session, “Symposium on H$^0$ in Strong Fields,” chaired by W. W. Smith, with a discussion of his experimental and theoretical work on Stark effects in H$^0$.

After Koch's talk, the workshop was adjourned for lunch, after which tours of the linear accelerator were arranged with emphasis on a display of the equipment used in the H" studies. Peter Gram gave a brief and entertaining slide show introducing LAMPF to the conference attendees.

Winthrop W. Smith called together the afternoon session, which was a continuation of the segment begun by Koch, “Symposium on H$^0$ in Strong Fields,” with a brief description of how H$^0$ can be produced with near-luminal velocities (either by stripping or by photodetachment) at LAMPF. Subsequently, the same techniques which have been used successfully to study H" can be applied to H$^0$. In particular, the behavior of the low-lying states of H$^0$ can be observed for the first time in very strong fields. The next speaker was Thomas H. Bergeman, SUNY, Stony Brook, who presented calculations on the effects
of strong fields on $H^0$, emphasizing the possible interest in fluctuations in oscillator strength above threshold. Harris J. Silverstone, Johns Hopkins, next introduced the workshop to the arcane (to many of us) mathematics involved in summing the divergent series in the Stark effect. Charles Clark, National Bureau of Standards, Washington, discussed the spectroscopy of $H^0$ in a magnetic field, and results of calculations on the CRAY computer using thousands of Sturmian functions. At 5 T, one finds an amazingly rich structure in this simplest of structures. The final speaker of the workshop was Munir H. Nayfeh, University of Illinois, who reported recent work on two-photon spectroscopy in the $H^0$ atom.

The organizers wish to thank J. V. Martinez, USDOE; Louis Rosen, Director of LAMPF; Marcus Price, Chairman, Physics and Astronomy, University of New Mexico; and Dean F. Chris Garcia, College of Arts and Sciences, University of New Mexico, for their steadfast support. They also wish to acknowledge with many thanks the Physics and Astronomy secretarial staff at the University of New Mexico for their patience and help. Finally, it must be admitted that the whole workshop would have collapsed without the talents and hard work of Alice Horpedahl and Linda Tyra at LAMPF.

—P. A. M. Gram and H. C. Bryant
III. RESEARCH

Nuclear and Particle Physics

Measurement of Parity Violation in the p-Nucleon
Total Cross Sections at 800 MeV
(Exp. 634, EPB)
(Los Alamos, Univ. of Illinois)
Spokesmen: R. Carlini and R. Talaga (Los Alamos) and V. Yuan (Univ. of Illinois)

The goal of this experiment is to measure the contribution of the weak force to nucleon-nucleon scattering at 800 MeV. Although the scattering is dominated by strong and electromagnetic interactions, the weak interaction may be identified by the signature of parity violation. In this experiment longitudinally polarized protons are scattered from an unpolarized target, and parity violation manifests itself as a small helicity dependence in the total cross section.

The experiment is one of a series of experiments to measure the weak nucleon-nucleon interaction as a function of energy. Calculations of the helicity-dependent asymmetry of the total cross section have been published for energies corresponding to those experiments. At 15 and 45 MeV the calculations\(^1\)\(^-\)\(^3\) are in good agreement with the experimental results\(^4\)\(^-\)\(^5\) of \(\sim 1 \times 10^{-7}\). However, at 6 GeV the prediction\(^6\) is \(0.5 \times 10^{-7}\) whereas the experimental value\(^7\) is \((2.6 \pm 0.6) \times 10^{-4}\), more than an order of magnitude larger. At 800 MeV the Henley and Krejs calculations\(^6\) predict the asymmetry to be \(\sim 1 \times 10^{-7}\).

The experiment uses the LAMPF polarized proton beam at an energy of 800 MeV. Polarization is reversed at a rate of 30 Hz at the injector. Two ion chambers determine the cross section by measuring the transmission of the polarized proton beam incident on target. A diagram of the experimental layout is shown in Fig. 1. Both detectors are integrating types, specially designed to handle the full polarized proton beam current. By analyzing the signal for a component correlated with the 30-Hz polarization reversal frequency we can determine the magnitude of any helicity dependence of the total cross section. Auxiliary detectors measure systematic contributions that can result in an apparent helicity-dependent cross section actually unrelated to the weak force. Systematics of this type includes the effects of residual transverse polarization, position motion, intensity modulation, and a phase-space distribution of residual transverse polarization. A large part of the experiment is dedicated to measuring the sensitivity of the transmission detectors to changes in these beam characteristics at the 30-Hz polarization reversal frequency.

The desirable placement for the beam through the apparatus is along an axis that minimizes the effect of the systematic contributions. Before taking any production data this axis is experimentally determined and the beam is located along it to a precision of 0.1 mm. Throughout the run, changes in beam properties are minimized when possible. Long-term beam motion and 30-Hz intensity modulation were held constant by means of servo-feedback systems.

A limiting factor to the sensitivity of the experiment is the noise level of the transmission detectors. To judge the performance of the detectors the noise level is compared to \(I^{-1/2}\), where \(I\) is the beam current incident on target. This noise level corresponds to the noise caused solely by counting statistics in the case of a 50% transmission target. In the early part of this year we worked on a new

![Fig. 1.]
Schematic of experimental apparatus.
detector design to decrease the noise level of the transmission detectors and to understand the origin of this noise, which in previous runs was ~15 times counting statistics. As reported in the previous progress report the source of the noise was spallation products produced in the foils of the ion chambers themselves! Before the July run new detectors (with electrodes parallel to the beam) were built to tolerance levels necessary to reach a sensitivity equal to counting statistics.

During the second half of 1981 the experiment ran for 1 week in July and for another week at the end of November. The July run was conducted with many new pieces of apparatus. In addition to building new ion chambers we developed improved low-noise amplifiers and signal-sampling electronics, a polarimeter for use at high beam currents, and an automated beam-scanning target. A large portion of time spent during the run was devoted to optimizing the performance of the apparatus.

Data were taken primarily with the target out. Both slow-reversal (NN and RR) states of the polarized source were examined for consistency in their target-out, helicity-dependent cross-section measurements. There was no difference for the two source states within statistics at a level of $1 \times 10^{-7}$ in the raw asymmetry. Using the beam-scanning target we were able for the first time to scan the profile of the beam and map the distribution of residual transverse polarization components across that profile. Measurement of the polarization distribution within the beam is essential to the systematic error analysis of the experiment. A target-out noise level of 1.2 times counting statistics was achieved in the ion-chamber transmission detectors. Finally, at the conclusion of the run target-in data were also taken, with a ratio of noise/counting statistics of 4.0.

After the July run a model was developed explaining that the increased noise with the target-in configuration is a result of particles, which are multiple scattered in the target, hitting the collection plates of the detector and producing spallation products. Calculations based on this model and the data taken in July were made in order to determine optimum target position and thickness for data collection. The choice involved striking a balance among several competing considerations regarding target thickness and position. For instance, the helicity-dependent change in cross section ($\Delta \sigma /2\sigma$) is related to the measured change in transmission ($\Delta T /2T$) by a factor of $1/[P(nT)]$. Hence a thick target is desirable because sensitivity in the measurement of the helicity-dependent cross section is enhanced for a given sensitivity in the raw measurement of transmission asymmetry. On the other hand, a thick target increases the amount of multiply scattered particles that hit the downstream ion-chamber plates, thereby undesirably increasing noise from spallation. Additionally, close proximity of the target to the downstream ion chamber results in reduced chamber noise, but at the same time increases sensitivity to polarization systematics. Based on these considerations a 10-cm H$_2$O target was located 150 cm in front of the downstream transmission detector.

As an alternative to producing longitudinally polarized beam by means of the Wien filter located close to the source, a first attempt was made in the November run to take data by using the superconducting spin-precessing solenoid located in the EPB. Use of the EPB precessor to achieve longitudinal polarization is desirable because it allows vertical polarization to be provided to Line C (HRS). As a consequence, a broader range of experiments can be active in Line C while polarization is longitudinal in the EPB. Once longitudinal polarization was obtained by means of the precessor we were able to investigate control of residual polarization components as well as to measure the distribution of residual polarization across the profile of the beam. The results show a disturbingly large variation in transverse polarization across the profile of the beam with the spin-precession solenoid on. More study is needed to determine the origin of this effect and to search for a cure. For the remainder of the run the precessor was switched off and we returned to the Wien filter as the source for longitudinally polarized beam.

During the November run data were taken in several target thickness/position configurations. For the first time we were able to gather information regarding the dependence on target position of the experimental sensitivities to systematic contributions. Using the beam-scanning target, a profile distribution map of polarization components was made for both NN and RR source configurations. As a result of the calculations based on the July data, large improvement in the target-in noise was realized and a noise level as low as 1.4 times counting statistics was achieved with a 10-cm H$_2$O target. After the extensive study and minimization of systematic contributions for the target-in configuration were completed, some production data were taken with an average beam current of 2.5 nA. Preliminary analysis indicates that a statistical precision of $\sim 2 \times 10^{-7}$ in $\Delta T /2T$ was achieved in less than two shifts of data taking. This corresponds to a measurement in $\Delta \sigma /2\sigma$ of better than $1 \times 10^{-4}$. The transmission of the H$_2$O target used ($T = 0.85$) was of...
similar magnitude to that expected from our liquid H\textsubscript{2} target presently under construction. A detailed analysis of the data, including systematic contributions, is currently under way.

REFERENCES


Measurement of the Relative Sign of Neutron and Proton Transition Matrix Elements in (p,p') Reactions
(Exp. 627, HRS)
(Los Alamos, Massachusetts Institute of Technology, Univ. of South Carolina)
Spokesmen: M. V. Hynes (Los Alamos) and A. M. Bernstein (Massachusetts Institute of Technology)

The sensitivity of proton scattering to both proton and neutron densities offers the possibility of testing our understanding of the neutron structure of nuclei in a new way. In particular, s-d shell nuclei have been the subject of extensive shell-model calculations whose experimental tests have largely relied on proton densities derived from electron scattering. For \(T=1\) systems, a technique for deriving the magnitudes of the neutron \(M_N\) and proton \(M_p\) transition matrix elements for low-lying \(c^+\) states using the \(BE2\) values from mirror nuclei has been developed by Bernstein, Brown, and Madsen.\textsuperscript{1} This technique relies strictly on the electromagnetic properties of the state and on isospin invariance. Applications of this approach to the results from hadronic probes have been very few.

The mirror nuclei results determine only the magnitudes of \(M_N\) and \(M_p\), not their relative sign. This arises from taking the square root of the \(BE2\) value in the derivation.

In another language this lack of information about the relative sign simply means that one cannot say whether the \(2^+\) state of interest is isoscalar or isovector in character.

In this experiment, now complete, we have measured the relative signs for the first two \(2^+\) states \((2^+_1\) and \(2^+_2\)\) in \(^{30}\text{Si}\), \(^{34}\text{S}\), and \(^{42}\text{Ca}\). The data were taken in the HRS channel at LAMPF during two runs in August and November totaling 120 h of polarized N-type beam at 500 and 800 MeV. Silicon-30 and -34 were selected because of recent shell-model calculations by Brown and Wildenthal\textsuperscript{*} that indicated that the neutron and proton contributions to the cross sections for the \(2^+_1\) states in these nuclei have the same relative sign whereas for the \(2^+_2\) state in \(^{34}\text{S}\) they have opposite sign. This low-lying isovector \(2^+\) state in an s-d shell nucleus was a great surprise to the theorists. It was suspected that the shell-model calculation was in error. The results of our measurement for this state confirm its isovector character, thus confirming the shell-model results. The isoscalar character of the \(2^+_2\) state in \(^{30}\text{Si}\) as predicted by the shell-model was also confirmed. The results for \(^{42}\text{Ca}\) are still under analysis and a shell-model calculation for this f-shell nucleus is expected soon.

\textsuperscript{*}B. A. Brown and B. H. Wildenthal, private communication (to be published).

REFERENCE


A Test of the Interacting Boson Approximation
(Experiment done at Bates Linac, Bates Exp. #782)
Spokesman: M. V. Hynes (Los Alamos)

In addition to the ground state, the three low-lying and resolvable \(2^+\) states in \(^{156}\text{Gd}\) allow for a test of the interacting boson model of Iachello and Arima. Our
results show that the model is inadequate to describe the data within the context of s- and d-wave bosons. This points to the importance of including higher order terms in the model.

Electron Scattering from the Oxygen Isotopes
(Experiment done at Bates Linac, Bates Exp. #756)
Spokesman: M. V. Hynes (Los Alamos)

After several-thousand hours of beam time this experiment has finally been concluded. The data represent a complete study of the excited states of $^{16}\text{O}$ up to 20 MeV, and of $^{17}\text{O}$ and $^{18}\text{O}$ up to 10 MeV. This work has produced 4 Ph.D. theses and 12 journal articles. The importance of this study to nuclear structure arises from the fact that $^{17}\text{O}$ and $^{18}\text{O}$ are perhaps the best laboratories in which to test our understanding of the addition of one or two neutrons to a double closed-shell nucleus. This experiment was also the starting point for the proton-scattering experiments at Indiana and LAMPF.

Structure of States in the Oxygen Isotopes via Measurements of the Spin-Depolarization and Spin-Rotation Observables
(Exp. 643, HRS)
(Los Alamos, Univ. of California at Los Angeles, Massachusetts Institute of Technology, Univ. of Virginia, Lawrence Livermore Lab.)
Spokesmen: M. V. Hynes (Los Alamos) and B. Aas (Univ. of California at Los Angeles)

The importance of nuclear-medium corrections (such as Pauli blocking) has recently been the topic of intense theoretical and experimental discussion. The possibility of constructing these medium corrections in a fundamental microscopic formalism without phenomenology has arisen from the theoretical work of Brieva and Rook¹ and von Geramb.² In their work the problem of an energetic proton in infinite nuclear matter has been solved. Using these results we have constructed a density-dependent force or effective $t$ matrix that can be applied to finite nuclei by use of the local-density approximation and in conjunction with the extensive electron-scattering data on $^{16}\text{O}$.

¹H. V. von Geramb, private communication (to be published).
²H. V. von Geramb, private communication (to be published).

This approach has had great success at lower energies (135 MeV).³ It is the main thrust of the current experiment to test this approach at 500 MeV. The crucial difference between 135 and 500 MeV or higher energies is the rapid increase in inelasticity caused by, among other things, the opening of the pion channel. The central theoretical question is whether or not the nuclear-matter formalism applied by use of the local-density approximation is indeed applicable at 400 MeV or whether one must resort to a field-theoretical description for the medium corrections.

Data were taken in November using a 500-MeV $N$-type beam on $^{16}\text{O}$. Although results are still in the analysis stage, it appears that the importance of medium corrections is far less at 500 MeV than it was at lower energies. The details of this result will become more apparent when the asymmetry and other spin observables have been analyzed.

The experiment is scheduled to run 240 h in June using $L$- and $S$-type beam to complete the required measurements. The availability of the focal-plane polarimeter at HRS allows for a complete test of the nuclear-matter results because one can test predictions for spin observables other than asymmetries. The lower energy results were incomplete in this regard.

REFERENCES


Measurement of the Triple-Scattering Parameters $D, R, A, R'$, and $A'$ for Proton-Proton and Proton-Neutron Scattering at 500 and 800 MeV
(Exp. 392, HRS)
(Univ. of Texas at Austin, Rutgers Univ., Los Alamos)
Spokesman: G. W. Hoffmann (Univ. of Texas at Austin)

The small-momentum-transfer parts of the fundamental nucleon-nucleon ($N-N$) amplitudes for $p-p$ and $p-n$ are critical first-order ingredients for microscopic calculations that rely on the impulse approximation. Note also, if the free amplitudes are modified by the nuclear medium it is still necessary to determine the free amplitudes so that the modifications can be applied.

For elastic scattering from a spin-zero target nucleus, only the spin-independent, $a(q)$, and spin-orbit, $c(q)$, amplitudes are needed for the calculations. However, to
determine \(a\) and \(c\) from \(N-N\) data, the other Wolfenstein amplitudes \((m, g, \text{and } h)\) must also be determined. In the past, a determination of the \(a\) and \(c\) amplitudes directly from only \(N-N\) cross-section and analyzing-power data at 800 MeV led to three solutions. One of these solutions was basically equivalent to the phase-shift solution obtained by Arndt using all the available data. Thus, data other than cross-section and analyzing-power data apparently remove the three-solution ambiguity noted. However, there are very few 800-MeV data at small-momentum transfer (especially for \(p-n\)) that constrain \(m, g, \text{and } h\), so the \(a\) and \(c\) amplitudes determined by phase-shift analysis may not be accurate at the level required for microscopic analyses of 800-MeV \(p+n\) nucleus data aimed at determining nuclear structure information.

Thus, Exp. 392 was run to provide data that will help further constrain the small-momentum-transfer parts of the double-spin-flip amplitudes \((m, g, \text{and } h)\), which in turn implies additional constraints on \(a\) and \(c\) for the phase-shift analysis.

The first phase of this experiment was completed during runs in April and September 1981. The Wolfenstein triple-scattering parameters, \(D, A, R, A', \text{and } R'\) were measured for quasi-free proton-nucleon scattering at 800 MeV (using a LD\(_2\) target) for laboratory scattering angles of 6, 10, 15, 20, and 25° (except for \(D\), which was not measured at 20 or 25°) using the HRS, the focal-plane polarimeter (FPP), and a recoil-particle detection system. Six orientations of beam polarization were used during the experiment: \(n(\text{up/down}), s(\text{left/right}), \text{and } l(\text{parallel/antiparallel}).\) The HRS detected the forward quasi-elastic high-energy protons while the recoil counter detected, in coincidence with the HRS, the recoil proton or neutron.

At the HRS focal plane the protons were rescattered by the FPP carbon analyzer to determine two of the outgoing proton’s spin components (transverse/horizontal and transverse/vertical). Because of precession of any spin component not parallel to the HRS magnetic fields, the spin components measured at the focal plane were actually mixtures of the orthogonal set of spin components at the target. It is for this reason that the Wolfenstein triple-scattering parameter \(D\) could not be measured at 20 or 25°, at the momenta corresponding to these angles, the outgoing proton’s transverse/vertical spin component precesses to a nearly longitudinal component at the focal plane and cannot be determined. The polarizations measured at the focal plane during the experiment were separated into the appropriate polarization components at the target to determine the triple-scattering parameters.

The second arm, the recoil-particle detection system, facilitated identification of quasi-free proton-proton and proton-neutron scatterings from deuterium. By requiring either a recoil neutron or a recoil proton in coincidence with the HRS-detected event, it was possible to measure both the quasi-free proton-proton and proton-neutron triple-scattering parameters. The quasi-free \(p-p\) data, when compared with free \(p-p\) data to be taken in the next phase of the experiment, will provide some indication of the validity of using quasi-free data to help determine the free nucleon-nucleon scattering amplitudes at 800 MeV. However, based on the results obtained in Exp. 385 (\(p+n\) quasi-free analyzing powers), we expect the quasi-free \(p-n\) results to correspond to the free \(p-n\) case. Also, comparison of some of the quasi-free \(p-p\) data obtained in this experiment with free \(p-p\) data (Exp. 194) obtained at EPB shows remarkable agreement, again suggesting that the quasi-free and free results are the same.

Replay of the data taken during the April 1981 run is complete and a final workup of the data is in progress. Data obtained in September 1981 are now being replayed. Preliminary results of the off-line analysis of the data taken in April \(6, 10, \text{and } 15°\) for proton-neutron, and \(10\) and \(15°\) for proton-proton) are shown in Figs. 1-10. The solid curves are the SF81 phase-shift predictions of Arndt. As is seen, good agreement is found for the proton-proton parameters, as expected, since existing data have already partially determined the scattering amplitudes. However, for proton-neutron parameters these data represent the first measurements of this type at 800 MeV. Thus, the disagreement between experiment and phase-shift predictions is not surprising.

The discrepancies between the phase-shift predictions and the experimental data (particularly for \(A'\) and \(R\)) for the proton-neutron system indicate that these data, along with the data taken in September 1981, should prove very useful in constraining the scattering amplitudes at small-momentum transfer at 800 MeV. The September run obtained data at 6, 20, and 25°, and the statistical errors associated with the \(D, A, R, A',\text{and } R'\) parameters obtained from that run for both \(p-p\) and \(p-n\), for all angles, will be about \(\pm 0.015\).

* By the "Ann Arbor Convention," \(D = D_{NN}, R = D_{SS}, A = D_{LS},\) \(R' = D_{SL}, A' = D_{LL}.\)
Figs. 1-10.
Results for D, R, A, R', and A' for (a) p-n and (b) p-p at 800 MeV obtained during the April run.
Measurement of Spin-Flip Probabilities in Proton Inelastic Scattering at 800 MeV and Search for Collective Spin-Flip Modes (Preliminary Survey) (Exp. 411, HRS)
(Los Alamos, Univ. of Minnesota, Rutgers Univ.)
Spokesmen: N. M. Hintz (Univ. of Minnesota) and J. M. Moss (Los Alamos)

Experiment 411 has received beam time at 397 and 497 MeV to measure the spin-flip probability (SFP) in inelastic scattering. The 397-MeV data for $^{12}$C and $^{208}$Pb have been replayed and the data reduction is complete. The replay of the 497-MeV data is under way.

The results obtained for the $1^{+}$, $T=0$ (12.71-MeV), $1^{+}$, $T=1$ (15.11-MeV), and $2^{+}$, $T=1$ (16.11-MeV) states in $^{12}$C are shown in Figs. 1(a)-(c). The solid curves plotted along with the data are calculations done with the code DWBA-70 using the Cohen-Kurath wave functions for these states and the Love-Franey 425-MeV effective interaction. For the 12.71-MeV state the calculations

\[1^2C(p,p')^{12}C, 1^+, T=0 \text{ (12.71 MeV)}\]
\[T_p=397 \text{ MeV}\]

\[\begin{array}{c}
\text{SPIN-FLIP PROBABILITY} \\
0 & 0.2 & 0.4 & 0.6 & 0.8 & 1.0 \\
\theta_{c.m.} (\text{deg}) & 0 & 5 & 10 & 15 & 20 & 25
\end{array}\]

\[1^2C(p,p')^{12}C, T=1 \text{ (15.11 MeV)}\]
\[T_p=397 \text{ MeV}\]

\[\begin{array}{c}
\text{SPIN-FLIP PROBABILITY} \\
0 & 0.2 & 0.4 & 0.6 & 0.8 & 1.0 \\
\theta_{c.m.} (\text{deg}) & 0 & 5 & 10 & 15 & 20 & 25
\end{array}\]

\[1^2C(p,p')^{12}C, T=1 \text{ (16.11 MeV)}\]
\[T_p=397 \text{ MeV}\]

\[\begin{array}{c}
\text{SPIN-FLIP PROBABILITY} \\
0 & 0.2 & 0.4 & 0.6 & 0.8 & 1.0 \\
\theta_{c.m.} (\text{deg}) & 0 & 5 & 10 & 15 & 20 & 25
\end{array}\]

Figs. 1(a)-(c).

Spin-flip probability for the transition to the
(a) $^{12}$C, $1^+$, $T=0$ state at 12.71 MeV,
(b) $^{12}$C, $1^+$, $T=1$ state at 15.11 MeV, and
(c) $^{12}$C, $2^+$, $T=1$ state at 16.11 MeV
measured with an incident beam of 397-MeV protons. The solid curve is the calculation for this state done with the code DWBA-70 using the Cohen-Kurath wave functions and the Love-Franey effective interaction.
predict the shape of the data reasonably well, although
they are slightly high for the forward angles. The calcu­
lations for the 15.11-MeV state reproduce the 4 and 6°
data points exactly, but are too low at the larger angles.
The 16.11-MeV state calculations fall below the data at all
angles.

The discrepancies between these calculations and the
data may yield information on the nucleon-nucleon effec­
tive interaction. At angles less than 3° the cross section
for the isoscalar transition to the 12.71-MeV state is due
mostly to a combination of the tensor and the spin-orbit
forces, with only a small contribution from the central
spin-dependent force. The effect of the spin-orbit force
on the SFP can be seen in the fall off in SFP between 2
and 10° and after 18°. Although the 15.11-MeV-state
cross section is dominated by the central force out to
about 7°, the interference between the central and tensor
forces can be seen in the difference between the
calculated 0° value of SFP = 0.58 and the pure central
force value of SFP = 0.67, and also in the fall off of the
predicted SFP between 0 and 7°. Further calculations
are under way to test the sensitivity of the results to
details of the wave functions and to the relative strengths
of the various parts of the nucleon-nucleon effective in­
teraction.

REFERENCE


\[ \bar{p} + \text{Nucleus Elastic Scattering at 500 MeV} \]
\[ \text{(Exps. 425/433, HRS)} \]
\[ \text{(Univ. of Texas at Austin, Northwestern Univ.)} \]
\[ \text{Spokesmen: G. W. Hoffmann (Univ. of Texas at Austin)} \]
\[ \text{and K. K. Seth (Northwestern Univ.)} \]

The data obtained in this experiment were presented in
the last progress report. Here, we report the results of re­
cent theoretical analyses.

The solid curves of Figs. 1 and 2 are results of
Kerman-McManus-Thaler (KMT) calculations using
proton-nucleon \((p-N)\) amplitudes obtained recently by
Arndt (solution SL81) through phase-shift analysis of
nucleon-nucleon \((N-N)\) data. The proton densities were
obtained from the empirically known charge densities,
whereas the neutron densities (three-parameter Fermi or
Gaussian distributions) were varied to obtain the best fits
to the cross-section data.

Unfortunately, the theoretical analyzing powers show
poor qualitative agreement with the data forward of 20°.
As seen from Fig. 2, apart from reproducing the correct
(positive) overall sign of the envelopes, the curves fail to
track the data. Particularly disturbing is the fact that
very little structure in \(A_y\) is predicted forward of 20°, but
the data continue to oscillate. Also, the minima in the
theoretical cross sections (Fig. 1) are too deep.

Noteworthy is the fact that the neutron-proton rms
radius differences are about 0.1 F smaller than values

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Elastic angular distributions for 500-MeV \(p + \bar{p}\) on \(40,48\text{Ca}, 90\text{Zr}, \text{and } 208\text{Pb}, \text{and results of KMT}
calculations (curves).}
\end{figure}
obtained at 800 MeV, which are about 0.1 F smaller than that predicted by Hartree-Fock calculations (see Fig. 3). Thus, a consistent analysis leads to an apparent energy dependence for the deduced neutron distributions.

We see similar problems with impulse-approximation calculations at 500 and 800 MeV: the $A_y$ predictions are poor near $q = 1.0$-1.5 F$^{-1}$ for each nucleus studied at both energies, and the deduced neutron rms radii are too small; the discrepancies at 500 MeV are larger, however, than at 800 MeV.

The sensitivity of the 500-MeV theoretical results to density uncertainties, to phase-shift amplitude errors, and to second-order correlation contributions was investigated, as already done at 800 MeV, and we conclude that such uncertainties cannot account for the observed systematic discrepancies. The velocity-dependent, electromagnetic spin-orbit potential, which is significant for $A_y$ for small $q$ at 800 MeV, was included (not included in Fig. 2) but does not account for the discrepancies. Also, effects on the observables of the proper relativistic transformation of the nuclear $N$-$N$ amplitudes from the $N$-$N$ center-of-momentum (c.m.) system to the Breit frame were found to be small. Finally, the importance of Fermi motion averaging was considered. Calculations at 500 MeV were carried out as above, except that several $N$-$N$ amplitudes corresponding to $N$-$N$ laboratory energies varying between 325 and 800 MeV.

**Fig. 2.**
Analyzing powers for 500-MeV $^p + ^{40,48}$Ca, $^{90}$Zr, and $^{208}$Pb, and results of KMT calculations as discussed in the text.

**Fig. 3.**
Results obtained for the neutron-proton rms radius differences for $^{40}$Ca and $^{208}$Pb at 500 and 800 MeV.
were used; the featureless structure in $A_y$ near $q = 1 \text{F}^{-1}$ persisted, making it unlikely that the neglect of Fermi motion averaging is the cause of the discrepancies.

Thus, as a result of the sensitivity studies and because there is little reason to suspect the phase-shift analysis at 500 MeV, we are forced to consider the possibility that a more fundamental theoretical inadequacy exists in the conventional application of KMT. Because systematic and similar problems exist at 500 and 800 MeV, the clear implication is the same inadequacy at both energies. We believe an important clue to the origin of the difficulties is that theory fails to reproduce $A_y$ at both energies over the same region of small-momentum transfer. Since any breakdown of the impulse approximation should be momentum transfer dependent, we speculate that momentum-transfer-dependent medium effects are present at 500-800 MeV that lead to a breakdown of the impulse approximation at small $q$.

It is interesting to determine if effective amplitudes can be found, through slight modification of the phase-shift amplitudes at small $q$, that lead to better agreement with experiment. We have found the following phenomenological results.

1. Modifications to $\text{Re}(t^0)$ and $\text{Re}(t^{so})$ do not significantly affect $A_y$ or the neutron-proton rms radius differences $\Delta r_{np}$.

2. Increasing $\text{Im}(t^0)$ worsens the $A_y$ prediction and $\Delta r_{np}$ gets smaller yet, whereas a 10% suppression of $\text{Im}(t^0)$ at small $q$ improves $A_y$ and increases $\Delta r_{np}$. However, variation in $\text{Im}(t^0)$ alone cannot resolve the $A_y$ and $\Delta r_{np}$ discrepancies at 500 and 800 MeV.

3. Based on a series of calculations, we find that enhancement of $\text{Im}(t^{so})$ between $q = 0.4$ and $0.75 \text{F}^{-1}$ improves the agreement between experiment and theory for $A_y$, and suppression in this region worsens the agreement considerably.

Optimized results are shown by the dashed curves in Fig. 2. Note that the description of the data forward of $20^\circ$ is qualitatively improved and that the reasonable impulse-approximation description beyond this angle is not disturbed. Similar calculations at 800 MeV provide a much better fit to the $\vec{p} + ^{40}\text{Ca} A_y$ data obtained in Exp. 352 (see Fig. 4). Note that the KMT calculation that leads to Fig. 4 did not include the electromagnetic spin-orbit potential. Based on the results seen in Fig. 4, we anticipate a quantitative fit to the 800-MeV data when this effect is included in a calculation that accounts for the medium effects.

The imaginary, effective spin-orbit amplitude for $p + p$ is shown in Fig. 5 (dashed curve) and lies well outside the error corridor of the free amplitude (shaded band) obtained from phase-shift analysis; the $p + n$ comparison is similar.

4. Finally, we note that a 10% (5%) suppression of $\text{Im}(t^0)$ at 500 MeV (800 MeV) and the spin-orbit potential shown in Fig. 5 yields the expected $\Delta r_{np}$ for $^{40}\text{Ca}$ as well as considerably improved descriptions of the $A_y$ data at both energies.

Because little theoretical work has been done concerning effective interactions for energies greater than about $q(F')$.

### Fig. 4.

*Results of KMT calculations for $A_y$ for 800-MeV $\vec{p} + ^{40}\text{Ca}$ (see text).*

### Fig. 5.

*The dashed curve is the effective $\text{Im}(t^{so})$ used to generate Figs. 1, 2, and 4.*

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200 MeV, it is not possible to compare our phenomenological results to theoretical expectations. We point out, however, that the Pauli blocking estimate of Clemente! and Villi suggests that \( C(t^0) \) should be reduced by about 10% (5%) at 500 (800) MeV, and that an extrapolation of a comparison of impulse-approximation and medium-modified spin-orbit optical potentials between 100 and 200 MeV hints that the medium-modified \( C(t^0) \) amplitude at higher energies is larger than the impulse approximation \( C(t^0) \).

We conclude that a proper explanation of both the 500- and 800-MeV data demands an accurate, quantitative accounting of nuclear-medium corrections to the impulse approximation. Such findings are also consistent with results obtained recently in a KMT analysis of 400-MeV proton scattering from \(^{208}\)Pb.

The \(^{12}\)C \((p,p')^{12}\)C Reaction at 400, 600, and 700 MeV
(Exps. 432/531, HRS)
(Rutgers Univ., Los Alamos, Univ. of Minnesota, CEN Saclay, Univ. of Texas at Austin, Univ. of California at Los Angeles, Univ. of Pittsburgh)

**Spokesmen:** C. Glashausser (Rutgers Univ.) and J. Moss (Los Alamos)

Differential cross sections and analyzing powers for the \(^{12}\)C \((p,p')^{12}\)C reaction have been measured for incident proton energies of 400, 600, and 700 MeV. Results were obtained for states up to an excitation energy of about 21 MeV and over a momentum transfer range of 0.3-2.1 F\(^{-1}\). Preliminary results for the 12.71-MeV, 1\(^+\), \( T = 0 \) and 15.11-MeV, 1\(^+\), \( T = 1 \) states and the lack of evidence for pion precursors have been reported previously.\(^1\)

Optical-model calculations for simultaneous fits to the elastic cross-section and analyzing-power data are being performed. Preliminary results indicate that a reasonable overall fit at 400 MeV may be obtained by increasing the real spin-orbit potential radius by about 20% and the imaginary spin-orbit potential strength by a factor of 2 over values used in previous calculations where analyzing-power data were not available.\(^2\)

Data analysis is almost complete for all states. In addition to the well-known natural-parity collective states, the spectrum is rich in unnatural-parity states of different spins with both \( T = 0 \) and \( T = 1 \). The energy independence of the absolute cross sections noted for the 12.71- and 15.11-MeV states, together with the negative sign of \( A_y \) at forward angles for the 12.71-MeV state, should be very useful in identifying unknown states.

An example is the state at 18.27 MeV. The \( d\sigma/d\Omega \) and \( A_y \) shown in Figs. 1 and 2, respectively, are consistent only with the unnatural-parity, \( T = 0 \); a spin of 2\(^-\) is likely from the position of the peak in the angular distribution. The complex at 19 MeV has been studied carefully, and states have been clearly identified at 19.28, 19.40, and 20.6 MeV. Overlapping states at 19.58 and 19.74 MeV have been tentatively identified for values of \( q \) larger than about 1.2 F\(^{-1}\).

The 1\(^-\) (\( T = 0 \)) state at 10.84 MeV is also interesting. The cross-section angular distribution is strikingly similar to that for the 9.65-MeV 3\(^-\) state, even at the smallest values of \( q \) measured. Distinguishing between \( \ell = 1 \) and \( \ell = 3 \) giant resonances by such small-\( q \) cross-section measurements in \((p,p')\) thus looks impossible;
Excitation of the Giant Resonance Continuum with Intermediate-Energy Protons (Exp. 473, HRS)
(Los Alamos, Massachusetts Institute of Technology, Univ. of Minnesota)
Spokesmen: G. Adams (Massachusetts Institute of Technology) and T. Carey and J. Moss (Los Alamos)

At small-momentum transfers ($q < 3 \text{ F}^{-1}$), inelastic scattering with energy loss of 5-50 MeV leads to the excitation of broad giant resonances (GRs) and a nearly featureless continuum on which the GRs lie. Since for hadron scattering the continuum cross section is typically 5-10 times that contained in GRs, it is obviously of great interest to try to understand its excitation, if only to better understand the characteristics of GRs.

In this report we first show that the cross section for the low-excitation-energy continuum excited by 800-MeV protons may be understood in terms of a single-collision model based on Glauber theory. A significant feature of the calculation, which is also seen in the data, is a decrease in the continuum cross section at small angles because of Pauli blocking. Then, looking at continuum analyzing powers and spin-flip probabilities, we present evidence that spin-dependent strength is greatly suppressed in the low-excitation-energy region of the nuclear continuum.

A typical GR-plus-continuum spectrum for 800-MeV protons on $^{116}\text{Sn}$ is shown in Fig. 1, together with

Fig. 1.
Spectrum of $^{116}\text{Sn}$ compared with calculations using the FG and SIS approximations.

Fig. 2.
Analyzing power for 18.27-MeV ($^2\text{p}, T = 2^-, 0$) state at $E_p = 400, 600, and 700$ MeV.

there are small differences, however, in $A_y$. Analysis of all these states with the new DWBA-81 code is just beginning.

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theoretical curves, which are discussed below. One sees the giant quadrupole-monopole resonance doublet near $E_x = 14$ MeV and the high-energy octupole resonance near $E_x = 23$ MeV. We have chosen the region near $E_x = 30$ MeV, which appears free of any obvious GRs, for evaluation of the angular distribution of the continuum shown in Fig. 2. A most interesting feature of the angular distribution is an obvious decrease in cross section at small scattering angles. This is, to our knowledge, the first evidence of such behavior. In GR studies with 100- to 200-MeV alpha particles (the bulk of all GR work), an exponential increase in continuum cross sections with decreasing scattering angle has always been observed.\(^2\)

It is plausible to assume, for the scattering of intermediate-energy protons with small energy loss and small-momentum transfer, that single collisions dominate. In this spirit Bertsch and Scholten\(^3\) have developed a model for continuum excitations based on Glauber theory.\(^1\) The differential cross section is expressed as

$$\frac{d^2\sigma}{d\Omega dE} = \left(\frac{d\sigma}{d\Omega}\right)_{NN} N_{\text{eff}} S(q,E)
$$

where $(d\sigma/d\Omega)_{NN}$ is the differential cross section for free nucleon $(N-N)$ scattering and $S(q,E)$ is the nuclear response function. The effective number of target nucleons participating in the single-collision cross-section $N_{\text{eff}}$ is determined as

$$N_{\text{eff}} = \int db^2 \frac{\chi(b)e^{-x(b)}}{\sigma_{NN}^T},$$

where

$$\chi(b) = \int_{-\infty}^{\infty} dz \rho \sigma_{NN}^T.$$ 

Taking $\sigma_{NN}^T = 40$ mb, we find $N_{\text{eff}} = 7.6$ for scattering from $^{116}$Sn at 800 MeV.

The response function is evaluated using the Fermi-gas (FG) model and the semi-infinite slab (SIS) approximation, which treats the effects of Pauli blocking in the nuclear surface more realistically. The curve labeled FG in Fig. 1 (and in Fig. 2) shows that the FG model is not able to account for the shape of the continuum spectrum. It does, however, yield the qualitative features of the angular distribution — in particular, the decrease in cross section at small angles. This decrease is due to the fact that the recoil nucleon does not have sufficient momentum to rise above the Fermi surface; it is thus Pauli blocked.

The main defect of the FG model seems to be an overestimate of the Pauli blocking at small $q$. The SIS calculation, which will be described in detail elsewhere,\(^3\) remedies this defect by giving the nucleus a surface region where the effects of Pauli blocking are partially suppressed. It is clear that a proper treatment of the surface is necessary for a realistic model of $S(q,E)$ because, in $^{116}$Sn, most of the contribution to $N_{\text{eff}}$ comes from a region of the nucleus where the density is less than one-quarter that of nuclear matter. The curves labeled SIS in Figs. 1 and 2 show that the spectral shape and angular distribution are now very well reproduced.

The evidence strongly suggests the dominance of single-step quasi-free scattering. On this basis, one would also expect the polarization observables for the continuum to be similar to the free $N-N$ values. Figure 3(a)}
shows that this expectation is confirmed in the case of the analyzing power for the \( ^{116}\text{Sn}(p,p')^{116}\text{Sn} \) reaction at 800 MeV.\(^4\) Very similar results are found for less extensive data on \( ^{90}\text{Zr} \) with 500-MeV protons and for \( ^{208}\text{Pb} \) at 400 MeV [Figs. 3(b) and (c)].

In sharp contrast to this simplicity, the spin-flip probabilities (SFPs on figures and equations) for the continua in \( ^{208}\text{Pb} \) (7-22-MeV excitation energy at \( E_p = 400 \) MeV) and \( ^{90}\text{Zr} \) (12-29-MeV excitation energy at \( E_p = 500 \) MeV) are consistent with zero, whereas the \( N- \) and \( Z- \) weighted values from the phase-shift solutions\(^4\) are near 0.2 and 0.1, respectively.

We believe that the large difference between the free \( N-N \) and continuum SFPs is due, at least in part, to the difference between the scalar and vector (spin-dependent) response functions. It has been shown\(^2\) that inelastic proton scattering with spin transfer (\( \Delta s = 1 \)) invariably leads to a large SFP (\( S > 0.5 \)), whereas reactions in which \( \Delta s = 0 \) dominates result in SFPs near zero. Thus, the small SFP seen here implies a deficiency of \( \Delta s = 1 \) over \( \Delta s = 0 \) scattering with respect to the free \( N-N \) case.

Nuclear collectivity associated with long-range fields is known to be mostly spin independent, with the result that the low-excitation-energy spectra of nuclei abound with scalar collective excitations (including GRs). Less is known about spin collectivity, but present evidence suggests that it is not nearly as strong as the spin-independent variety.\(^6,7\) Qualitatively, at least, the SFP data are in accord with this observation.

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Proton Scattering from \( ^{20}\text{Ne} \) at 0.8 GeV (Exp. 475, HRS) (Univ. of South Carolina, Univ. of Texas, Univ. of Minnesota, Michigan State Univ.)

Spokesman: G. S. Blanpied (Univ. of South Carolina)

In several recent publications, coupled-channels analyses of ~1-GeV proton inelastic scattering from light, \( s-d \) shell nuclei and heavy rare-earth nuclei have been shown to be generally successful, provided deformation and multistep processes are properly treated.\(^1-6\) These calculations, which assume the collective rotational model, provide excellent descriptions of the data for the lowest \( 0^+, 2^+ \), and \( 4^+ \) states in \( ^{24,26}\text{Mg} \) (Ref. 6).

The multipole moments of the empirically determined optical potentials, which are related to those of the deformed-matter densities by Satchler's theorem,\(^7\) can be compared with the multipole moments of the charge densities obtained by electromagnetic measurements. In
general, the deduced $M(E2,\text{ matter})$ moments are 10-20% smaller than those of the charge densities for $^{12}\text{C}$, $^{24}\text{Mg}$, and $^{26}\text{Mg}$ (Refs. 2 and 6).

In these calculations the radius parameter of the optical potential is deformed by

$$R(\theta) = R_0 \left(1 + \beta_2 \gamma_2 + \beta_4 \gamma_4 + \ldots\right). \quad (1)$$

The results for $^{12}\text{C}$ and $^{24}\text{Mg}$ indicate that $\beta_4 \sim 0$, so that the hexadecapole moment is small, whereas $\beta_4$ for $^{26}\text{Mg}$ is somewhat larger. Results from low-energy hadron scattering suggest that $\beta_4$ in $^{20}\text{Ne}$ is large ($\beta_4/\beta_2 \sim 0.5$) (Refs. 8-15). To further the study of intermediate-energy proton inelastic scattering from light, deformed nuclei, data for $^{20}\text{Ne}(p,p')$ at 0.8 GeV were taken with the High-Resolution Spectrometer (HRS).

Since this was the first experiment at the HRS to use a gas target, some details are given here. The experiment consisted of scattering 0.8-GeV protons from a $^{20}\text{Ne}$ gas target, enriched to 99.95%. The measured angular distributions extend from 5.3-26.3° c.m. for all states up to about 12 MeV. The $(p,p')$ data presented here are for the excitation of the (ground, $0^+$), (1.634-MeV, $2^+$), (4.247-MeV, $4^+$), and (8.7-MeV, $1^-$ and $6^+$) states in $^{20}\text{Ne}$.

Data were also acquired for a $^{14}\text{N}$ gas target of identical geometry and a $^{208}\text{Pb}$ foil. The ratios of the $^{14}\text{N}$ gas-target data to previous $^{14}\text{N}$ measurements that used a solid melamine target$^{16}$ provide a value of the beam-interaction volume in the gas target as a function of scattering angle. The interaction volume is found to be constant to $6.8^\circ_{\text{lab}}$, where it falls off as $1/\sin \theta_{\text{lab}}$. A least-squares fit to the ratio of gas/solid for $^{14}\text{N}$ was used to compute the absolute normalization of the $^{20}\text{Ne}$ data presented here, with an overall uncertainty of about 10%. The absolute scattering angle was determined to $\pm 0.05^\circ$ by comparing the $^{208}\text{Pb}$ data taken here with that of Ref. 17. The resulting angular distributions for the $0^+$, $2^+$, $4^+$, and unresolved ($1^-$ to $6^+$) states are presented in Fig. 1.

Coupled-channels calculations using a deformed optical potential have been made in which the $0^+$, $2^+$, $4^+$, and $6^+$ states in the ground-state rotational band (GSRB) are coupled with deformation up to $\beta_6$. The results for various values of the parameters are given in Fig. 1. Distorted-wave-Born-approximation (DWBA) calculations using a spherically symmetric optical potential are also shown for comparison with the coupled-channels results.

Fig. 1.
Angular distributions of $^{20}\text{Ne}(p,p')$ at 0.8 GeV for the $0^+$, $2^+$, $4^+$, and unresolved doublet ($1^-$ + $6^+$) are shown. The curves result from coupled-channels and DWBA calculations as discussed in the text.

The Woods-Saxon potential parameters for the coupled-channels calculations, given in the low-energy notation $(V, W, r, a, r_w, a_w,$ and $r_o)$ are $(-5.0$ and $+48.0$ MeV, 1.06, 0.46, 1.06, 0.46, and 1.05 F). The solid curves shown in Fig. 1 result from coupling the $0^+$, $2^+$, $4^+$, and $6^+$ states with parameters $\beta_2 = +0.46$, $\beta_4 = +0.27$, and $\beta_6 = +0.03$; the long-dashed curves are the result of coupling only the $0^+$ and $2^+$ with $\beta_2 = +0.57$ and $\beta_4 = \beta_6 = 0$. The short-dashed curves are from DWBA calculations. The optical-potential parameters
for the DWBA calculations are \((V, W, r, \alpha, \alpha_m, \alpha_w, \text{ and } \alpha'_w) = (-7.6 \text{ and } 45.1 \text{ MeV}, 1.03, 0.571, 1.03, 0.571, \text{ and } 1.05 \text{ F})\), with \(\beta_2 = 0.63\) for the \(2^+_1\), \(\beta_4 = 0.50\) for the \(4^+_1\), and \(\beta_6 = 0.16\) for the \(6^+_1\) states.

Both the relatively large cross section for the \(4^+_1\) state and the position of the first minimum in the angular distribution for the \(2^+_1\) state provide evidence for a large hexadecapole deformation for the \(^{26}\text{Ne}\) ground state. Since the \(6^+_1\) state is unresolved from a nearby \(1^-\) state, it is difficult to make a quantitative evaluation of the \(\beta_6\) deformation. The angular distribution for excitation of the \(1^-\) state should be very forward peaked and should fall off faster than that for the \(6^+_1\) state. A coupled-channels calculation with \(\beta_2 = +0.46\), \(\beta_4 = +0.25\), and \(\beta_6 = +0.07\) is given by the dot-dashed curve for the \(6^+_1\) state. The two coupled-channels curves for the \(6^+_1\) state thus represent a reasonable range of possible strength of this angular distribution.

As has been done previously for \(^{12}\text{C}\), \(^{24}\text{Mg}\), and \(^{26}\text{Mg}\) (Refs. 2 and 6), multipoles of the deformed optical potentials can be related to those of the matter distributions by Satchler's theorem.\(^7\) The moments that result from the solid curves \(\beta_2, \beta_4, \beta_6 = 0.46, 0.27, 0.03\) are \(M(E2) = 0.168\) eb, \(M(E4) = 0.0244\) eb\(^2\), and \(M(E6) = 0.0033\) eb\(^3\), whereas the values for \(\beta_2, \beta_4, \beta_6 = 0.46, 0.25, 0.07\) are \(0.0168\) eb, \(0.0248\) eb\(^2\), and \(0.0038\) eb\(^3\). \(M(E2) = 0.163\) for only \(0^+, 2^+\) coupling, \(\beta_2 = 0.57\), and \(\beta_4 = \beta_6 = 0\). Thus, the magnitude of the \(2^+_1\) moment determined here is 0.168 eb, compared to the \(B(E2)\) value of \(0.171 \pm 0.011\) eb from the average of electromagnetic studies\(^19\) [with some measurements as high as \(0.179-0.183\) (Refs. 20 and 21)], \(0.150\) eb from shell-model results using effective charges,\(^19\) and \(0.159\) eb from Hartree-Fock calculations.\(^22\) Thus, the ratio of the \(M(E2)\) from 0.8 GeV to that extracted in electromagnetic measurements for the \(N = Z\) nuclei \(^{12}\text{C}\) and \(^{24}\text{Mg}\) is about 0.9, whereas the value determined here for \(^{20}\text{Ne}\) agrees with the average of the electromagnetic values\(^19\) but is about 0.9 in individual cases.\(^20,21\)

Calculations are planned that will facilitate the direct comparison of the data with transition matrix elements predicted from shell-model results using the Chung-Wildenthal interaction.\(^19\)

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6. G. S. Blanpied et al., submitted to Phys. Rev. C.
The recent report of $8^+$ and $10^+$ levels of the $^{26}\text{Si}$ GSRB\(^5\) has further supported a collective description of this nucleus and has stimulated efforts to find high-spin levels in $^{26}\text{Mg}$. From Exp. 476 we have evidence for a $6^+$ state in $^{26}\text{Mg}$ at 8.03 MeV. The evidence arises from data taken in an experiment to determine analyzing powers and differential cross sections for 0.8-GeV polarized-proton inelastic scattering from levels in $^{26}\text{Mg}$. The experiment was performed using the HRS. Though the level at 8.03 MeV has been observed previously,\(^3\) the limited data obtained in the past have been insufficient to permit any spin assignment.

The angular distribution measured in this experiment for protons exciting the 8.03-MeV level is shown twice in Fig. 1. The theoretical curves shown are discussed below. The following observations yield support for the $6^+$ assignment for the 8.03-MeV level.

1. The position of the first maximum in the angular distribution with respect to other states of known spin in $^{26}\text{Mg}$ implies a transferred angular momentum $>4$, indicating the excitation of a state with $J > 4$. Whereas the distribution of Fig. 1 peaks at about $13^\circ$, the $4^+$ levels peak at $~11^\circ$, with all other levels of known spin peaking at smaller angles.

2. Coupled-channels calculations for a $6^+$ level in a GSRB in $^{26}\text{Mg}$ reproduce reasonably well the observed angular distribution for the 8.03-MeV level. The results of these calculations, made using the code JUPITER\(^6\) with the same parameters as the solid curves of Fig. 9 in Ref. 3, are shown in the lower portion of Fig. 1. As is seen in the figure the angular distribution observed is well described by these calculations, though perfect agreement has not been achieved. The values of $\beta_6$ shown would indicate that the 64-pole deformation is quite small ($\beta_6 = -0.02 \pm 0.01$). The magnitude of the differential cross section is well predicted except for the angle farthest away from the maximum where other channels of the reaction process may contribute. These calculations may be improved by using a varying rather than a fixed $\beta_2$, but this modification to the computer code has not been made. Also, the present version of JUPITER does not include a $Y_{10}$ term in the Hamiltonian, thus not allowing coupled-channel calculations for a $5^-$ level. In the $K^\pi = 0^-$, $(1^-, 3^-, 5^-)$ band of $^{26}\text{Mg}$, it was noted that coupled-channels calculations for the $5^-$ level, which did not include such a direct step from the ground state, were an order of

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Polarized Proton Scattering from $^{24,26}\text{Mg}$ at 0.8 GeV (Exp. 476, HRS)
(Univ. of South Carolina, Univ. of Texas, Rutgers Univ.) Spokesman: G. S. Blanpied (Univ. of South Carolina)

Rotational band structure has been recognized as a systematic feature in the spectra of light nuclei with $20 < A < 28$ with partially filled $s$-$d$ shell levels, and has been suggested for $^{20}\text{Ne}$, $^{22}\text{Ne}$, $^{24}\text{Mg}$, and $^{28}\text{Si}$. In addition to the resemblance of the observed series of levels to established features of collective rotational bands, such proposals have been supported quite well by collective-model coupled-channels calculations in several cases.\(^1\),\(^2\) These calculations reproduce most of the measured angular distributions of proton excitations of these levels, giving strong support for the assignment of these levels to collective rotational bands.

A good example\(^3\) is the level scheme of $^{26}\text{Mg}$. The states in $^{24}\text{Mg}$ can be grouped into a ground-state rotational band (GSRB) consisting of the $(0.00-\text{MeV}, 0^+)$, $(1.37-\text{MeV}, 2^+)$, $(4.12-\text{MeV}, 4^+)$, and $(8.12-\text{MeV}, 6^+)$ levels. Additionally, there is evidence for $K^\pi = 2^+$, $0^+$, $0^-$, and $3^-$ bands. In fact, nearly all levels below 10 MeV in $^{24}\text{Mg}$ are believed to belong to a rotational band. Aside from $^{24}\text{Mg}$, levels in $^{20}\text{Ne}$, $^{22}\text{Ne}$, and $^{26}\text{Si}$ have been assigned to a GSRB, and the $6^+$ member of the GSRBs in each of these nuclei has been observed.\(^4\) The extension of these ideas to $^{26}\text{Mg}$ would seem to be straightforward, particularly since the features of the $^{24}\text{Mg}$-level scheme show strong evidence of collective behavior. However, no level with spin $>4$ has been reported previously. Hence, a collective description of $^{26}\text{Mg}$ has been based on a series of rather limited bands, with some evidence of band mixing.\(^3\)
Fig. 1.
Comparison of measured angular distribution for 8.03-MeV level in $^{26}$Mg with DWBA (upper portion) and coupled-channels (lower portion) calculations.

Magnitude too low in predicting the observed angular distribution.  
3. Distorted-wave-Born-approximation (DWBA) calculations for $\ell = 5$ angular distribution reproduce the observed phenomena quite well. The results of these calculations are shown in Fig. 1, where the potential used is that of Ref. 3. Here, values of $\beta_5 = 0.14$ and $\beta_6 = 0.07$ were used. A general feature of high-spin DWBA calculations performed on nuclei in this region is that the angular distributions predicted by the calculations peak at larger angles than observed. Hence, these calculations support an assignment of $J > 5$ because, as seen in the figure, the $\ell = 5$ distribution matches the peak quite well whereas the $\ell = 6$ curve is seen to peak at a larger angle than measured. Though the validity of applying DWBA calculations to deformed nuclei is questionable, it is interesting to note that a satisfactory fit to the data may be obtained by such a spherical potential and no coupling.

4. Comparison with known $6^+$ levels in $^{24}$Mg can suggest, by arguments based on systematics, that the level at 8.03 MeV may be a $6^+$. In $^{24}$Mg, a $6^+$ level is observed at 8.12 MeV, which is very nearly the same in energy as the 8.03 MeV observed for the level under discussion, though the angular distributions are not similar. Another level at 9.53 MeV in $^{24}$Mg has been identified as a $6^+$ level, however, and its shape (peaking at about 14°) and its magnitude at maximum (0.28 mb) bear a strong resemblance to the 8.03-MeV level in $^{26}$Mg. The lack of resemblance between the 8.12-MeV level in $^{24}$Mg and the 8.03-MeV level in $^{26}$Mg probably results from the difference in interference between direct and multistep excitation for those levels.

5. Agreement with rotor and shell-model predictions of energy of excitation also suggests that the observed level at 8.03 MeV may be a $6^+$ level. Comparison with rigid-rotor calculations for neighboring nuclei suggests that such a model may be a useful tool in predicting GSRB energies, though the energies predicted are usually higher than those observed, as shown in Table I. Basing the moment of inertia for $^{26}$Mg on the $4^+ \rightarrow 2^+$ energy difference yields a prediction of 8.29 MeV for a GSRB $6^+$ in $^{26}$Mg, adding support to the assignment of $\ell = 6$ for the 8.03-MeV level. Predictions for the $6^+$ in several s-d nuclear spin nuclei compared to the measured value are also given for comparison.

**TABLE I**

| Excitation Energy (in MeV) of the First $6^+$ States in Several Deformed $s$-$d$ Shell Nuclei (Rotator Calculations Based on $4^+ \rightarrow 2^+$ Transition Energy) |
|----------------------------------|----------|----------|----------|----------|
| $^{20}$Ne                         | $^{22}$Ne | $^{24}$Mg | $^{28}$Si | $^{26}$Mg |
| Observed                         | 8.78     | 6.31     | 8.11     | 8.54     | (8.03)*  |
| Rotor                            | 8.36     | 6.63     | 8.45     | 9.08     | 8.29     |
| CW                               | 8.54     | 6.26     | 8.47     | 9.06     | 8.73     |

*Proposed here as $6^+$.

CW denotes shell-model calculations using Chung-Wildenthal interaction (see Ref. 7).
Shell-model calculations using the Chung-Wildenthal interactions have been performed for several s-d shell nuclei. These calculations, which are also given in Table I, again usually predict higher energies for the members of the GSRB than are observed (except for $^{20}$Ne). These calculations predict a $6^+$ level at 8.73 MeV, which may be regarded as an upper limit on the energy of such a state. The 8.03-MeV state would then be a possibility for that $6^+$ level.

Theoretical analyses of the other data from this experiment are in progress.

*B. H. Wildenthal (private communication).

REFERENCES


**Precision Studies of $\vec{p} + p \rightarrow d + \pi^+$ as Probe of Dibaryon Resonances (Exp. 508, HRS) (Northwestern Univ.) Spokesman: K. K. Seth (Northwestern Univ.)**

Pronounced structures in $p-p$ total cross sections $\Delta\sigma_L$ and $\Delta\sigma_T$ have been reported in the $E_p = 500$-800-MeV region. These have been interpreted as dibaryon “resonances” in the $^{1}D_2$ and $^{3}F_3$ channels. Detailed phase-shift analyses of these data reveal that these resonances are largely inelastic. Because the only inelastic channel of any importance that is open at these energies is that for single-pion production, it is obvious that the strongest signals of these resonances should appear in this channel. Further, because polarization variables are sensitive to interference between different partial waves, it may be expected that their measurement and analysis as a function of incident energy will provide very discriminating evidence for the existence (or nonexistence) of these resonances. This point of view has motivated us to start precision studies of the cross section ($\sigma$) and analyzing power ($A_{yo}$) of the reaction $\vec{p} + p \rightarrow d + \pi^+$ in the energy range 550-800 MeV in 50-MeV steps.

Data so far have been taken at 547, 597, 647, 697, and (as a part of our Exp. 10/233) at 792 MeV; that is, only a gap at 750 MeV remains. Recoil deuterons, in their narrow recoil cone (generally <$18^\circ$), were detected to obtain data at extremely forward and backward pion-production angles. Pions were detected to cover the remaining angular range. The total angular range covered was $4^\circ \leq \theta_{\text{cm}}(\pi) \leq 168^\circ$. Solid targets (CH$_2$) were used for the first part of the data at 547 and 647 MeV. A liquid-hydrogen target was used for all subsequent energies. Preliminary results for the analyzing power at 457, 647, and 792 MeV are shown in Figs. 1-3. These have been analyzed to give coefficients of the orthogonal polynomials,

$$4\pi \sigma_{oo} = \sum_{n \text{ even}} a_n P_n(\cos \theta)$$

and

$$4\pi A_{yo} = \sum_{n} b_n P_n(\cos \theta),$$

where

$$\sigma = \sigma_{oo} + \vec{P}_B \cdot \hat{n} \sigma_{yo}.$$
The data for 597 and 697 MeV are still being analyzed. Preliminary results indicate that all coefficients of $\sigma_{y0}$ ($a_0$, $a_2$, $a_4$, and $a_6$) and the even coefficients of $\sigma_{y0}$ ($b_0$, $b_2$, and $b_4$) all show resonant behavior at $\sim$600 MeV, as they should, because of their direct coupling to the $N\Delta$ channel through the $^1D_2$ channel of the initial $p-p$ system. However, what is quite surprising is that coefficients $b_1$ and $b_3$ of $\sigma_{y0}$ which do not couple directly with the even partial waves of the initial $p-p$ system, show very strong resonant behavior at $\sim$675 MeV. This is not predicted by any of the calculations available to us so far, including the well known work of Niskanen and the new and much more ambitious analysis of Blankleider and Afnan. Do the data require introduction of a resonance in the $^3F_3$ channel? Excited as we are about our results we cannot go that far, at least not yet!

REFERENCES


**p-p Elastic Scattering at 800 MeV**  
(Exp. 563, HRS)  
(Univ. of Texas at Austin, Rutgers Univ., Los Alamos)  
Spokesman: G. W. Hoffmann (Univ. of Texas at Austin)

To determine the appropriate nucleon-nucleon amplitudes needed for microscopic analysis of proton-nucleus data, it is necessary to have good nucleon-nucleon (p-p and p-n) data to sufficiently constrain the phase-shift analyses. In addition, because it is the small-momentum-transfer parts of these amplitudes that are required for the Kerman-McManus-Thaler (KMT) calculations, the appropriate N-N data must correspond to small-momentum transfer.

Because the N-N work in Areas B and EPB tended to be constrained to medium- to large-momentum transfer, we have conducted several experiments that provide needed small-momentum-transfer N-N data for phase-shift analysis.

Experiment 563 obtained high-quality elastic differential-cross-section data for p-p at 800 MeV for center-of-momentum scattering angles 6-90°. Before this experiment the only other 800-MeV data in existence were from Willard et al., and it was believed that these data were incorrect because of a number of cross-normalization checks made at HRS over the years. The Exp. 563 data are shown in Fig. 1, along with the Willard data, forward-angle data from two other recent LAMPF experiments (Exps. 15 and 289), and a recent Gatchina (Andreev) experiment. The absolute normalization of the Exp. 563 data was obtained at 14° (c.m.) by

\[ \theta_{\text{c.m.}} \]

\[ \frac{d\sigma}{d\Omega} (\text{mb/sr}) \]

**Fig. 1.**  
The new Exp. 563 p-p elastic cross-section data at 800 MeV are compared with other data sets and with a phase-shift prediction.
normalizing to the Exp. 289 and Gatchina data, which agree at this angle.

The expected gross discrepancy with the Willard data is clearly evident from Fig. 1. The solid curve is a recently obtained phase-shift prediction (solution W181) of Arndt incorporating the new Exp. 563 data in the data base. The fit is excellent over the entire angular range. However, as seen in Fig. 2, the important \( \text{Im}(a) \) and \( \text{Im}(c) \) amplitudes obtained from the phase-shift analysis incorporating the new data (solid curves) are insignificantly different from the results obtained previously (dashed curves) without these data.

\[ \text{Fig. 2.} \]

The solid curve is the phase-shift solution obtained using the new data and the dashed curve is the solution before the data were incorporated in the data base.
Search for Giant Monopole and Giant Magnetic Dipole Excitations at 0°
(Exp. 630, HRS)
(Los Alamos, Univ. of Minnesota)
Spokesmen: J. B. McClelland, J. M. Moss, and T. Carey
(Los Alamos), and N. Hintz (Univ. of Minnesota)

Progress has been made on the development of the HRS facility to allow measurement of \((p,p')\) reactions at 0°. This development was motivated by strong interest in identifying giant monopole and dipole excitations in nuclei. It is often the case that, at the smallest nonzero angle at which cross sections can be measured (~3.5°), the cross section for these states has dropped by a factor of 5 from that at 0°.

The method for performing this type of measurement involves transmission of the unscattered beam at 0° through the spectrometer and above the focal-plane detectors such that only excited states of the target nuclei are registered in the detectors.

The goal is to devise a system free enough of background to be capable of measuring beam-target interactions at the few-parts-in-10^6 level with respect to the beam. During three development runs, we have identified the major limiting factors in attaining this goal, the foremost being beam quality at the target. It was necessary to tailor the H̅ beam before entry into Line C using Line X strippers, thus eliminating beam halo without use of Line C collimators; slit scattering from Line C collimators was found to be disastrous at the focal plane. Once a clean beam was delivered to the target, the next major effect was the horizontal position of the beam on target. The size and shape of the observed background changed dramatically over the range of HRS acceptance, probably associated with pole-face scattering in the HRS dipoles.

Special hardware was constructed for the 0° inelastic measurements. To allow for unobstructed passage of the beam at the focal plane, single-ended trigger scintillators were installed with phototubes at the low-energy end. Special focal-plane wire-chamber supports were designed to allow the beam to pass as close as possible (~76.2 mm) to the active region of the chamber. For beam monitoring purposes an ion chamber and beam profile chamber were installed downstream of the focal-plane detectors.

At this level of development we were able to obtain the very clean spectrum in Fig. 1 of \(^{12}\text{C}(p,p')\) at 500 MeV over the excitation region of 6-27 MeV. Very noticeable in this spectrum is the \(^1\text{+}, T = 1\) state at 15.11 MeV. It is possible to obtain the ratio of this state to the \(^1\text{+}, T = 0\) state at 12.71 MeV, which gives a fairly model-independent measure of the strength of the central-to-tensor force at 0°, because the \(T = 0\) state is excited primarily by the tensor exchange whereas the \(T = 1\) state

![Fig. 1.](image)

*The \(^{12}\text{C}(p,p')\) spectrum taken at 0° with a 497-MeV incident proton beam.*
is excited by the central part of the force. A distorted-wave-impulse-approximation (DWIA) calculation using the Love-Franey force gives a value of 10 for this ratio, whereas the preliminary data yield 14 ± 2. A $^{90}$Zr spectrum has been measured at 500 MeV and is being analyzed at the present time.

Improvements being considered for future runs involve active collimators before and after the target, since we feel we are still seeing remnants of the elastic scattering (beam) being degraded into the region of excited states, as well as perhaps some target frame interactions.

**Reactive Content of the Optical Potential at 800 MeV (Phase II)**

(Exp. 642, HRS)

(Univ. of Texas at Austin, Rutgers Univ., Los Alamos)

Spokesmen: G. W. Hoffmann (Univ. of Texas at Austin) and J. McGill (Los Alamos)

The 800-MeV $(p,p')$ inclusive data obtained in Exp. 470 indicate that the reactive content of the optical potential at this energy stems from two-nucleon quasi-free processes. This in turn provides justification for using the impulse approximation as a starting point for $p +$ nucleus calculations at 800 MeV.

If we look for details in the inclusive spectra we note the possible existence at forward angles of two broad structures in the region identified with pion production. One peak appears to be located about 350 MeV/c from the quasi-elastic peak, whereas a second, broader peak is located roughly 600 MeV/c from the quasi-elastic peak. Because the inclusive $(p,p')$ experiment detects both recoil and decay protons, it may be that these two structures map to each type of proton. The recoil-proton spectrum is expected to be more like that for a two-body reaction $\left(p + N \rightarrow p_{\text{recoil}} + \Delta \right)$ than the decay-proton spectrum $\left(p + N \rightarrow p_{\text{recoil}} + p_{\text{decay}} + \pi \right)$, which is more like that for a three-body final state. It is possible to estimate the relative yield from recoil and decay protons using the isobar production model of Wallace; we find 29% recoil and 71% decay. It does appear from the data that the first structure is narrower and smaller in magnitude than the second.

Unfortunately, Exp. 470 did not cover the “two peak” region of the $(p,p')$ spectra with sufficiently fine steps to obtain the details of the structure. Providing such data is important for refining the quasi-elastic-production doorway model and for our further understanding of the reaction process. Also, analyzing-power data analogous to the cross-section data would be very useful for a more quantitative investigation of these important processes at 800 MeV.

We expect the $(\vec{p},p)$ inclusive analyzing powers obtained for all $N \approx Z$ nuclei to be close to the weighted average of the analyzing powers for $\vec{p} + p$ and $\vec{p} + n$. Specifically, (1) we expect $A_y(\theta, p')$ on the quasi-elastic peak for any $N \approx Z$ nucleus to be the same as the weighted average of the known analyzing powers for elastic $\vec{p} + p$ and $\vec{p} + n$; (2) in the pion-production region the analyzing powers for $N \approx Z$ nuclei should be similar to those for $^2\text{H}(\vec{p},p')$; and (3) since two types of $\Delta$ production are occurring (leading to the detection of decay and recoil protons), the $A_y(\theta, p')$ data might help separate these processes. Here, as in (2), for $N \approx Z$ nuclei the structure in $A_y(\theta, p')$ should be like that for $^2\text{H}(\vec{p},p')$.

Observations consistent with these ideas will provide even more support for the quasi-free picture of reactions at 800 MeV and the use of the impulse approximation at medium energies. Agreement with expectations might also suggest that inclusive data in the quasi-elastic region can be used to directly obtain effective amplitudes for the $p +$ nucleus microscopic calculations.

We plan to continue our study of the reactive content of the optical potential at 800 MeV by providing these additional data for $\vec{p} + ^1\text{H}$, $^2\text{H}$, and $^{12}\text{C}$. The data for $^{12}\text{C}$ have been obtained and are shown in Figs. 1(a)-(d). The $^1\text{H}$ and $^2\text{H}$ data will be obtained in the immediate future using $^1\text{H}_2$ and LD$_2$.

Because the interpretation of the $\vec{p} + ^{12}\text{C}$ data must be made in terms of the $\vec{p} + ^1\text{H}$ and $^2\text{H}$ data, a comprehensive discussion of the physics to be learned from the data shown in Figs. 1(a)-(d) must await completion of the experiment. We do note, however, that the values of the analyzing power for $\vec{p} + ^{12}\text{C}$ on the peaks of the quasi-elastic parts of the spectra are equal to the weighted averages of the corresponding $(\text{free}) \vec{p} + p$ and $\vec{p} + n$ analyzing powers (if the small background is properly accounted for) and that a significant structure in the analyzing power is seen just above pion threshold for all four inclusive spectra obtained between 5 and 20°.

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July-December 1981

PROGRESS AT LAMPF

Los Alamos National Laboratory
Figs. 1(a)-(d).

Inclusive $(\bar{p},p')$ cross sections and analyzing powers obtained for $^{12}$C at 800 MeV.
Asymmetry Measurement of the \((p, \pi^\pm)\) Reactions on \(^9\text{Be}\) at 650 MeV
(Exp. 649, HRS)
(Univ. of Texas at Austin, Massachusetts Institute of Technology, Univ. of Minnesota)
Spokesman: Bo Höistad (Univ. of Texas at Austin)

The \((p, \pi)\) reaction process has resisted many attempts during the last years to be understood in detail. There is as yet no simple model that can explain the most salient features of the experimental data. The difficulty in interpreting the data at intermediate proton energies is due to the fact that the data show no clear signature of either the reaction dynamics or the nuclear wave functions involved. Instead, the large variety in shapes and magnitudes found in the differential cross section is probably due to an interplay between the reaction diagrams and the nuclear structure. This is clearly seen in the data obtained at low energy, but to a lesser extent in the high-energy data where the influence of the nuclear structure is suppressed.

One important piece of information about the reaction mechanism is obtained from measurements of the analyzing power \(A_y\). Early data at 200 MeV from TRIUMF indicated similarities between the elementary \(pp \rightarrow dn\) amplitude and the \((p, \pi)\) reaction on nuclei. Later data, however, show much larger sensitivity to the nuclear structure involved, and any resemblance to the \(pp \rightarrow dn\) data is difficult to see. At energies above the \((3,3)\) resonance no data exist for targets with \(A > 2\). The aim of the present experiment is to measure the analyzing power in both \(\pi^+\) and \(\pi^-\) production on \(^9\text{Be}\), leading to a description of final states in \(^{10}\text{Be}\) and \(^{10}\text{C}\), respectively.

The first half of this experiment was run in April 1981, and the preliminary results are shown in Fig. 1. The analyzing power for \(\pi^+\) goes through a clear minimum at rather small angles. This result bears no resemblance at all to the \(pp \rightarrow d\pi\) data at the same energy, which show positive analyzing power for all angles. However, data from the \(pd \rightarrow \pi n\) reaction show a negative minimum in \(A_y\), but at a larger angle. Another feature in the \(^9\text{Be}(p, \pi)\)\(^{10}\text{Be}\) reaction is the indication of a nuclear structure dependence, since the positions for the minima of \(A_y\) from the transitions to the ground state and 3.37-MeV state are separated by about 10°.

Regarding the \(^9\text{Be}(p, \pi^-)\)\(^{10}\text{C}\) reaction, only one angle has been measured so far. Transitions to all final states in \(^{10}\text{C}\) yield positive analyzing power. The datum point in Fig. 1 refers to the transition to the peak at 5.3-MeV excitation energy. It is interesting to note that the low-energy data from the \(^9\text{Be}(p, \pi^-)\)\(^{10}\text{C}\) reaction show negative \(A_y\) for forward angles. In fact, an attempt to explain the negative \(A_y\) in this reaction has been made for the low-energy data.\(^1\) Assuming that the elementary reaction is a \(pn \rightarrow pp\pi^-\) process and that the two final protons couple to spin zero, it is possible to use arguments based on simple angular-momentum coupling to predict opposite sign of \(A_y\) for (for example) the \(^{12}\text{C}(p, \pi^-)\)\(^{13}\text{O}\) reaction (\(\Delta J = 3/2\)) and the \(^9\text{Be}(p, \pi^-)\)\(^{10}\text{C}\) reaction (\(\Delta J = 1/2\)). This result is confirmed by experimental data at low energy. However, as seen, the high-energy data give another result. This is perhaps not surprising since the subthreshold arguments also assume a directional preference of the bound neutron in its Fermi motion with respect to the incident proton. Such assumptions are certainly invalid at high energies.

From the \((p, \pi^\pm)\) data obtained in this experiment we conclude that the analyzing power is sensitive to the incident energy, the nuclear final state involved, and the charge of the pion. It is therefore likely that these measurements contain important information about the reaction mechanism. In phase II of this experiment, the
angular distribution of $A_y$ will be extended to larger angles.

REFERENCE


$\pi^\pm$-Nuclear Elastic Scattering at Energies Between 30 and 80 MeV
(Exp. 561, LEP)
(Virginia Polytechnic Institute and State Univ., Oak Ridge, Los Alamos, Univ. of South Carolina, Massachusetts Institute of Technology, Univ. of Maryland)
Spokesmen: M. V. Hynes (Los Alamos), F. Obenshain (Oak Ridge), and M. M. Blecher (Virginia Polytechnic Institute and State Univ.)

A run in November started the last round of this survey-like experiment in which the study of elastic scattering from a series of isotopes will provide constraints on the theoretical understanding of the isovector part of the n-nuclear interaction. We completed the measurements on $^{12}$C, $^{13}$C, and $^{14}$C at 80- and 65-MeV $\pi^\pm$.

A Search for Nuclear Critical Opalescence Using the Reaction $^{40}$Ca($\pi^+,2\gamma$)
(Exp. 541, LEP)
(Los Alamos, Univ. of Louvain, Univ. of North Carolina)
Spokesman: M. D. Cooper (Los Alamos)

Critical opalescence is the premature onset of pion-like behavior in real nuclei induced by the proximity of a pion-condensed state at roughly twice nuclear-matter density. The nature of the precursor of the condensed state is such that the pion field, which is always present around nuclei, is enhanced by medium corrections. The enhanced field introduces a spin-isospin correlation among the nucleons. Because the density is below criticality, the range of the pion field is still fairly short, and only modest effects in real nuclei are expected. This theoretically predicted phenomenon is manifested by enhanced cross sections for processes involving virtual pions of low energy and momenta near 300 MeV/c.

The inclusive $^{40}$Ca($\pi^+,2\gamma$) reaction at 50 MeV appeared to be a good candidate to use in a search for this phenomenon because of (1) the large atomic mass of $^{40}$Ca, (2) the high nuclear transparency of 50-MeV pions, (3) the natural ability of a pion to become virtual after interaction with the nucleus, (4) the ability to reach 300-MeV/c momentum transfer, and (5) the use of many final states to remove uncertainties in nuclear wave functions.

Even in the absence of any observable precursor phenomenon the measurement of this reaction presents several interesting challenges. Some of the processes contributing to the cross section involve understanding pion absorption far off the mass shell. Additionally, the role of the $\Delta$ resonance must be accounted for in the radiative capture, a phenomenon usually ignored in the interpretation of stopping experiments.

During July and August 1981 (cycle 30), 5 weeks were devoted to measuring the $^{40}$Ca($\pi^+,2\gamma$) reaction. About 3 weeks of this time were devoted to taking data. The two photons were detected using the LAMPF $\pi^0$ spectrometer. As the reaction is expected to have a very small cross section, random backgrounds were expected to be troublesome, but the preparations for three anticipated problems worked very well: (1) shielding for the required close geometry protected the counters adequately; (2) two-photon backgrounds from $\pi^0$ decay were completely eliminated by placing the detectors inside the kinematically forbidden region for $\pi^0$ decay; and (3) random counts from two photons produced by two different pions in the target were rejected by a target hodoscope designed to observe multiple particles over a large beam spot. The result of this apparatus was complete elimination of cosmic rays beyond the measurable limit and a random background from the beam corresponding to a singles flux of seven high-energy photons per second.

The beam hodoscope performed remarkably well. It consisted of 40 scintillation counters ~1.5 mm thick by 8 mm wide by 100 mm long. Short light guides connected the scintillators to 19-mm (3/4-in.) Amperex 1911 photomultiplier tubes. No rate effects were noticed up to $10^6$ particles/s average. Individual counters were characterized by better than 99.5% efficiency, 15% pulse-height resolution, and 1.5-ns time resolution. The gap between counters was always <38 $\mu$m.

The use of the beam hodoscope is illustrated by two idealized events shown in Fig. 1, which is a scale drawing of the hodoscope arrangement of the active area of the counters about the target, the solid rectangles indicating...
struck counters. Figure 1(a) displays a promising candidate where a pion disappears in the target and is in time coincidence with both x rays; another extraneous particle goes through about 10 ns earlier. Figure 1(b) portrays a rejected accidental in which two pions interact in the target, each producing one photon in a gamma-detector arm.

A Monte Carlo simulation of the hodoscope completely characterized the performance, with the added assumption that 2% of the events fired neighboring counters. The quality of the agreement is reproduced in Table I, which tabulates the probability of producing a pattern of \( n \) particles upstream and \( m \) particles downstream for a given trigger of the \( \gamma \) detector. The agreement with experiment is excellent except for very rare off-diagonal events.

Data were taken at central momentum transfers at 140 and 280 MeV/c with a resolution (FWHM) of 35 MeV/c. It is our impression that the reaction was observed at both settings with about 50% background. The expected sensitivity above background should be 5 nb/sr². Since the data are still being analyzed, no conclusions can be drawn at this time.

### Table I

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Elastic Scattering of Pions in the Energy Range 20-50 MeV
(Exps. 29/54, LEP)
(Oak Ridge, Los Alamos, Massachusetts Institute of Technology, Univ. of South Carolina, Tel Aviv Univ., Virginia Polytechnic Institute and State Univ.)
Spokesman: R. Burman (Los Alamos)

A program of low-energy, pion-nucleus elastic-scattering measurements has been in progress at LAMPF for some time. With the measurement of data at 20 MeV it is now complete.

The research reported here involves the scattering of 20-MeV positive pions ($\pi^+$) from $^{12}$C, $^{16}$O, $^{40}$Ca, $^{90}$Zr, and $^{208}$Pb. These data, together with data from previous measurements at 30, 40, and 50 MeV, yield a rather complete description of the energy and mass dependence of the pion scattering in this low-energy region.

As we demonstrate, the absorptive s-wave strength is much stronger at 20 MeV than would be expected from the 30- to 50-MeV data or from the predictions based on free p-nucleon amplitudes. A theoretical method based on parameters obtained from pionic-atom data has been successful in constructing an optical potential that correctly predicts our measured cross sections without any adjustable parameters. This is in agreement with the conjecture that the method accurately predicts low-energy data, 30 and 40 MeV, but begins to break down at 50 MeV.

The elastic cross sections were determined at 17 angles in 2-angle sets with plastic-scintillator telescopes and at forward angles with detectors sensitive to the $\pi$-$\mu\nu$ decay. The telescopes were kept fixed at lab angles of 90° and 100° during the entire experiment to provide consistency checks of the calibration. In all cases, with the exception of one angle set for lead, the relative normalization was better than 4%.

The differential cross sections were calculated, taking into account the finite angular acceptance and efficiency of the telescope detector systems. Multiple scattering in the target at a given angle, pion decay in flight, and reactions in the detector were also taken into account in the calculation. Typically, all these effects amounted to a 10 or 20% correction to the cross sections. The statistical uncertainties were ~7%.

A phenomenological optical-model analysis was carried out for the measured angular distribution for each target. The form of the $\pi N$ $t$ matrix used to calculate the optical potential was

$$t(E(k),q,q') \propto b_0(E) \frac{(k^2 + a_0^2)^2}{(a_0^2 + q^2)(a_0^2 + q'^2)} + b_1(E) \frac{(k^2 + a_1^2)^2}{(a_1^2 + q^2)(a_1^2 + q'^2)} - q \cdot q' .$$

The $E$ and $k$ are the on-shell energy and momentum, and $q,q'$ are the off-shell initial and final momenta. The range parameters $a_0$ and $a_1$ for the $\pi N$ interaction are equal, $a_0 = a_1 = 500$ MeV/c. The s- and p-wave parameters $b_0$ and $b_1$ were varied to obtain a minimum $\chi^2$.

In Fig. 1 we show a plot of the parameter $\text{Im}b_0$ as a function of energy for each of the nuclei $^{16}$O, $^{40}$Ca, $^{90}$Zr, and $^{208}$Pb. The values at 30, 40, and 50 MeV were taken from our previous work. As can be seen from the figure, the absorptive s-wave parameter at 20 MeV is much...
larger than those for the other energies. The curve shown is a theoretical prediction based on $\pi N$-interaction data; it, too, is much lower than the values obtained from our analysis.

The explanation for this increase in $I_m b_0$ at 20 MeV is not obvious, but it could be related to the penetrability of the pion into the nuclear volume and the many-body aspects of the nuclear interaction.

The work of Stricker, Carr, and McManus is another approach to the problem of obtaining a pion-nucleus optical-model potential. These authors have developed an optical model with parameters obtained from pionic-atom data. Their model was compared with positive-pion elastic-scattering data at 30, 40 and 50 MeV. The agreement between theory and experiment is very good at 30 and 40 MeV, but at 50 MeV the model appears to break down, since some of the detail seen in the experiment is not reproduced.

The curves shown in Fig. 2 were calculated by Professor McManus. We have plotted our 20-MeV data on the same graph without any relative normalization. The agreement between theory and experiment is quite satisfactory.

Study of Isovector Giant Resonances with Pion Charge Exchange
(Exps. 412, 525, and 607, LEP)
(Tel Aviv Univ., Los Alamos, Case Western Reserve Univ.)
Spokesmen: H. W. Baer and J. D. Bowman (Los Alamos)

Much progress has been made in the analysis of the ($\pi^+,\pi^0$) data taken in March-April 1981. The Monte Carlo simulation of the $\pi^0$ spectrometer solid angle has been thoroughly investigated and checked against data on the $\pi^+ p \to \pi^0 n$ reaction. The spectrometer acceptance as a function of energy is understood to 10% absolutely and a few percent relatively. Computer programs have been written that allow us to correct the measured spectra for relative acceptance; to shift, smooth, add, and subtract histograms; and to perform peak fitting using measured line shapes. All the data are available as normalized $n^0$ kinetic-energy spectra ($d^2\sigma/d\Omega dT$) vs scattering angle. The data set is for 164-MeV beam energy, is in the angular range 0-30°, and includes targets $^2\text{H}$, $^{12}\text{C}$, $^{40}\text{Ca}$, $^{90}\text{Zr}$, $^{120}\text{Sn}$, and $^{208}\text{Pb}$. Preliminary results were discussed in the June 1981 Progress Report (LA-8994-PR). We discuss here selected new results derived from the more recent data analysis.

Giant Dipole Resonance (GDR)

$^{12}\text{C}$ and $^{40}\text{Ca}$. These targets serve the purpose of establishing the magnitude of the GDR cross sections where isospin splitting and blocking do not broaden and reduce the signal, and where we can compare ($\pi^+,\pi^0$) spectra with ($\pi^+,\pi^0$) spectra to get a better understanding of the continuum.
Fig. 1.
The measured $\pi^0$ spectra for the $^{40}$Ca($\pi^+,\pi^0$) reaction at 164 MeV. The arrow marks the expected position of the analog of the giant dipole resonance in $^{40}$Ca at 20-MeV excitation. The solid line is the smoothed, but nonrenormalized, 3° spectrum. It was used for the background shape at each angle in the GDR cross-section determinations.

The $^{40}$Ca($\pi^+,\pi^0$) spectra at six scattering angles are shown in Fig. 1. A very clear manifestation of the GDR is observed at the expected $\pi^0$ energy. Inspection of Fig. 1 shows that the continuum remains constant over the angular range of this experiment.

The solid line shown with each spectrum is the smoothed 3° spectrum without any renormalization. One sees that this line gives an excellent description of the continuum between 100 and 135 MeV for the spectra 3-22°. Therefore, a reasonable measure of the shape of the background under the GDR is the 3° spectrum where the contribution of the GDR is expected to be at a minimum. The same assumption was used to analyze the $^{40}$Ca($\pi^-,\pi^0$) data (Fig. 2) for the GDR peak areas and centroids.

The $\pi^0$ kinetic energies for the two states of an isospin triplet produced by the $^{40}$Ca($\pi^+,\pi^0$) reaction are related by

$$\Delta T(ANALOGS) \approx \Delta Q = \Delta E_1(40K)$$

$$+ \Delta E_2(40Ca) - 2\Delta_{np},$$

where $\Delta E_1(40K) = 7.13$ MeV and $\Delta E_2(40Ca) = 7.45$ MeV are the Coulomb displacement energies\(^1\) and $\Delta_{np} = 1.293$ MeV is the neutron-proton mass difference. This gives $\Delta T = 12.0$ MeV for the expected shift in the GDR states. The measured displacement for the 14° spectra is $12.1 \pm 0.4$ MeV, where the error represents the statistical uncertainty. One sees that the observed peak positions and the displacement of the two peaks are consistent with identifying them as the GDR analogs.

The excess counts in a 12-MeV interval centered about the expected position of the GDR were used in the determination of the cross sections. A Gaussian function was fit to these counts to determine the peak centroids.
The measured $^{40}\text{Ca}(\pi^\pm,\pi^0)$ cross sections compared with the function $|\beta[J^\Delta(qR) - J^\Delta(3^\circ)]|$ expected for a $\Delta L = 1$ transition. The error bars reflect the statistical error associated with the model-dependent analysis of the background shape.

and widths. For the three angles, 10, 14, and 18°, the peak centroid is constant to better than ±1 MeV. The widths appear to be angle dependent, with a minimum width observed at 14°. The fits to the data at this angle gave (FWHM) 6.6 ± 0.7 MeV for the $(\pi^+,\pi^0)$ spectrum and 6.1 ± 0.5 MeV for the $(\pi^-,\pi^0)$ spectrum. These values are larger than the 5.0 ± 0.2-MeV instrumental resolution and are consistent with a GDR width of 4 ± 2 MeV (FWHM).

The extracted angular distributions for both the $(\pi^+,\pi^0)$ and $(\pi^-,\pi^0)$ reactions are displayed in Fig. 3. In a strong absorption model$^2$ for a $\Delta L = 1$, spin-independent transition on an $N = Z$ nucleus, the angular distribution has the form

$$\frac{d\sigma(\theta)}{d\Omega} = \beta k^2 J^\Delta(qR),$$

where $q = h|k-k'|$ is the momentum transfer and $R$ is the interaction radius. A value of $R = 4.80$ F was used, which is the average value of the interaction radii at 164 MeV deduced$^3$ from an analysis of $\pi^+$ and $\pi^-$ elastic scattering on $^{40}\text{Ca}$. Because of the Coulomb energy difference of the two final states, the $q$ values and, therefore, $J^\Delta(qR)$ are quite different at 0°; for the $(\pi^+,\pi^0)$ reaction, $q = 26$ MeV/c and $J^\Delta(qR) = 0.093$, and for the $(\pi^-,\pi^0)$ reaction, $q = 13$ MeV/c and $J^\Delta(qR) = 0.023$. The maximum $J^\Delta(qR) = 0.34$ occurs at 15.4° for $(\pi^+,\pi^0)$ and at

![Fig. 2.](image1)

![Fig. 3.](image2)
16.0° for \((\pi^-,\pi^0)\). Since the GDR cross sections were extracted by subtracting the 3° spectra, the proper functional form to compare to the measured angular distribution is
\[
\beta[J_\beta(qR) - J_\beta(3°)].
\]
This function normalized to the central three points in each of the angular distributions is shown by the solid lines in Fig. 3. Values of the deduced \(\beta\) are 2.55 and 2.50 mb/sr for the \((\pi^+\pi^0)\) and \((\pi^-\pi^0)\) reactions, respectively.

To see if the magnitudes of the measured cross sections are consistent with previous knowledge of the GDR, we calculated the value of \(\beta\) using the Goldhaber-Teller form of the transition density,
\[
\Delta\rho_t = \hbar\sqrt{8N}\left(3A^3 \cot \frac{\pi}{2m_p^2}\right)^{1/2}
\]
\[
\frac{d\rho_0}{dr} Y_{lm}(\theta, \phi),
\]
which is normalized to exhaust the classical \(E1\) sum rule, where \(\hbar\) is the excitation energy, \(d\rho_0/dr\) is the derivative of the nucleon density \(\rho_0 = \rho_t + \rho_p\), \(Y_{lm}\) is the spherical harmonic of order \(l\), \(A\) is the atomic number, and \(m_p\) is the proton mass. Inserting this transition density into an eikonal model for the scattering amplitude and then making several numerical approximations in evaluating the resulting integrals leads to the value \(\beta = 2.8\) mb/sr. The agreement between the measured cross sections and the model value gives a first indication that the excitation of the GDR in pion charge-exchange scattering near resonance energies does not involve pathological features, rather, it may be understood quantitatively as a single-step charge-exchange scattering at the nuclear surface. The same radial dependence and normalization of the transition density also work for \(E1\) photon absorption and \(\pi\) charge exchange.

A secondary feature of the data is the angle-dependent broadening of the GDR peak (Fig. 1), which is particularly noticeable in the 22-28° spectra of Fig. 1. These data are consistent with excitation of states near 25 MeV in \(^{40}\text{Ca}\). The angular distribution for these states appears to have a minimum near 14° and to rise at the large angles. An intriguing possibility, consistent with the data, is that this excess cross section is due to transitions with \(\Delta L = 1, \Delta S = 1\) (spin-flip), producing \(1^- \cdot c \cdot 2^-\) states. Such states, with predominant particle-hole configurations \(1f_{5/2}^21d_{5/2}^2\), are expected at several million electron volts above the GDR. Both distorted-wave-impulse-approximation calculations and eikonal-model calculations with collective form factors indicate that such \(2^-\) states have angular distributions that have a first peak near 30°. The \(1^-, \Delta S = 1\) states have a maximum at 0°. Further studies of this feature are of interest.

The \(^{40}\text{Ca}(\pi^+\pi^0)\) data constitute the first observation and angular distribution measurements of the GDR in pion single-charge-exchange scattering. The favorable signal-to-background conditions, the sharply oscillating angular-distribution shape, and the seemingly transparent theoretical interpretation of the cross sections make the study of the GDR with the \((\pi^+\pi^0)\) reactions look quite promising.

\(^{12}\text{C}(\pi^-\pi^0)\). The measured spectra (Fig. 3) show a peak rising above the continuum at angles 10-28°. The smoothed 3° spectrum is shown with each measured spectrum. One sees that for angles 10-20° the spectra rise above the solid line in the region 115-150 MeV (corresponding to 15-50-MeV excitation in \(^{12}\text{C}\)). This result differs from what was observed in the \(^{40}\text{Ca}(\pi^+\pi^0)\) reaction where the continuum remained constant from 3-28°.

The \(^{12}\text{C}(\pi^+\pi^0)\) spectra do remain constant near the value of 30 µb/sr MeV between 95 and 110 MeV at all scattering angles.

As a first analysis of the \(^{12}\text{C}\) GDR differential cross sections, we followed the prescription used for the \(^{40}\text{Ca}\) analysis. The excess counts above the 3° spectrum in an interval centered on the observed peak position were taken for the peak areas. For \(^{40}\text{Ca}\) the width of this interval was 12 MeV. Comparison of the \(^{12}\text{C}\) and \(^{40}\text{Ca}\) spectra at angles near the maxima of the GDR cross sections shows that the \(^{12}\text{C}\) GDR peak is broader. Therefore, a large interval of peak area integration is appropriate. An interval of 16 MeV extending from 19-31 MeV in \(^{12}\text{C}\) was used. The centroid of this peak area in the 22° spectrum occurs at 145 MeV, which corresponds to 25 MeV in \(^{12}\text{C}\).

The angular distribution obtained with this model of the background is shown in Fig. 4. The function \(\beta[J_\beta(qR) - J_\beta(3°)]\) with value \(\beta = 2.45\) mb/sr is compared with the data. The value \(R = 3.16\) F was used. This is the average of \(R^+\) and \(R^-\) deduced from the position of the first minimum of elastic \(\pi^+\) and \(\pi^-\) scattering at 180 MeV. The maximum value of \(J_\beta(qR)\) for this value of \(R\) occurs at 25°. One sees that the rise of the GDR cross

a forward-peaked angular distribution of the form

\[ \frac{d\sigma}{d\Omega}(0) J_0(qR) \]

a 0° cross section

of about 500 \( \mu b/sr \);

a radius parameter \( R \), which is the same as the radius parameter determined by elastic pion scattering;

an excitation energy \( \hbar \omega \) of \(~170\text{ MeV} \times A^{-1/3}\), the hydrodynamical estimate for the energy of the isovector monopole resonance in the target nucleus; and

a width of a few million electron volts.

These cross-section estimates were carried out using a Tassi form for the transition density. A sum rule normalization with blocking determined the amplitude of the transition density.

\[ \Delta \pi_0 = Ghc \left( 2m_p C^2 A <r^2> \hbar \omega \right)^{-1/2} \left( 3\rho_0 + r \frac{d\rho_0}{dr} \right) \]

Here \( G \) is a blocking factor (0.73 for \(^{120}\text{Sn}\)) and \( <r^2> \) is the rms nuclear radius. The other symbols are defined above.

Figure 5 shows the double-differential cross section for the reaction \(^{120}\text{Sn}(\pi^-\pi^0)X\) at five scattering angles from 4.5-22°. Figure 6 shows a subtracted spectrum, which is the difference between the 4.5 and 11.0° spectra. The positive-going peak is the isovector monopole signal and the negative-going peak is the well-known isovector dipole. Figures 7(a) and (b) give the areas extracted from various difference spectra for the monopole and dipole peaks.

In Table I we summarize the radius parameter, maximum cross sections, and energies and widths for the...
The double differential cross section $d^2\sigma/dQdE$ ($\mu$b/sr MeV) for the reaction $^{120}\text{Sn}(\pi^-,\pi^0)X$ as a function of $\pi^0$ kinetic energy $T_{\pi^0}$ for scattering angles between 4.5 and 22.0°. The incident $\pi^-$ kinetic energy is 165 MeV.

monopole and dipole peaks. The dipole results are compared with existing experimental data and the monopole results are compared with theoretical expectations. The agreement between the present data and predictions made before the experiment was done is remarkable and supports the first experimental observation of the isovector monopole resonance.

REFERENCES


Fig. 6.
The difference between the 4.5 and 11.0° spectra for the reaction $^{120}$Sn($\pi^-,\pi^0$)X.

Figs. 7(a) and (b).
(a) Areas for the monopole peak in $^{120}$Sn($\pi^-,\pi^0$)X extracted from fits to difference spectra. The 11.0° spectrum was used as a reference. The solid line is a fit to the form $\beta[J^2(qR) - J^2_{11.0°}]$.
(b) Areas for the dipole peak in $^{120}$Sn($\pi^-,\pi^0$)X extracted from fits to difference spectra. The 4.5° spectrum was used as a reference. The solid line is a fit to the form $\beta[J^2(qR) - J^2_{4.5°}]$. 
TABLE I

SUMMARY OF DEDUCED PARAMETERS FOR THE MONOPOLE AND DIPOLE PEAKS PRESENT IN THE $^{120}\text{Sn}(\pi^-,\pi^+)\chi$ REACTION DATA

<table>
<thead>
<tr>
<th>Quantity</th>
<th>This Work</th>
<th>Other Results</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius parameter $R$</td>
<td>7.5 ± 0.7 F</td>
<td>6.87 F</td>
<td>$\pi^-$ elastic scattering</td>
</tr>
<tr>
<td>$\frac{d\sigma}{d\Omega}(\text{max})$</td>
<td>200 ± 40 µb/sr</td>
<td>340 µb/sr</td>
<td>Sum rule estimate with blocking (Ref. 8)</td>
</tr>
<tr>
<td>Excitation energy in $^{120}\text{Sn}$</td>
<td>21.3 ± 0.85 MeV</td>
<td>20.9 MeV</td>
<td>Electron scattering (Ref. 8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>This Work</th>
<th>Estimates</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius parameter $R$</td>
<td>7.3 ± 0.6 F</td>
<td>6.87 F</td>
<td>$\pi^-$ elastic scattering</td>
</tr>
<tr>
<td>$\frac{d\sigma}{d\Omega}(\text{max})$</td>
<td>740 ± 85 µb/sr</td>
<td>450 µb/sr</td>
<td>Sum rule estimate with blocking (Ref. 7)</td>
</tr>
<tr>
<td>Excitation energy in $^{120}\text{Sn}$</td>
<td>30.9 ± 0.5 MeV</td>
<td>34.5 MeV</td>
<td>Hydrodynamical estimate (Ref. 9)</td>
</tr>
<tr>
<td>Width</td>
<td>7.2 ± 2.0 MeV</td>
<td>Few MeV</td>
<td>Related widths (Ref. 7)</td>
</tr>
</tbody>
</table>

High-Resolution Study of $(\pi^+,pp)$, $(\pi^+,pd)$, and Other $(\pi^+,xx)$ Reactions on $^6,^7\text{Li}$, $^{14}\text{N}$, and $^{16}\text{O}$ (Exp. 315, LEP)
(Carnegie-Mellon Univ., Los Alamos, Massachusetts Institute of Technology, Univ. of Washington, Arizona State Univ.)

Spokesman: William Wharton (Carnegie-Mellon Univ.)

By looking at a large variety of pion-annihilation reactions and doing a high-precision kinematically complete experiment, we study the mechanism by which the pion annihilates in a nucleus. Pion propagation and annihilation inside nuclei is a fundamental but difficult problem to understand.

Because most annihilations involve multiparticle (≥3-particle) final states, coincidence experiments are invaluable and potentially richer in information than are single-arm experiments. For this reason we collected a large amount of high-quality two-particle coincidence data from pion annihilation on light nuclei at several pion energies between 38 and 90 MeV. The data, which were obtained during the last 2 years at the LEP channel using two spectrometer systems to detect charged particles in coincidence, are either in the reduction stage or are still in the primitive on-line form collected during the monitoring of our recent experiment. The reactions studied are $(\pi^+,xx)$, where $xx$ can be any combination of two-hydrogen isotopes ($p,d,t$). We also measured $^6,^7\text{Li}(\pi^+,\text{HeHe})$ cross sections.

The large cross sections of some of these reactions are surprising. The $^7\text{Li}(\pi^+,pd)$ cross section is more than 20% larger than the $^7\text{Li}(\pi^+,pp)$ cross section. Some of our $(\pi^+,pd)$ data were presented and discussed at the Indiana University Cyclotron Facility (IUCF) Pion Workshop.¹

Our $(\pi^+,pp)$ missing-mass resolution was as good as 1.0 MeV with the channel set at $\Delta p/p = 0.5\%$. Figure 1 shows a missing-mass spectrum for the $^{16}\text{O}(\pi^+,pp)^{14}\text{N}$ reaction. The dominant peak in the spectrum is the $1^+$ state at 3.95 MeV. We also see the $^{14}\text{N}$, 1+ ground-state transition. This transition is known to involve two units...
of angular momentum that have a 50% probability of being either in the internal motion or the center-of-mass motion of the two removed nucleons. By looking at the recoil momentum distribution for the ground-state transition, we are investigating the relative strength of pion absorption on two nucleons in an internal \( L = 0 \) and \( L = 2 \) configuration.

Between the two \( 1^+ \) states is a 2.3-MeV \( 0^+ \), \( T = 1 \) state that is very weak in this spectrum. Such a transition would involve pion absorption on a \( T = 1, S = 0 \) nucleon pair rather than on a \( T = 0, S = 1 \) pair, which is the case in the 3.95-MeV transition. The ratio of the known spectroscopic strengths and isospin Clebsch-Gordan factors for the 3.95-MeV \( 1^+ \) and 2.3-MeV \( 0^+ \) transitions is 3.5. The ratio of the cross sections is much larger than this, indicating that absorption on a \( T = 0, S = 1 \) pair is much stronger than on a \( T = 1, S = 0 \) pair.

Fig. 1.
The \( ^{16}\text{O}(\pi^+,pp)^{14}\text{N} \) missing-mass spectrum at \( T_\pi = 60 \text{ MeV} \), proton angles 60 and 102.7°.

A Study of Neutrino-Electron Elastic Scattering
(Exp. 225, Neutrino Area)
(Univ. of California at Irvine, Los Alamos)
Spokesman: H. H. Chen (Univ. of California at Irvine)

This experiment, designed to measure v-e elastic scattering, completed its first shakedown run during the last week of beam in November 1981. The central detector was completely installed during the summer and autumn. The first 13 of 40 modules of scintillators and the first 13 of the horizontal flash chambers were instrumented. The cosmic-ray anticoincidence shield, composed of ~600 drift chambers, was installed. About 95% of the drift chambers have been connected to an electronics system that provides a veto signal for incoming cosmic rays. Figure 1 is a diagram of the end view of the apparatus.

Fig. 1.
End view of apparatus for v-e elastic scattering.
The preliminary results of this shakedown run were satisfying. The central detector worked quite reliably with very little tuning. Based on feasibility studies made with a prototype detector 5 years ago, the background trigger rates in the central detector scaled linearly with the mass of the detector, adding confidence to our expected rates with the full detector. The background trigger rate with at least three layers of the central detector scintillators in coincidence was 585 s⁻¹. With an anticoincidence signal from the drift chambers the rate dropped to 0.62 s⁻¹. Cosmic-ray effects derive from three main components.

1. Incoming cosmic-ray muons stop within the central detector and subsequently decay after the veto signal ends. We measured the stopping $\mu^+$ rate in the 13 instrumented layers of the central detector as $(8.0 \pm 0.5)$ s⁻¹. For this run we used an 8-µs-long gate, corresponding to 3.6-$\mu^+$ lifetimes. Therefore, the trigger rate from muons that decayed after this time was $0.21 \pm 0.01$ s⁻¹. The rate expected from the feasibility study for this same condition is 0.26 s⁻¹. Figure 2 shows an event of this kind in the flash chambers.

2. Cosmic-ray neutrons appear in the detector through their interaction with active material, giving highly ionizing recoil protons. By looking at events with large pulse heights in the scintillators ($dE/dx$ per scintillator layer of $>3$ times minimum ionizing), we obtained a rate of $(0.17 \pm 0.08)$ s⁻¹ for events of this kind. The feasibility study predicted a rate of 0.16 s⁻¹.

3. Because parts of the antishield that cover known geometrical gaps were not yet part of the overall veto signal, the residual trigger rate beyond that from the backgrounds listed above was attributed to veto-system inefficiency. This residual rate of $(0.18 \pm 0.09)$ s⁻¹ corresponds to an antisystem inefficiency of $\sim 3 \times 10^{-4}$. We expect that when we connect the gap counters to the system the antisystem inefficiency will approach the $10^{-5}$ level.

We will analyze the current data to look for still finer effects and to set limits on contributions to the trigger rate within the beam gate. During the winter and spring of 1982 we plan to instrument the rest of the central detector, add diagnostics and additional counters to the antishield, and make several more tuning runs to discover and block leaks through the antishield. We expect to be fully instrumented and capable of looking for neutrino events when the beam returns during the summer of 1982.

A Measurement of the Rare-Decay $\pi^0 \rightarrow e^+e^-$ (Exp. 222, P³)
(Los Alamos, Arizona State Univ.)
Spokesman: R. E. Mischke (Los Alamos)

Evidence for the rare-decay $\pi^0 \rightarrow e^+e^-$ has been obtained in an experiment that measured the invariant mass spectrum of $e^+e^-$ pairs produced by 300-MeV/c $\pi^-$ mesons interacting in a liquid-hydrogen target. Interest in this decay dates back to the first calculation by Drell in 1959. Since then many models have been used to estimate the branching ratio. The effects of vector dominance, baryon loops, direct quark-lepton coupling, weak neutral currents, and Higgs bosons have been included by different authors. In general, most results show only small enhancements over a minimum branching ratio, called the unitarity lower limit. Thus, the branching ratio is expected to be

$$B = \frac{\Gamma(\pi^0 \rightarrow e^+e^-)}{\Gamma(\pi^0 \rightarrow \gamma\gamma)} \geq 4.8 \times 10^{-8}.$$ 

There has been one previous report of a measurement of the branching ratio for this decay with the result $B = (2.2^{+2.4}_{-1.4}) \times 10^{-7}$.

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*Peter Herczeg, private communication.
Our experiment used a beam of $1.8 \times 10^7 \pi^-/s$ incident on a 5-cm-diam and 25-cm-long liquid-hydrogen target. Most $e^+e^-$ pairs coming from the target resulted from $\pi^0$ decays, often with a photon being converted through Compton scattering or pair production. These pairs always have an effective mass $< m_{\pi^0}$ because some energy from the $\pi^0$ is carried away by undetected $e^+$ or $e^-$. Another source of pairs was the reaction $\pi^-p \to n^+e^-e^-$; here the effective mass of the pair ranges from near 0 to 410 MeV/c$^2$.

The $e^+$ and $e^-$ were identified and momentum analyzed in the magnetic spectrometer shown in Fig. 1. Multiwire proportional chambers (MWPCs) were placed on both sides of a large-aperture magnet. Behind the chambers a row of scintillation counters was used to detect a charged particle on either side of the beam line, and a gas Čerenkov counter provided identification of electrons. In the center of the magnet a uranium plug served as a beam stop for the incident pions. The acceptance of the spectrometer was designed to be optimal for forward-produced $\pi^0$'s, which decayed into an $e^+e^-$ pair transverse to the $\pi^0$ direction.

A total of $2.4 \times 10^{13} \pi^-$ produced $\sim 50,000$ candidate events. A reconstruction program took the hits recorded by the MWPC planes and considered all plausible combinations to find the best-fit tracks. About one-third of the candidate events contained two acceptable tracks. Cuts were applied to define a fiducial volume for the apparatus and to eliminate accidental coincidences. Acceptable events were required to intersect within the volume of the target. The final data sample contained 1330 events, and the effective mass distribution is shown in Fig. 2. Most of the events with an effective mass $< m_{\pi^0}$ come from $\pi^0$ decays and most events with masses above $m_{\pi^0}$ come from $\pi^-p \to n^+e^-e^-$. To separate the contributions from the various modes, a Monte Carlo simulation determined the mass spectrum from $\pi^0 \to e^+e^-$, from backgrounds from other $\pi^0$ decay modes, and from $\pi^-p \to n^+e^-e^-$. The simulation was designed to reproduce the dynamics and kinematics of each process as well as the geometry of the experiment. Other effects, such as chamber resolution and inefficiencies, were also included. The program generated simulated hits in the chambers, which were processed by the same routines used for the data analysis. The resulting mass spectra are shown in Fig. 3. Several checks were made to ensure that the Monte Carlo simulation reproduced all essential aspects of the data sample.

A $\chi^2$-minimization routine was used to determine a best fit of the Monte Carlo spectra to the data. The best

![Top view of apparatus. The incident beam of $\pi^-$ comes from the left and charge exchanges in the $H_2$ target. The resulting $e^+e^-$ from $\pi^0$ decay are detected by the multiwire chambers, the scintillation counters, and the Čerenkov counter.](image)
fit is shown in Fig. 2; it has a $\chi^2$ of 49.1 for 47 degrees of freedom. The fit requires $58(\pm 19) \pi^0 \rightarrow e^+e^-$ events. Normalizing to the contribution from Dalitz decay events, as determined from the Monte Carlo and the fit, gives

$$B = (18 \pm 6) \times 10^{-8}.$$  

The error given is dominated by the statistical uncertainties in the subtraction of background. We have investigated possible systematic effects that could affect the branching ratio. These include our assumptions about the photon-conversion probability, the form factor in $\pi^0 \rightarrow e^+e^-\gamma$, and various cuts on the data. We estimate an overall systematic uncertainty of <10%.

Our result is almost four times the unitarity lower limit. The accuracy is sufficient to give us confidence that we have seen the decay $\pi^0 \rightarrow e^+e^-$, but not adequate for us to distinguish between models that predict different contributions to the amplitude for this process.

REFERENCES

High-Precision Study of the $\mu^+$ Decay Spectrum
(Exp. 455, P$^3$)
(Los Alamos, Univ. of Chicago, National Research Council in Canada, Carleton Univ.)
Spokesmen: H. L. Anderson (Los Alamos) and W. W. Kinnison (Univ. of Chicago)

The object of this experiment is to establish a more precise knowledge of the constraints of the weak interaction. It will test with five times greater sensitivity whether V-A correctly describes the weak interaction in amplitude and phase, as current dogma asserts. The experiment measures the momentum spectrum and asymmetry of the positrons in the process $\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$. The experiment features:

- a surface muon beam at momentum 29 MeV/c with polarization close to 100%. The momentum spread, $\Delta p/p$, is $\approx 2\%$. An electrostatic deflector removes the electrons and provides a muon beam of high purity that is deflected out of the aperture of the apparatus whenever a muon enters the apparatus;
- a time projection chamber (TPC) for determining the momentum and emission angle of the positrons from the $\mu$'s that decay within the fiducial volume of the chamber. The chamber operates in a magnetic field of high uniformity, $\approx 0.2\%$, and gives the $(x,y,z)$ coordinates of many points along the helical positron trajectory;
- a readout that uses eight-bit “flash” encoders to give precise time and amplitude measurements of the “pad” pulses. The flash encoder measures the shape of the pad pulse by sampling its amplitude every 40 ns. This allows for a precise time measurement of the centroid and a measurement of the total charge in the pulse to be compared with pulses from neighboring pads to determine position (see Fig. 1); and
- a system geared for high statistics. The event rate is 100/s for $10^6$ s for a total of $10^8$ events in each of several runs planned.

Most of the features outlined above were operational in the last 6 months of 1981. We also accomplished the following:
- The magnetic field was explored with nuclear-magnetic-resonance (NMR) probes and trimmed.

Fig. 1.
Pulse heights from neighboring pads, indicating how a precise position may be obtained by interpolation.
with auxiliary coils to produce the desired uniformity over a large fraction of the fiducial volume.

- The muon beam was tuned during a 1-week test run in July and gave a satisfactory rate within a 2-cm-diam spot with a momentum spread \( \Delta p/p \approx 2\% \).

- In a second test run in September we mounted one of our TPC modules in the magnet and in the beam and were able to display the stopping \( \mu^+ \)'s within the chamber by drift-time measurements. We could change the location along the axis of the chamber where the \( \mu^+ \)'s stopped by adding or subtracting a moderator. We measured range and range straggling and found \( \Delta R/R = 0.037 \), in agreement with theory, and \( \Delta p/p = 2\% \).

- In our third test run in November we read out the pad signals with 173 flash encoder readouts. This allowed full reconstruction of events. Our software programs allowed us to do reconstruction on line and we obtained several thousand events. We show an example in Figs. 2(a)-(d).

- We obtained several thousand events with a graphite target placed at the entrance opening of the TPC. These are being analyzed off line to obtain a Michel spectrum in the region defined by our trigger. This

Figs. 2(a)-(d).

(a) The \((x,y)\) view of an event with momentum 22.7 MeV/c, emission angle \( \theta = \text{CR}^{-1}(-0.919) \).
(b) The \((y,z)\) view of the event.
(c) The \((x,z)\) view of the event.
(d) Three-dimensional view of the event.
The exclusive DCX reaction, in which the residual nucleus is left in a discrete final state, has been studied in several recent experiments. Various puzzles remain, for example, in the diffraction-like structure seen in the angular distributions and in the relative magnitudes of double-isobaric-analog and nonanalog transitions. The unexpectedly large cross sections for the latter, which were observed in the first experiments on $^{16}$O and $^{18}$O, have led to the realization that not only the configurations of the initial and final nuclear states but also the spectrum of intermediate states play important roles in the description of this process.\textsuperscript{5,6} In the inclusive DCX reaction, by comparison, nuclear structure enters in the configuration of the initial state, the question of intermediate states merges into a description of the propagation of $\pi^0$s or $\Delta$'s in nuclear matter, and the final state must be properly antisymmetrized (that is, "Pauli blocking" will be important).

Previous data on inclusive DCX reactions are both sparse and contradictory. Large discrepancies exist among calculations,\textsuperscript{2,7,8} as well as among measurements,\textsuperscript{9,10} of the $^4$He($\pi^+,\pi^+$) cross sections. A more recent investigation of the $^4$He($\pi^+,\pi^-$)4p process\textsuperscript{10} yielded results greatly exceeding those of a prediction\textsuperscript{8} based on sequential single-charge-exchange scatterings, leading the authors\textsuperscript{10} to deduce the dominance in this process of scattering from mesonic-exchange currents. A recent measurement\textsuperscript{4} completed at SIN of the $^{16}$O($\pi^+\pi^-$) cross section at $T_{\pi^+}=240$ MeV was found to disagree markedly with earlier results obtained using nuclear emulsions.\textsuperscript{11} The observed pion energy spectrum and angular distribution showed little resemblance to the shape expected from four-body phase space. Clearly something interesting is occurring in this reaction, but no theoretical calculations have as yet been performed.

In the present experiment we have undertaken a systematic investigation of the inclusive DCX process in complex nuclei with good statistical accuracy over a broad range of incident pion energies and outgoing pion angles. It is hoped that the resulting data set will provide motivation for further theoretical study and thus lead to a better understanding of the DCX reaction mechanism in both inclusive and exclusive processes.

The work reported here has concentrated on measurements of the $^{16}$O($\pi^\pm,\pi^\mp$) and $^{40}$Ca($\pi^\pm,\pi^\mp$) cross sections; some exploratory results were also obtained for $^{12}$C and $^{208}$Pb. Data were taken for incident pion energies between 120 and 270 MeV and for outgoing pion energies between 10 MeV and the four-body phase-space cutoff ($\sim$30 MeV below the kinematic limit) at angles between...
25 and 130°. The accuracy is everywhere better than ~10%, limited mainly by counting statistics. Auxiliary measurements of the differential cross section for π⁺-p elastic scattering were performed at each incident energy to obtain an absolute normalization of the DCX cross sections.

The experiment was performed in the P3-East channel using the 325-MeV/c, 180° double-focusing spectrometer (Fig. 1). The spectrometer was equipped with a multiwire proportional counter (MWPC) between the two 90° dipoles and a focal-plane detector consisting of two MWPCs, a plastic scintillator, and a fluorocarbon Čerenkov counter. This spectrometer is well suited for inclusive DCX measurements; because the flight path from target to focal plane is only 3.5 m, one can observe pions with energies as low as 10 MeV and can correct reliably for pion decay. The double-focusing property keeps the focal plane small while maintaining a relatively large momentum acceptance (Δp/p = 9%) and solid angle (ΔΩ = 15 msr), thus reducing shielding and background problems. Low background rates were essential to the success of this measurement of cross sections as low as 0.01 μb/MeV-sr. Backgrounds were further reduced by demanding a coincidence between the midplane MWPC and the focal-plane chambers and scintillator in the event trigger, thus ensuring that the detected particle came through the spectrometer.

Electrons (or positrons) resulting from conversion of decay photons from π⁺'s produced in (π⁺,π⁰) reactions in the target were separated from pions in the analysis by examining the pulse height in the Čerenkov counter for each event. Electrons always produced a large pulse; pions of energy <90 MeV produced either no light or a pulse of sufficiently smaller amplitude so that the separation was unambiguous. For higher energies the pion and electron distributions began to overlap, but a peak-fitting procedure still allowed adequate separation. In the (π⁺,π⁺) measurements a copious proton yield was observed, together with smaller numbers of deuterons and tritons. These were cleanly separated from the pions by examining either the scintillator pulse height or the flight time between the midplane and focal-plane chambers. A stringent cut on the particle trajectories through the two focal-plane chambers allowed the elimination of most of the muons; the remaining contamination will be assessed with the aid of a Monte Carlo calculation.

Solid 12C, CH2, 40Ca, and 208Pb targets of thickness 0.5-1 g/cm² were used. For the 16O measurements the target was 1.1 g/cm² of H2O contained in an aluminum frame with 0.05-mm Mylar windows. The π-p scattering data were obtained from a (CH2-12C) subtraction. For the DCX runs, backgrounds were measured with an empty target frame and with an empty H2O container, and were found to be <2%.

The incident pion beam was monitored both by an ion chamber placed immediately following the last quadrupole in the P3-East channel and a scattered-particle telescope that observed, at 90° to each side of the beam, an auxiliary 3-mm-thick CH2 target located 3 m downstream from the scattering chamber. A profile monitor just upstream of the scattering chamber measured the steering and focusing of the beam. Intercomparison among these monitors provided a continuous check of beam monitoring and ion-chamber gain.

Preliminary analysis of the 16O and 40Ca DCX results has yielded pion spectra of which typical examples are shown in Fig. 2. The absolute normalization of these cross sections was determined from a comparison with the auxiliary π-p scattering results obtained using identical apparatus and analysis procedures. The present

Fig. 1.
The 325-MeV/c double-focusing spectrometer.
The doubly differential cross section for the reaction $^{16}\text{O}(\pi^+,\pi^-)$ for $T_{\pi} = 240$ MeV compared at $\theta_{\pi^-} = 25^\circ$ and $130^\circ$. Where errors are indicated they are statistical; where not shown they are smaller than the plotted symbols.

Data for $^{16}\text{O}(\pi^+,\pi^-)$ at $T_{\pi} = 240$ MeV are found to be in good agreement with previous SIN results.\(^4\)

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Preliminary Report on a New Pion-Beta Decay Experiment
(Exp. 32, P3)
(Temple Univ., Los Alamos)
Spokesman: R. J. Macek (Los Alamos)

The conserved-vector-current (CVC) hypothesis, a cornerstone of the unified theory of electromagnetism and weak interactions, provides a precise prediction for the branching ratio of the pion-beta decay reaction \( \pi^+ \rightarrow \pi^0 e^+\nu \). The predicted ratio is \( 1.045 \times 10^{-8} \) with an uncertainty of 0.5% due to errors in the pion masses and an additional 1% uncertainty due to the electromagnetic corrections. The most precise existing experiment is that of Depommier et al., who found a branching ratio of \( 1.000 \pm 0.08 \times 10^{-8} \).

This experimental result is consistent with the theory within the errors, but it is clearly very desirable to improve the experimental precision so that it approaches that of the theory. Also, since all previous experiments used the same technique (of stopping pions), it is possible that similar systematic errors could have given spurious agreement with the theory. We are in the process of analyzing LAMPF Exp. 32, which is a new pion-beta decay experiment, using a new technique with different types of systematic error. Here we present a preliminary report to indicate the extent and quality of the data obtained.

In contrast to the previous experiments done with stopping pions, this one observes decays in flight of a 400-MeV \( \pi^+ \) beam in the P3-East channel. The massive \( \pi^0 \) from the \( \pi^+ \) beta decay has essentially the same momentum as the \( \pi^+ \), and we detect the two energetic \( \gamma \) rays from the \( \pi^0 \) decay. It is necessary to use a very intense beam of \( 2 \times 10^8 \pi^+/s \). Figure 1 shows our apparatus.

To avoid background from pion charge exchange the decays take place in a vacuum tank at \( 2 \times 10^{-7} \) torr. There is an intense flux of secondary \( \mu \)'s from the decay of the \( \pi^0 \)s. The beam is collimated and the detectors located so that they cannot see these \( \mu \)'s. The last collimator is toroidally magnetized iron to reduce \( \mu \) scattering out of the collimator. This magnetization of the collimator allowed us to run at a beam rate 3 times more intense than would otherwise have been tolerable.

To monitor this intense beam we used ion chambers and \( \pi \rightarrow \mu \nu \) detectors downstream of the experiment.

The \( \gamma \) rays were detected by a new detector using the lead-glass counters from the LAMPF \( \pi^0 \) spectrometer and \( XY \) scintillation hodoscopes for position definition. The time and energy calibrations of the detectors were frequently checked by swinging a \( \mathrm{CH}_2 \) target inside the vacuum tank into the beam and producing \( \pi^0 \)s by charge exchange. As a final calibration the entire tank was filled with \( \mathrm{H}_2 \) gas and the beam changed to \( \pi^- \).

In Fig. 2 is given the spectrum of the sum of the two \( \gamma \) energies after selecting on prompt timing of each \( \gamma \) with respect to the beam rf and making some low-energy cuts in each of the counters. There is a clean, well-defined peak with the expected energy resolution. To verify the pion-beta decay identification one can look at the transverse momentum and coplanarity. These

![Figure 1](image_url)

**Fig. 1.**
Layout of pion-beta-decay apparatus.

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Also see Ref. 2 for a discussion of previous experiments.
variables show distinct peaks as expected for beta decay. These variables provide additional cuts, but it is not necessary to make any but very mild cuts to further clean up the event selection.

The events shown in Fig. 2 represent very nearly our final sample. A later analysis gave a total of $1127 \pm 33$ events after background subtraction. Including uncertainties in the incident pion flux, detection efficiency, and various other corrections, we quote a preliminary result of $(1.05 \pm 0.06) \times 10^{-8}$ for the branching ratio.

Presently, we are analyzing the beam monitor data (we had several different monitors), including phase-space data. We are hopeful that this will not be a major contributor to the final accuracy, but we have learned that long-term monitoring of high-intensity pion beams at the 1% level is a significant technical problem.

We expect to improve our estimates of uncertainties and to be able to produce a number with a quoted error determined mainly by the statistics (that is, at about the 4% level), and thus to have a significantly better value for the branching ratio of pion-beta decay, although still not with a precision approaching that of the theory.

REFERENCES


Crystal Box Experiment
(Exps. 400/445, SMC)
(Los Alamos, Stanford Univ., Univ. of Chicago)
Spokesmen: C. M. Hoffman, J. D. Bowman, and H. S. Matis (Los Alamos)

This experiment and some aspects of the data-acquisition system have been described in the preceding three progress reports. Briefly, this experiment aims to search with unprecedented sensitivity for the lepton-flavor violating decays $\mu^+ \rightarrow e^+e^-e^-$, $\mu^+ \rightarrow e^+\gamma\gamma$, and $\mu^+ \rightarrow e^+\gamma\gamma$. The detector consists of a modular array of 396 NaI(Tl) crystals, a precision cylindrical drift chamber, and an array of plastic scintillation counters. A schematic view of the apparatus is shown in Fig. 1.

The goal for this experiment is to be sensitive to the three rare-decay modes with branching ratios smaller than $10^{-11}$. To achieve this goal in a reasonable amount of running time ($\sim 10^6$ s) one must have a copious source
of muons and a large acceptance for the events of interest, and one must be able to eliminate background processes to at least the expected level of sensitivity. We plan to stop $5 \times 10^5 \mu^+/\text{s}$ in the center of the detector. This rate, together with the acceptance of the apparatus ($\sim 25\text{-}50\%$ depending on the mode), gives the desired sensitivity. The major source of backgrounds is the chance coincidence of $e^+$'s and $\gamma$'s from the uncorrected decays of several muons. These backgrounds are eliminated by requiring the detected particles to be in time coincidence and by imposing conservation of energy and momentum; good background rejection depends on good resolutions in timing, position, and energy.

We have performed extensive tests with prototypes of each part of the detector. The achieved resolutions are shown in Table I. These resolutions are more than adequate to reject backgrounds to the desired levels.

A test run in August 1981 at the SMC was used to define the final parameters for the electronics for the drift chamber, and an LRS-4290 system was successfully used to read out a test chamber. The preamplifiers and amplifier discriminators, which supply signals to the time-digitization system, also performed up to expectations. The only major change in the electronics was to reduce the bandwidth of the preamplifiers somewhat to minimize the crosstalk between adjacent drift-chamber cells. The performance of the electronics and the chamber was satisfactory. We demonstrated the ability of the chamber and the read-out system to operate at beam rates higher than we expect for the experiment.

The NuCon Company of Livonia, Michigan is manufacturing the end plates for the drift chamber. After a painstaking upgrading of their five-axis machine they have demonstrated that they can successfully make the end plates within tolerances. We expect delivery of the end plates early in 1982, and the stringing of the chamber will begin shortly thereafter. We expect the chamber and all its electronics to be ready by the summer of 1982.

A major test run occurred in November 1981 at the SMC to test the electronics, the data-acquisition system, the on-line software, and the scintillator array. In almost all respects this run was extremely successful. It demonstrated that these major components of the experiment perform as expected. The stand that will be used to support the apparatus was assembled and used for this test. In addition, 100 channels of constant-fraction discriminators, 40 channels of mean timers, the nonadjacency and geometry boxes, several logic fan-out modules, and a CAMAC latch were all constructed for this run. However, the need for some minor modifications in the output-pulse generation by the constant-fraction discriminators and the mean timers was uncovered. In all other respects all these modules operated successfully. More importantly, the basic philosophy that went into designing the trigger electronics proved to be correct. The propagation delay through all the electronics was measured so that delay cables for all the signals can be constructed. The time resolution of the scintillation counters and the electronics was within specifications.

We were not able to use the PDP-11/44 computer, which was purchased for this experiment, because of problems between the computer and the microprogrammed branch driver. These problems are being worked on by Group MP-1. Instead, a PDP-11/45 computer was used for this run. Generally speaking, the data-acquisition software worked well, though several bugs were uncovered and the need for some additional
features was demonstrated. The large-scale-integrated-
(LSI) circuit system to read out the NaI information also
worked quite well. The pulse-height modules and the tim­
ing modules designed and built at Stanford University
were satisfactory.
The manufacture of the NaI crystals at the Harshaw
Chemical Corporation ran into some additional
problems that slowed the delivery date; the problems ap­
pear to be solved but delivery is not expected before early
1982.
The next 6 months will be spent building and install­
ing the remaining electronic components (photomultiplier
bases for the NaI detectors, the remaining 450 channels
of constant-fraction discriminators, a high-voltage dis­
tribution panel for the NaI detectors, the remaining drift­
chamber electronics, and various special-purpose
modules). Final assembly and testing of the entire detec­
tor should be completed by summer 1982.

<table>
<thead>
<tr>
<th>Table I</th>
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<tr>
<td>PROPERTIES OF $^{241}$Am AND $^{243}$Am</td>
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<td>DEDUCED FOR MUONIC X-RAY DATA</td>
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<tr>
<th>Nuclide</th>
<th>$Q_d$ (e$b$)</th>
<th>$B(E2; 5/2 \rightarrow 7/2)(e^2b^2)$</th>
<th>$c(F)$</th>
<th>$&lt;r^2&gt;(F^2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$Am</td>
<td>$4.420 \pm 0.030$</td>
<td>$7.243 \pm 0.087$</td>
<td>$7.061 \pm 0.0004$</td>
<td>$34.72507$</td>
</tr>
<tr>
<td>$^{243}$Am</td>
<td>$4.272 \pm 0.028$</td>
<td>$6.482 \pm 0.079$</td>
<td>$7.0815 \pm 0.0004$</td>
<td>$34.86609$</td>
</tr>
</tbody>
</table>

*aThe $a$ is fixed at $0.552$ F.
\[ p(\vec{r}) = p_0(1 + e^x)^{-1}, \]
\[ x = \frac{r - c_0(1 + \beta_2 Y_{20} + \beta_4 Y_{40})}{a}, \]  
(1)

from muonic-atom data, it is necessary that good data exist for both \( K \) and \( L \) muonic x rays. Unfortunately, this condition is not satisfied in the present case. The HFS in the \( L \) lines is so extreme that little information can be extracted from them. Consequently, it has been assumed that both isotopes are adequately described by a skin thickness \( a = 0.522 \) \( \text{F} \). With this constraint, values for \( c \) and \( <r^2> \) may be obtained from the \( K \) data alone, \( <r^2> \) being given by

\[ \frac{\int p(\vec{r}) r^2 d\tau}{\int p(\vec{r}) d\tau}. \]

The equal-\( a \) assumption appears well justified, given the fact that both isotopes have the same Nilsson configurations \( (|523\rangle) \) in their ground states. In fact, under this assumption \( \delta<r^2>_{243-341} \) proves to be independent of the actual choice of \( a \). As can be seen from the table, a value of \( \delta<r^2> = 0.141 \text{ F}^2 \) is deduced. Efforts to interpret this isotope shift and apply it to understanding the \( ^{240}\text{Am} \) fission isomer are continuing.

**REFERENCES**


Inelastic Pion Scattering by \( ^{17}\text{O}, ^{18}\text{O}, \) and \( ^{19}\text{F} \) (Exp. 369, EPICS)  
(Univ. of Minnesota, Los Alamos)  
Spokesman: D. Dehnard (Univ. of Minnesota)

Data on pion inelastic scattering from \( ^{17}\text{O} \) have been taken successfully at EPICS, completing Exp. 369. The EPICS cooled-gas target using liquid nitrogen as the refrigerant worked very well, as did the gas recovery system, which was needed to recover the isotopically enriched target gases. A spectrum for 164-MeV \( \pi^+ \) scattering from \( ^{17}\text{O} \) at 42° is shown in Fig. 1.

Because the target gas was enriched to only \( \sim 50\% \) in \( ^{17}\text{O} \), background runs with \( ^{18}\text{O} \) (and an empty target) were taken where necessary. Runs from Exp. 570 will be used to remove \( ^{16}\text{O} \)-contaminant peaks. All the data tapes have been replayed and the data are being analyzed.

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**Fig. 1.**  
Spectrum for 164-MeV \( \pi^+ \) scattering from oxygen at 42°.
Elastic Scattering of Pions from $^{12,14}$C at 164 MeV in 1° Bins
(Exps. 539/622, EPICS)
(Univ. of Texas, Univ. of Minnesota, Los Alamos, New Mexico State Univ.)
Spokesmen: H. Baer (Los Alamos) and D. Holtkamp (Univ. of Minnesota)

In analyzing the elastic-scattering data from Exps. 539/622 [$^{14}$C($\pi^+\pi^-$)$^{14}$C; $^{12}$C($\pi^+\pi^-$)$^{12}$C at 164 MeV], a great amount of effort has been spent in obtaining the angular distributions in 1° bins instead of the usual full acceptance (~4°) of the EPICS spectrometer, because such data are particularly useful in outlining minima. It was determined in the analysis that the 1° bins of EPICS were well calibrated and centered correctly. On that basis a kinematic analysis using the 1° capability of EPICS provides a reliable angle calibration of the experimental data, that is, it reveals any effect caused by the angular divergence of the beam on the target and shows whether or not the spectrometer is moving off center. For the first part of Exp. 539, movement of the spectrometer off center caused the true scattering angle to decrease ~0.05° every 10°.

A preliminary analysis of elastic scattering on $^{14}$C from the first part of Exp. 539 is presented in Figs. 1 and 2. Figure 3 displays fits to these data using PIESDEX, a code developed by E. Siciliano and M. Johnson. Figure 4 shows the final $\pi^+$ cross sections for the $^{12}$C strip target data, which were taken simultaneously with the $^{14}$C data. The slope of the 1° bins in the $^{12}$C data is correct to within error bars. To obtain a smooth angular distribution for the 1° binned data, it was necessary to normalize the experimental yields every 10° using hydrogen runs. At the 5° midpoints between normalization runs, normalizations had to be averaged. Severe (10-20%) problems existed in the slope of the 1° data when different normalizations were not used every 10°. The relative solid angles of the 1° bins were found to be a strong function of angle.

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Fig. 1.
Elastic cross sections for $\pi^+$ incident at 164 MeV on $^{14}$C.

Fig. 2.
Elastic cross sections for $\pi^-$ incident at 164 MeV on $^{14}$C.
We have successfully completed measurements of the first clear-cut double-analog transition to a highly excited state in the continuum. The reactions $^{48}\text{Ca}(\pi^+,\pi^-)^{48}\text{Ti}$ and $^{48}\text{Ti}(\pi^+,\pi^-)^{48}\text{Cr}$ were studied at $\theta = 5^\circ$ and $E(\pi^+) = 130, 180, 235, \text{ and } 290 \text{ MeV}$. The double-analog transitions in both reactions were clearly observed. The one in $^{48}\text{Ti}$ occurs to a $T = 4, J^\pi = 0^+$ state at 17.379 MeV, which had been earlier identified by Sherr and colleagues in a $^{56}\text{Ti}(p,\alpha)^{48}\text{Ti}$ experiment. It is interesting to note that the transition is seen even more clearly in our double-charge-exchange (DCX) experiment, as is illustrated in Fig. 1, which shows the 180-MeV spectra. The double-analog transition to the 8.75-MeV state in $^{48}\text{Cr}$ is seen equally clearly.

The experiment on $^{48}\text{Ca}$ was done to determine how analog DCX cross sections increase with $(N - Z)$. All first-order theories predict an increase $\propto (N - Z)(N - Z - 1)$ due to an increase in neutron pairs, and a decrease $\propto A^{-x}$, (with $x$ between 3 and 4) due to absorption. This would predict, for example, a ratio

$$\frac{\sigma(5^\circ,^{48}\text{Ca})}{\sigma(5^\circ,^{42}\text{Ca})} \approx 20.$$
An earlier exploratory investigation by us had indicated that this ratio is strongly quenched, perhaps by as much as an order of magnitude. On-line analysis of the present experiment indicates that this is true. The measured ratio is $\sim 3$.

Earlier, we suggested, on the basis of the preliminary experiment, that this quenching might arise because of an interfering contribution from an isotensor term in the pion-nucleus optical potential. The suggestion should be considered seriously now in view of the clear results of the present experiment.

REFERENCES


Investigation of the Strong Cancellations of Neutron/Proton Transition Amplitudes in $^{14}$C (Exp. 622, EPICS)

(Univ. of Minnesota, Los Alamos)

Spokesman: D. Holtkamp (Univ. of Minnesota)

Experiment 622 has been completed. Excitation functions for $\pi^\pm$ scattering at two momentum transfers, as well as a limited angular distribution for $\pi^\pm$ scattering at 120 MeV, were measured.

Three candidates for $4^-$ states ($T = 1$) in $^{14}$C are identified at 11.67, 15.2, and 17.26 MeV. Excitation functions for these states are shown in Fig. 1, together with a curve proportional to $\sin^2 \theta$. These peak cross sections taken at a momentum transfer of $\sim 286$ MeV/c indicate that these transitions follow the trend of a $\sin^2 \theta$ curve. This behavior, together with the measured angular distribution shapes, is the basis for the tentative $4^-$ assignment. The angular distribution for the 17.26-MeV state at 164 MeV is shown in Fig. 2. Preliminary distorted-wave-impulse-approximation (DWIA) calculations assuming a pure $(d_{5/2}p_{3/2}^{-1})_-^m$ configuration are shown with the data and are seen to give a good fit (normalization of the calculation is arbitrary). In addition, these states exhibit the same angle and energy dependences as known M4 transitions in $^{12}$C, $^{13}$C, and $^{16}$O.

Fig. 1.

Excitation functions for three levels proposed as $(4^-, T = 1)$ states. The solid line is a curve proportional to $\sin^2 \theta$.

Fig. 2.

Angular distribution for $\pi^+$ inelastic scattering at 164 MeV to the 17.26-MeV level, together with preliminary DWIA calculations (solid line).
Nonanalog Double Charge Exchange
(Exp. 577, EPICS)
(New Mexico State Univ., Univ. of Penn., Univ. of Texas, Los Alamos)
Spokesmen: S. J. Greene (New Mexico State Univ.) and H. T. Fortune (Univ. of Pennsylvania)

The fact that nonanalog pion double-charge-exchange (DCX) cross sections can be as large as those for analog DCX is a surprise. A recent EPICS experiment was devoted to studying this point. A 164-MeV angular distribution was measured for the reaction $^{16}\text{O}(\pi^+ , \pi^-)^{16}\text{Ne}$ ground state (g.s.). Also measured were the $(\pi^+ , \pi^-)$ ground-state transitions from targets of $^{28}\text{Si}$ and $^{40}\text{Ca}$ at a laboratory angle of $5^\circ$ and bombarding energy of 164 MeV.

Figure 1 shows the $^{16}\text{Ne}$ (g.s.) angular distribution and contrasts it with the 164-MeV $^{18}\text{Ne}$ (g.s.) distribution resulting from analog DCX on $^{16}\text{O}$. The $^{18}\text{Ne}$ angular distribution is not simple diffractive, having a minimum near $21^\circ$, corresponding to a nuclear radius of $\sim 5.7 \text{ fm}$, which is unphysically large. The first minimum of the $^{16}\text{Ne}$ distribution is about $32^\circ$, appearing to be diffractive in nature, an angle corresponding to a nuclear radius of $\sim 3.3 \text{ fm}$.

In Fig. 2 we show the new $A$ dependence data and include previous $180$-MeV data. Both sets appear to be reasonably described as following an $A^{-4/3}$ mass dependence. The 180-MeV set may be normalized to the 164-MeV set by using $^{16}\text{Ne}$, which was measured at both energies, and by the observation that all nonanalog transitions exhibit the same energy dependence in this region. The combined set indicates $A^{-4/3}$, with some variations that may be traceable to nuclear structure shell level effects.

The mixing element for a $\Delta$ component in the ground-state wave function of $T = 2$ nuclei varies as $A^{-1}$. We have proposed the mechanism shown in Fig. 3, a single-step DCX reaction resulting in formation of a $\Delta^{++}$, as a way of explaining the $A^{-4/3}$ dependence. The $A^{-1}$ amplitude gives an overall $A^{-2}$ in cross section, which then multiplies a fundamental cross section of $R^2 \propto A^{2/3}$.

The reaction amplitude, in the Eikonal model, varies as

$$f(k,q) = \beta k R a \frac{f(\pi^+ n \to \pi^- \Delta^{++})}{f(\pi^+ N \to \pi^+ N)} J_\theta(qR),$$

where $J_\theta(qR)$ is the angular part of the transition.

![Fig. 1.](image)

*Fig. 1.*

The $^{16}\text{O}(\pi^+ , \pi^-)^{16}\text{Ne}$ (g.s.) and $^{18}\text{O}(\pi^+ , \pi^-)^{18}\text{Ne}$ double isobaric analog state (DIAS) angular distributions at $T_\pi = 164 \text{ MeV}$.

![Fig. 2.](image)

*Fig. 2.*

A dependence of nonanalog DCX ground-state transitions from $T = 0$ targets, at $T_\pi = 164$ and $180 \text{ MeV}$.
Fig. 3.

Single-step DCX leading to the formation of a $\Delta^{++}$.

where

$$\beta = \frac{<\Delta^{++}n^{-1}|H|p^2n^{-2}>}{300 \text{ MeV}}.$$

is the $\Delta$ amplitude in the predominantly $p^2n^{-2}$ final nuclear ground state.

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Nuclear Chemistry

A Product Recoil Study of the $^{12}$C($\pi^{\pm},\pi N$)$^{11}$C Reactions over the Energy Range 90 to 350 MeV (Exp. 543, LEP and P$^3$)
(Carnegie-Mellon Univ., Purdue Univ., Los Alamos)
Spokesman: A. A. Caretto (Carnegie-Mellon Univ.)

Conceptually there are two major mechanisms by which a pion- (or proton-) induced nucleon-removal reaction might take place:

1. director knockout (DKO), whereby the incident pion strikes a bound nucleon, causing its ejection. The incident particle and the struck nucleon exit the nucleus without further interaction, leaving a residual nuclear excitation energy of less than about 10 MeV to preclude subsequent nucleon evaporation; and

2. inelastic scattering followed by evaporation (ISE), whereby the incident pion inelastically scatters off a bound nucleon, transferring between 10 and 20 MeV to that nucleon. The nucleon subsequently evaporates, which deexcites the nucleus and produces the nucleon-removal product.

Mechanism (1) would predict a relatively isotopic angular distribution for the recoiling $^{11}$C nuclei in $^{12}$C($\pi^{\pm},\pi N$)$^{11}$C, whereas mechanism (2) would predict a peak in the angular distribution at close to 90° to the direction of the incident pion.

We have chosen the relatively simple thick-target thick-catcher technique, employed previously$^{1-3}$ for studies of the $^{12}$C($p,\alpha$)$^{11}$C reaction, to learn some of the features of the recoil properties of the $^{12}$C($\pi^{\pm},\pi N$)$^{11}$C reactions. The experiment involved irradiations of target-catcher stacks with pions followed by assay of the induced $^{11}$C activity. The irradiations were performed at the P$^3$ and LEP channels at LAMPF. The pion energies ranged from 90-350 MeV, and the exposures lasted about 30 min.

The target stacks consisted of a 14.3-mg/cm$^2$-thick graphite foil sandwiched between 25-µm- (~5-mg/cm$^2$-) thick beryllium catcher foils of the highest available purity. Beryllium guard foils protected the stack from externally produced $^{13}$C recoils. The stacks were irradiated in two different orientations to the beam at each energy. In experiments designed to yield the projected forward and backward ranges, the stack was mounted perpendicular to the beam direction, whereas in those designed to yield the perpendicular ranges it was mounted at 10° to the beam.

Following irradiation, the $^{11}$C activity in the target and catcher foils was assayed with a $\gamma$-$\gamma$ coincidence counter consisting of two NaI(T1) scintillation detectors mounted on opposite sides of the target foil. The efficiency-calibrated system was set to count the 511-keV quanta resulting from annihilation of the 20.4-min $^{11}$C positrons.

The disintegration rates of the various foils were used to obtain the average projected ranges of $^{11}$C in carbon, designated $F_W$, $B_W$, and $P$. The quantities $F$, $B$, and $P$ are the fraction of the total number of $^{11}$C nuclei recoiling into the forward, backward, and perpendicular catchers, respectively, and $W$ is the surface thickness of the target. In the case of the 10-degree runs, the value of $P$ represents the average of the results obtained for the two catchers.

The energy dependence of the projected ranges is displayed in Fig. 1. We see that the projected forward ranges decrease with increasing pion energy, the projected perpendicular ranges are largely independent of energy, and the projected backward ranges increase with bombarding energy. Furthermore, the energy dependence of $F_W$ and $B_W$ is markedly stronger for incident $\pi^-$ than for $\pi^+$. Our results constitute the first determination of recoil ranges of $^{12}$C($\pi^{\pm},\pi N$)$^{11}$C reaction products; they may be compared with similar results previously obtained for the $^{12}$C($p,\alpha$)$^{11}$C reaction induced by protons of comparable energies.$^{1-3}$ Within the limits of uncertainty, the $F_W$ and $B_W$ values are equal, but the values of $P$ are significantly larger in the proton reaction, particularly at the lower energies.

Analysis of our pion reaction data is under way in terms of a two-velocity vector representation of the reaction, based on a quasi-free scattering model for describing on a microscopic level how momentum is transferred from the incident pion to the carbon nucleus. The velocity and kinetic energy of the recoiling nucleus will come from this analysis. In addition, a comparison with calculations based on the intranuclear cascade code ISOBAR plus the evaporation code DFF will be made. From these analyses we expect to be able to conclude something about the contributions of the DKO and ISE processes to the nucleon-removal reactions in the carbon as a function of pion energy and pion charge.
Helium-Jet Transport of Fission and Spallation Reaction Products
(Exp. 629, A&B-Nucchem)
(Los Alamos, Idaho National Engineering Lab., Univ. of Oklahoma)
Spokesmen: M. E. Bunker and W. L. Talbert, Jr. (Los Alamos) and R. C. Greenwood (Idaho National Engineering Lab.)

Fig. 1.

Energy dependence of the average projected range of $^{11}\text{C}$ from the $^{12}\text{C}(\pi^\pm,\pi\text{N})^{11}\text{C}$ reactions. FW, PW, and BW correspond to the forward, perpendicular, and backward ranges, respectively.

REFERENCES


The initial experiments conducted at LAMPF in 1981 have demonstrated that fissile products and spallation products ejected from thin uranium, tantalum, and rhodium targets bombarded with up to 3 μA of 800-MeV protons can be rapidly and efficiently transported over large distances using a relatively simple helium-jet system. A 1-ℓ target chamber was installed in the nuclear chemistry cave near the end of the H⁺ beam line. Helium containing NaCl aerosol flowed into the target chamber and back to a collection station 41 m from the target. The return flow was made through 1.6-mm i.d. capillary tubing. With a chamber pressure of 2 atm absolute, a helium flow rate of 30 cm³/s, and an aerosol generator temperature of 600°C, overall transport efficiencies of between 40 and 50% were observed for all nongaseous reaction-product elements recoiling from the targets. The time delay from beam turn-on to the arrival of the first activity at the collection station was measured to be about 2.8 s, which is in reasonable agreement with theoretical predictions. The median diameter of the NaCl aerosol particles was 0.04 μm.

It remains to be demonstrated whether the helium-jet transport technique will work satisfactorily when beam currents of ≥500 μA are incident on the target chamber. A retractable target chamber that will eventually be tested on Line A is being designed. The design will emphasize minimization of the total transport time and will incorporate helium-cooled entry and exit windows.

REFERENCES

Materials Science

Irradiation of Technologically Important Metals with 800-MeV Protons Using the Isotope Production Facility at LAMPF (Exp. 554, ISORAD) (Los Alamos)
Spokesmen: R. D. Brown and J. R. Cost (Los Alamos)

The goal of this experiment is to investigate the response of several metals, useful in accelerator technology, to irradiation with 800-MeV protons. The metals investigated were grouped into two categories, (1) those important as vacuum-line windows and target cladings, and (2) those denser metals of interest as spallation neutron targets. The present work represents a preliminary study of the effects of low fluences \(10^{16}\) to \(10^{20}\) protons/cm\(^2\) of 800-MeV protons on the yield strength, tensile strength, and ductility of samples of 304 stainless steel, Alloy 718, molybdenum, and tantalum.

Tensile samples (0.75 or 1.5 mm thick) were directly water cooled during irradiation and were tested at room temperature. Table I gives preirradiation and postirradiation results for the yield strength (at 0.2% offset) and the uniform plastic strain for our samples.

For the 304 stainless steel and annealed Alloy 718 the yield strengths increased by about a factor of 3 whereas the ductility dropped. In the bcc metals (tantalum and molybdenum) the yield strengths increased by at least a factor of 2. Tantalum samples retained significant ductility at room temperature, but several molybdenum specimens broke at <0.2% strain. This suggests that the ductile-brittle transition temperature for molybdenum was raised above room temperature during irradiation, as has been observed following neutron irradiation.

The results of a transmission electron microscopy analysis of the irradiation-produced microstructure before and after straining will be discussed in terms of changes in mechanical properties for the 304 stainless steel samples. Also, a quantitative analysis of each material's helium concentration will be made to test the calculated results of Coulter et al.\(^1\)

REFERENCE


### TABLE I

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield Stress Preirradiation</th>
<th>Uniform Plastic Strain Preirradiation</th>
<th>Uniform Plastic Strain Postirradiation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPa (psi)</td>
<td>MPa (psi)</td>
<td>(%)</td>
</tr>
<tr>
<td>304 stainless steel</td>
<td>134 (19 500)</td>
<td>383 (55 000)</td>
<td>77 (%)</td>
</tr>
<tr>
<td>Annealed</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Alloy 718</td>
<td>552 (80 000)</td>
<td>889 (129 000)</td>
<td>38 (%)</td>
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<tr>
<td>Annealed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Tantalum</td>
<td>141 (20 500)</td>
<td>290 (42 000)</td>
<td>36 (%)</td>
</tr>
<tr>
<td>Stress relieved</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Molybdenum</td>
<td>290 (42 000)</td>
<td>690 (100 000)</td>
<td>19 (%)</td>
</tr>
<tr>
<td>Stress relieved</td>
<td></td>
<td></td>
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</tbody>
</table>
Muon-Spin-Rotation (μSR) Studies in Spin-Glass Systems
(Exp. 499, SMC)
(Los Alamos, Univ. of California at Riverside, Rice Univ.)
Spokesmen: S. A. Dodds (Rice Univ.), R. H. Heffner (Los Alamos), and D. E. MacLaughlin (Univ. of California at Riverside)

Work on Exp. 499 during the past year has concentrated on two spin-glass alloy systems, AgMn and PdMn. The experimental program in the former system has been practically completed, at least for temperatures in the presently accessible range above ~2.5 K. We briefly summarize our results to date.

The μSR measurements in AgMn in zero field and in applied longitudinal and transverse fields up to 5 kOe have revealed several fundamental properties of the spin-glass transition and of elementary excitations in the spin-glass state. The effect of fluctuation modes of limited impurity-spin amplitude has been observed in both the μ⁺ static internal field distribution and in the μ⁺ dynamic relaxation function. This is of importance because two basically different classes of elementary excitations, quasi magnons and barrier modes, may possibly be distinguishable by the relative amplitudes of individual spin fluctuations. The experimental relaxation rate at temperatures approximately one-half \( T_g \) (glass temperature) is at least 50 times higher than expected on the basis of a computer simulation of the quasi-magnon-mode frequency distribution. Near and above \( T_g \) an anomalously large static distribution is induced by an applied field, and the rapid slowing of impurity-spin fluctuations as \( T_g \) is approached from above is quenched appreciably in fields \( \geq 1 \) kOe. We expect all these results to stimulate considerable further theoretical interest in spin-glass dynamics. We will finish work on the AgMn system by extending our measurements to below 1 K when our \(^{3}\)He cryostat is completed.

Work on PdMn alloys is still in progress. Two samples with manganese concentrations of 2 and 7 at.% have been studied. The former is a ferromagnet because of long-range positive manganese-manganese exchange interactions mediated by the exchange-enhanced host, whereas palladium plus 7-at.% manganese is a spin glass by virtue of direct near-neighbor antiferromagnetic couplings. The μSR behavior of the two systems differs markedly. A cusp-like anomaly in the zero-field μSR relaxation rate (\( \Lambda_{\text{max}} \sim 0.3 \mu\text{s}^{-1} \) at \( T_c = 5.6 \) K) is observed in the ferromagnetic specimen, whereas in the spin glass (\( T_g = 5.0 \) K) a much larger (>30 \( \mu\text{s}^{-1} \)) and considerably less well-defined anomaly was seen at \( T = T_g \).

A major goal of future work in this alloy system will be to understand this enormous difference. This will require samples of intermediate concentrations, as well as further studies of the samples now available.

We have refined our transverse-field measurements in PdMn and confirmed that at high temperatures, \( \Lambda \) lies well below the values calculated for inhomogeneous broadening in a paramagnetic dilute alloy. Measurements of \( \mu^+ \) diffusion in magnetically tagged palladium plus 300-ppm gadolinium have confirmed that muons are immobile below temperatures \( \sim 200 \) K, so \( \mu^+ \) depolarization is due only to hyperfine field static and fluctuation properties below this temperature. The observed discrepancy, therefore, is not due to muon diffusion. We have carried out computer calculations of the paramagnetic-state dipolar field at octahedral and tetrahedral interstitial \( \mu^+ \) sites using a theory rigorous for arbitrary concentration. This calculation yields a central \( \mu^+ \) resonance line, unshifted from the position calculated in the dilute limit and with approximately the dilute-limit line width. Near-neighbor satellites are observed, however, which average to a broad background in a polycrystalline specimen. Thus the anomalously narrow absorption lines observed are not due to geometrical effects of finite concentration. The remaining possibility is that near-neighbor pairwise antiferromagnetic interactions lead to reduced contributions to the static inhomogeneity. Although this mechanism seems to be the most reasonable candidate for the observed anomaly, the fact that the discrepancy is largest at temperatures of \( \sim 150 \) K seems to conflict with independent measurements, which give an interaction strength of \( \sim 40 \) K in temperature units.

Further work in PdMn will concentrate on understanding this anomaly through comparison of results from alloys of different concentrations. In addition, evolution of field and temperature dependences of muon relaxation rates as a function of concentration will yield information on the nature of the approach to an ordered state in the presence of increasing disorder in the impurity-spin configuration. These studies, together with investigations of ferromagnetic spin-glass FeMn, will be of importance in understanding how host-exchange enhancement affects the interplay between random and nonrandom impurity-spin configurations and dynamics in dilute alloys.
Models for $\mu^+$ Depolarization in Spin Glasses
(Los Alamos)

M. Leon

A number of models for the depolarization of $\mu^+$ in spin-glass systems have been formulated and implemented on the LAMPF Computer Facility VAX computer. It is hoped that some of these models will prove relevant and useful in interpreting the large amount of spin-glass $\mu$SR data being acquired at LAMPF. These models should also help to clarify our thinking about the different physics aspects of the spin-glass systems.

At present the models fall into two classes, (1) complete reorientation models, and (2) incomplete reorientation models. In class (1) the local internal magnetic field felt by the $\mu^+$ (always taken as static between jumps) is uncorrected in direction before and after a field fluctuation, whereas in class (2), in addition to the fluctuating directionally uncorrected component, there is also a static component to the local internal field. For both classes of models the algorithms allow for external fields either parallel or perpendicular to the initial polarization direction.*

For class (1) we have included, in addition to (a) a single correlation time (exponential correlation function) for the internal field fluctuations, the possibility of (b) a distribution of correlation times (again exponential correlation functions) and (c) nonexponential correlation functions. There is some evidence that neutron scattering favors (b) or (c). However, (c) gives difficulties with the physical requirement of homogeneity in time (at least with the functions we have investigated), so we will concentrate on (b) and attempt to test its compatibility with the data.

* Compare Y. J. Uemura and T. Yamazaki, to be published (LT-16).
and will see a neutron spectrum similar to that at our Radiation-Effects Facility. Samples irradiated to a fluence of $10^{17}$ n/cm$^2$ have shown losses in transmission and changes in the index of refraction. We are currently irradiating samples of three different fiber optic materials to compare such property changes. An experiment to examine in situ transmission changes and possible fluorescence is being planned. Experiments at extremely high fluxes have demonstrated the time dependence of transmission losses in fiber optics. It would be most interesting to see if similar results can be observed at our flux.

One method of heating the plasma in a fusion reactor involves passing rf power through a ceramic window in the reactor vessel. Increased power losses from radiation damage in these windows could result in their failure. John Fowler (Group CMB-5) is now measuring the loss tangent in alumina and sapphire as a function of frequency to 50 MHz, following neutron irradiations to fluences between $10^{15}$ n/cm$^2$ and $10^{18}$ n/cm$^2$. Additional samples of alumina and beryllia have been supplied by Oak Ridge; the loss tangent will be measured at frequencies as high as 100 GHz. Seven packets of these samples were irradiated in LAMPF run cycles 30-32; additional irradiations are definitely planned.

Samarium-cobalt permanent magnets may be used on the Proton Storage Ring if the material’s magnetic properties are not greatly altered because of scattered radiation. Samples of several permanent magnet materials have been irradiated for W. T. Hunter and E. D. Bush (Group MP-8). Samples irradiated to $10^{17}$ n/cm$^2$ have shown a drop of 1-2% in magnetic field.

Stuart MacEwen (Chalk River Nuclear Laboratory in Canada) has sent titanium tensile samples for irradiation. A group of samples has been irradiated with Dierckx’s samples to $\sim 10^{18}$ n/cm$^2$, and a second group has been irradiated to $\sim 10^{17}$ n/cm$^2$. These samples will be shipped to Canada for mechanical property evaluation.

Many activation foils have been irradiated for R. Reedy and P. Englert in connection with Exp. 691, “Simulation of Cosmic-Ray Production of Nuclides by Spallation-Produced Neutrons.”

The Effect of Dislocation Vibration on Void Growth in Metals
(Exp. 407, Line B, Nuclear Chemistry Cave)
[Eidg. Institut für Reaktorforschung (EIR)/SIN, Univ. of Illinois, Northwestern Univ., Massachusetts Institute of Technology, New Mexico Institute of Mining and Technology, Sandia Labs., Los Alamos] Cospokesmen: W. F. Sommer (Los Alamos) and D. S. Phillips (Univ. of Illinois)

The major purpose of this research has been to gain information about radiation-produced point-defect/dislocation interactions. The importance of these studies stems from the fact that under bombardment by energetic particles a lattice atom can receive sufficient energy to be removed from its lattice site; the basic product is a Frenkel defect, a vacancy-interstitial pair. Further, when the bombarding particles are very energetic (medium-energy neutrons and protons), the initial interaction can produce an energetic spallation nucleus that then moves through the lattice and produces a number of Frenkel defects. Additionally, spallation nuclei and evaporation nuclei enter the atomic inventory of the metal (or alloy) as an impurity. Dislocations are a major sink for point defects (vacancies, interstitials, and impurity atoms). Their configuration and concentration play an important role in determining the microstructural evolution of a metal system subjected to a radiation environment because they can strongly affect the mass transport and final configuration of the point defects. This microstructural evolution is the cause for mechanical property changes during irradiation.

We recently completed an experiment (the initial phase of LAMPF Exp. 407) that showed that void (collection of vacancies) formation was suppressed when, by the application of an external applied stress, dislocations were forced to move through the lattice. This work was motivated by a theoretical prediction of Green and Weertman. They considered the fact that in the void growth temperature regime ($0.35-0.5T_m$, where $T_m$ is the absolute melting point) interstitials are much more mobile than vacancies. Thus, the interstitials diffuse rapidly to sinks such as dislocations, whereas the slower moving vacancies build up in concentration in the lattice.
(This supersaturation is believed to lead to nucleation of voids.) Additionally, Green and Weertman considered the accepted theoretical explanation for void growth; dislocations have a bias towards the absorption of interstitials, leaving a net positive number of vacancies for absorption at the void. The void is considered to be unbiased. They postulated that by causing dislocations to "sweep out" the lattice, the vacancy supersaturation could be reduced and void formation would, accordingly, be reduced.

Our initial results support their prediction. One of our future goals is to improve our experiment by employing internal friction methods so that the forced dislocation motion can be monitored during the irradiation.

REFERENCES


Muon-Spin-Rotation (μSR) Measurements in Selected Ternary Metallic Compounds (Exp. 640, SMC)

Los Alamos, Univ. of California at Riverside, Rice Univ.

Spokesmen: S. A. Dodds (Rice Univ.), R. H. Heffner (Los Alamos), and D. E. MacLaughlin (Univ. of California at Riverside)

The goal of this experiment is to examine the properties of selected ternary metallic compounds that exhibit both superconductivity and magnetic order. Specifically, we wish to address the questions, (1) Does the onset of superconductivity affect the spin dynamics in the paramagnetic state and thus modify the magnetic ordering? and (2) To what extent does the onset of ferromagnetic order immediately suppress superconductivity (that is, is there a spin-fluctuation regime in the superconducting state)? We report on measurements in the systems Ho₄Lu₁₋ₓRhₓB₄ and Gd₄Lu₁₋ₓRhₓB₄ made during the beginning phase of this experiment.

The initial series of measurements for Exp. 640 were chosen in the system Ho₄Lu₁₋ₓRhₓB₄. For x = 0.7 this system exhibits a superconducting transition at $T_s \approx 7.7$ K and a magnetic transition at $T_M \approx 4.1$ K. For $x = 1$ the system exhibits a magnetic transition at $T_M \approx 6.6$ K, and for $x = 0$ it has only a superconducting transition at $T_S \approx 11.3$ K.

Transverse-field measurements in LuRh₄B₄ ($x = 0$) show no motional narrowing for $T < 200$ K, indicating that the $\mu^+$ is stationary in this temperature range. Thus, under the assumption that the $\mu^+$ mobility is unaffected by changing rare-earth species (that is, x), the dynamic $\mu^+$ relaxation rate $\Lambda(T)$ measured in the other rare-earth rhodium-boride compounds is due only to the fluctuating dipole fields produced by the rare-earth magnetic moments.

In HoRh₄B₄ ($x = 1$), we observed dynamic relaxation with the full muon asymmetry for 30 K $\leq T \leq 300$ K in zero-applied field. At $T \approx 28$ K the magnetic specific heat shows a Schottky anomaly because of the crystalline-electric-field (CEF) splitting of the Ho$^{3+}$ $J = 8$ manifold. Comparison of $\mu$SR data for GdRh₄B₄ (see below) and HoRh₄B₄ indicates that the maximum in $\Lambda(T)$ (see Fig. 1) seen at $T = 10-30$ K in the latter system is caused primarily by these CEF effects. Below $T \approx 10$ K the $\mu$SR data show a reduced asymmetry (about one-third), indicating the presence of a large (>$40$ μs$^{-1}$) static field component produced by the onset of a ferromagnetic-like transition. The dynamic relaxation shows a continual slowing down below $T_M$; no sharp transition at $T_M$ is observed. Also, below $T_M$ we observed no definite frequencies in the muon time spectrum, which, if observed, would be indicative of a unique static field. Calculations for both octahedral and tetrahedral $\mu^+$ stopping $\nu_{\mu}^{stopping}$ lead one to expect frequencies of several megahertz, far below $T_M$. Thus, the lack of observable frequencies might be traced to multiple stopping sites, which would tend to diffuse the spectrum.

A comparison of Ho₄Lu₁₋ₓRhₓB₄ for $x = 1$ and 0.7 (see Fig. 2) in the temperature range 50 K $\leq T \leq 300$ K at zero field reveals that $\Lambda/x$ scales roughly with $T/T_M(x)$. The data below 10 K are in striking contrast, however; for $x = 0.7$ a shoulder in $\Lambda(T)$ at $T \approx T_\text{S}$ is revealed. Measurements on Gd₀.₇Lu₀.₃Rh₄B₄ (see below), which exhibits no superconductivity at all, show that a shoulder cannot be caused by unusual effects of dilution of the rare-earth ions. Thus, the zero-field Ho₀.₇Lu₀.₃Rh₄B₄ data reveal an interesting effect of superconductivity on the magnetic-ion relaxation rate. This shoulder persists in applied longitudinal fields ($H_{\parallel}$) up to 1 kOe, but disappears at $H_{\parallel} = 5$ kOe, possibly because at 5 kOe the applied field exceeds $H_{\text{C2}}$ and destroys the superconducting state. Above $T = 35$ K,
Fig. 1.
Temperature dependence of the zero-field exponential muon-spin relaxation rate $\Lambda$ in HoRh$_4$B$_4$. $T_M = 6$. $K$ is the magnetic ordering temperature. The asymmetry reduction at low temperatures is ascribed to slow holmium moment fluctuations on the scale of the muon Larmor frequency in an average internal field. Instrumental resolution prohibits observation of $\Lambda \gtrsim 40 \mu s^{-1}$.

$\Lambda(T)$ shows no major change for applied longitudinal fields between 0 and 5 kOe.

The initial set of measurements on Ho$_x$Lu$_{1-x}$Rh$_4$B$_4$ described above left two major unanswered questions, (1) the effect of the CEF splitting on $\Lambda(T)$ for $T > 35$ K, and (2) the effect on $\Lambda(T)$ of dilution of the magnetic ion in the absence of superconductivity. For these reasons we chose to study the Gd$_x$Lu$_{1-x}$Rh$_4$B$_4$ system. For large gadolinium concentrations (encompassing $x \geq 0.7$), this compound exhibits no superconductivity in the temperature range of interest and thus the effects of dilution without superconductivity can be studied. Furthermore, there is no CEF splitting because gadolinium is an $S$-state ion.

Our preliminary results for Gd$_x$Lu$_{1-x}$Rh$_4$B$_4$ show that in zero-applied field for $x = 1$ ($T_M \approx 5.5$ K), $\Lambda(T)$ is essentially constant for $6$ K $\leq T \leq 300$ K, indicating that the rise in $\Lambda(T)$ seen in the holmium system is likely due to CEF splitting. At $T = 5.5$ K, there is an abrupt loss of asymmetry to one-third the value measured for $T \geq 6$ K, indicating a sharp phase transition accompanied by the onset of a large static component in the relaxation function. The muon dynamic relaxation rate then decreases as the temperature is lowered below $T_M$. This sharp transition at $T_M = 5.5$ K is destroyed by a 5-kOe applied field. The longitudinal field dependence of $\Lambda$ at $T = 5.5$ K is monotonically decreasing, reaching a plateau at about $H_\parallel = 1$-2 kOe, and remaining roughly constant between 2 and 5 kOe. Very analogous behavior
in both a zero- and an applied-longitudinal field is observed in Gd$_{0.7}$Lu$_{0.3}$Rh$_4$B$_6$, showing no unusual effects of rare-earth ion dilution.

The most interesting observation in this initial series of experiments is undoubtedly the striking effect of the onset of superconductivity on holmium moment dynamics for $x = 0.7$. Further experiments in related systems are planned to clarify the nature of this effect.
Biomedical Research

Pion Therapy Beam Development and Characterization
(Exps. 270 and 271, Biomed)
(Los Alamos, Univ. of New Mexico)
Spokesmen: M. Paciotti (Los Alamos) and A. Smith (Univ. of New Mexico)

The catalog of broad beams for static treatments has been expanded to provide fields with transverse dimensions up to 20 cm at each of three momenta corresponding to nominal depth penetrations of 12, 16, and 23 cm. Fan beams for dynamic treatments have been prepared at several channel momenta, and extensive beam tuning and dosimetry have been performed. Measured beam data have been provided for a three-dimensional treatment-planning code PIPLAN, with particles identified by position, angle, momentum, and type — that is, pion, muon, or electron.

An experimental method has been developed for detecting muons resulting from pion decay, using multiwire proportional counters located before and after the beam-shaping section of the channel. Analysis of these data has been facilitated by the use of a ray-tracing code. A new pyrocarbon target has been installed in the biomedical channel and is considered nearly optimum for high-intensity operations. The target can be set by the operator to maintain constant electron contamination. A multiwire chamber has been constructed and tested for use as a beam-profile monitor.

Considerable dosimetry has been directed toward providing characterization for a large variety of patient beams: broad, essentially parallel beams for static treatment; beams focused in one dimension and broad in the perpendicular dimension for one-dimensional dynamic treatment; and beams focused in two dimensions for two-dimensional dynamic treatment. For the static beams, three beam sizes (small, medium, and large) have been developed and characterized for each of three penetrations. Target volumes requiring larger field sizes are treated with combinations of abutted fields.

Dose rates for the pion therapy beams are a function of beam momentum, the beam tune (size) for a given momentum, and the size of the spread-peak region. Typical dose rates for the beams range from 0.02 to 0.03 rad/min/\mu A for each microampere of proton beam current on the biomedical pion target. In the summer of 1982 the proton beam current will be raised to 750 \mu A, resulting in about 600 \mu A of proton current on the biomedical pion target and yielding dose rates from 12 to 18 rad/min/\mu A. The average treatment volume is about 2.5 l for single parallel-opposed fields (abutting) during each treatment cycle, so the overall average treatment volume is probably closer to 2.5 l.

The narrow Bragg peaks of the pion beams are spread in depth by the use of a dynamic range shifter. The range shifter is computer controlled and can be programmed to produce spread peaks of varying dimension and shape, ranging in depth from 3-14 cm in 1-cm intervals. A series of such range-modulation functions has been developed for each momentum (148, 167, and 190 MeV/c). This is necessary because the peak-to-plateau ratio, beam contamination (electrons and muons), and momentum spread (resulting in differences in the full width at half maximum of the spread peak) are different for each momentum. For each spread peak it is possible to tailor the slope of the physical dose and consequently the distribution of stopping pions. It is also possible to produce spread peaks with uniform total dose, uniform high-linear-energy-transfer (LET) dose, or uniform biologically effective dose.

The range-modulation function describes the thickness of a bellows-controlled column of oil in the beam path vs time. The range-modulation development code takes measured, central-axis, unmodulated total and high-LET distributions, and by applying time weights offsets each curve by prescribed shifts in depth, sums all the offset curves together, and renormalizes to obtain the resultant modulated total and high-LET depth-dose curves. The program then uses a relative-biological-effectiveness (RBE) model to calculate the effective dose. The range-modulation functions have been completely redesigned, based on data obtained from gel-tube cellular experiments designed to measure cell-killing uniformity, to accomplish greater uniformity in biological effect for single-field treatments, and to confirm biological uniformity of treatments performed with opposed, overlapping portals.

An automated data-acquisition and analysis system has been developed for dosimetry measurements on the pion therapy beam using a PDP-11/70 computer and CAMAC interface. A multiple ionization chamber array (MICA) system, with associated software control, has been developed for dosimetry measurements. This system increases dosimetry data-acquisition rates by a factor equal to the number of data channels in use. The system has been tested and used with a linear array of 10 ionization chambers.
Accurate microdosimetry data are required for input to the algorithms used in the calculations of RBE, pion-effective dose, and range-shifter functions. Such data are obtained from a variety of experimental techniques, including Rossi-chamber proportional counters, solid-state detectors (totally depleted lithium-drifted silicon), and aluminum activation measurements. Rossi-chamber measurements are used as the primary source of microdosimetric data, but are time consuming. Therefore, one or two Rossi-chamber spectra are obtained for each beam tune and additional data are obtained from either solid-state detectors or aluminum activation, both of which permit rapid data collection. These are normalized by comparison with the Rossi-chamber data to obtain complete information on the spatial variations of high-LET dose for all therapy beams.

For biological experiments requiring special small-volume beams, custom collimators and/or boluses have been fabricated for each experiment and dosimetry has been performed using a combination of ion chambers and thermoluminescent detectors. Microdosimetric measurements have also been taken to aid in the interpretation of results.

Treatment-Planning Code Development
(Los Alamos)
P. Berardo

Dynamic treatments require the use of the three-dimensional treatment-planning code, PIPLAN. This code uses a ray-tracing model where actual pion trajectories in the three-dimensional volume represent pencil beams. PIPLAN calculates a dose distribution by summing the contributions of individual pencil beams as they pass through various parts of the anatomy [determined by computed-tomography (CT) scans] and clinical appliances. The dose distribution for a pencil beam is predetermined analytically in water as the sum of its separate components, including the effects of in-flight interactions and straggling. This dose is distributed in depth as a function of water-equivalent range along the trajectory, and radially as a function of multiple Coulomb scattering (which is both geometry and energy dependent). Distributing this dose entails accumulating at each point of interest the relative amount of dose at that point from each pencil beam. Because the treatment beams contain spatially nonuniform ratios of pions, muons, and electrons, and because each particle type has a distinctly different dose distribution, separate calculations are required for each particle type. To model an actual beam, then, requires an accurate phase-space representation of pencil beams. PIPLAN uses individually measured trajectories for each beam tune, with the spatial coordinates, angles, momentum, and particle type identified.

To improve the accuracy of PIPLAN, considerable effort has been devoted to development and incorporation of sophisticated models for beam smoothing, neutron dose caused by in-flight interactions in the plateau as well as in the peak region, multiple scattering through tissue inhomogeneities and air gaps between treatment appliances, range-modulation effects, external appliance effects (notably neutrons produced from pions stopping within the collimator), improved spatial resolution, and contour processing. A new computer code was written to reconstruct the same kind of image as digital x-ray radiography from integrated CT images, and automatic methods and algorithms have been developed and implemented to transcribe CT-scanner regions of interest (ROIs) to vector contours in treatment-planning programs. A new display capability was developed to superimpose pion-dose distributions on patient CT data on the cathode ray tube (CRT) of the EMI 7070 scanner. Two supporting libraries were completed: a beam-tune library and a range-shifter-function library. New models were also installed to account for the dose deposited by electrons from muon decay in the patient and by muons from pion decay in both the beam channel and the patient. Improvements to the case-file system (where all treatment-planning data for a given patient are collected), to the resolution and reduction of CT data, and to folding CT data into pion-dose calculations were also implemented.

Biomedical Instrumentation
(Los Alamos)
J. D. Doss

Hyperthermia

At the request of a physician in Shanghai, two Los Alamos hyperthermia sources with custom-designed probes have been loaned to the People's Republic of China. Neurosurgeons in China intend to use localized hyperthermia in combination with conventional surgical techniques to treat brain tumors. The Los Alamos rf probes will generate elevated temperatures in the region
where the bulk of the tumor has been surgically removed. Information on clinical results will be shared with the United States.

Drawings have been sent recently to two institutions that wish to construct hyperthermia units based on Los Alamos prototype instruments. The Western Instrument Company of Denver plans to produce a commercial instrument for veterinary applications, and Washington University in St. Louis plans to construct six to eight units for biological experiments.

A hyperthermia instrument loaned to the National Cancer Institute of Peru is being used in combination with radiation therapy for experimental treatment of melanoma. We have also designed special instrumentation for use in investigations of the effects of hyperthermia on fungus infections. The first experiment, in collaboration with the University of New Mexico School of Medicine, will occur in December. A proposal is being considered, from physicians at the Truman Medical Center in Kansas City, for the use of localized rf hyperthermia in the treatment of cervical intraepithelial neoplasm. This lesion is evidently a precursor of malignancies in the female reproductive tract, and is presently treated with electrocautery, cryosurgery, or laser beams.

Our computer code FIELD, which is used to calculate electric field strength and power density in tissue, has recently been rewritten so that it will be much easier to use for predicting the applied power distribution in hyperthermia treatments. A manual has been written to facilitate the use of this code at other institutions.

Ophthalmology

A variety of the multipolar circulating saline probes have been constructed at Los Alamos and tested at the McGeorge Eye Institute (MEI) in Oklahoma City. Although the probes exhibit all the advantages over the monopolar probe outlined previously, there is generally more damage to the corneal inner cell layer (endothelium) than was expected. While tests of these probes continue, we are constructing more sophisticated versions of the probe. Corneal-shape-modification instrumentation is essentially complete for loan to the University of New Mexico School of Medicine, but the actual start of experiments will probably be delayed until further results are forthcoming from the experiments at MEI.

Calculational Support
(Los Alamos)
D. J. Brenner

Development of a Realistic Deexcitation Code for Light Nuclei

The neutron radiotherapy programs require detailed high-energy neutron cross sections on light nuclei. We have improved the intranuclear cascade code VEGAS by adding a deexcitation code based on the Fermi breakup model, which includes the following features.

1. A breakup of up to seven particles is allowed.
2. Particle-unstable levels are allowed as intermediate states in a sequential breakup. Realistic nuclear data are used for these intermediate states.
3. Two-body breakup channels use a Coulomb barrier penetration factor based on Coulomb wave functions. Multiparticle breakup uses a threshold adjusted for Coulomb energy.
4. Two-body breakup of a given level is restricted to conserve parity and is inhibited by an angular-momentum barrier penetration factor.

The results of the code (double-differential and angle-integrated production cross sections) have been compared with some recent measurements at 27.4, 39.7, and 60.7 MeV taken at the University of California at Davis. In general, excellent agreement is found, with the exception of secondary deuteron-production cross sections, which are underestimated because direct-transfer reactions are not included in the formalism. As an example, the angle-integrated proton production cross section from the $^{12}$C$(n, xp)$ reaction at 39.7 MeV is shown in Fig. 1. Also, kerma factors (kinetic energy released in matter) have been calculated with the code. These factors are essential in high-energy neutron dosimetry, but until now calculations of kerma have been based on unrealistic nuclear models.

An electron transport Monte Carlo code has been developed primarily for use with low-energy \((1 < E < 10^5 \text{ eV})\) electrons in water vapor. Interest in a low-energy transport code in water has been generated by the development of several models of biological damage, all of which require quantities that must be calculated from radiation maps, that is, lists of all energy-deposition events in the field, their positions, types, and energies. In the code, cross sections for all the different possible ionizations and excitations are included together with elastic scattering, which is considered on an event-by-event basis rather than by using a multiple-scattering formalism.

Extensive corroborative work has been performed with the code, particularly by extending it to include various other gases and by successfully comparing its predictions to experiments done at the nanometer level in a very low-pressure cloud chamber.

Currently, the code is being modified so that the histories of the free radicals formed by ionizing events are recorded. These free radicals, particularly the hydroxyl radical, have been implicated in cell killing in a variety of different systems.

Calculation of Microdosimetric Spectra for Neutron Beams

Details of energy deposition in small sites (nanometers up to micrometers) are known to be important for the predictions of biological damage. In the case of neutrons, secondary charged particles and tertiary electrons must all be tracked to calculate the energy deposition in a specific site size.

A system to perform such calculations has been developed that involves (1) precalculating electron tracks of various energies, which are then stored; (2) precalculating heavy charged-particle tracks (protons, deuterons, and \(\alpha\) particles), using experimental and theoretical information on secondary electron-production spectra and then superimposing suitable electron tracks on the field. These charged-particle tracks are then stored; and (3) calculating neutron tracks using calculated secondary charged-particle-production spectra and superimposing suitable charged-particle tracks on the field.

As an example of the results of such a system, a calculation of the spectrum of energy deposited in a 1-\(\mu\)m sphere by 14-MeV neutrons is shown in Fig. 2 (points) compared with experimental data from the Radiological Research Accelerator Facility (RARAF) at Brookhaven (full line).

Interpretation of Soft X-Ray Biological Data using Low-Energy Electron Transport Code

Extensive experiments have been performed at the Medical Research Council (MRC) in England with very soft x rays, whose secondary electrons have a range of a few nanometers. These x rays are a fine probe of the possible biological interactions occurring between nearby
sites of energy deposition within the cell nucleus after irradiation. We have interpreted the data using the model

\[ \int t_i(x) \gamma(x) \, dx = \xi_i , \]

where \( t_i(x) \) is a function of the x-ray field, which we calculate with the low-energy electron transport code described above, \( \xi_i \) is related to the measured biological damage, and \( \gamma(x) \) is a function specific to the cell type used, describing the interaction between energy-deposition events in the nucleus. Given \( t_i \) and \( \xi_i \), we use an unfolding technique to derive \( \gamma \). Preliminary analysis reveals an interaction function \( \gamma \) limited to about 3 nm, considerably smaller than previous calculations in which less sophisticated calculations of \( t_i(x) \) were used.

Accurate data on \( \gamma \) is considered by many scientists to be a vital prerequisite to future calculations of the effects of low doses of radiation on mammalian systems, including man.
MP-Division Publications: Papers Submitted for Publication


J. A. McGill, "Inclusive Proton Spectra and Total Reaction Cross Sections for Proton-Nucleus Scattering at 800 MeV," Los Alamos National Laboratory report LA-8937-T.


C. M. Hoffman, "How to Build a Very Low Momentum K- Beam at a Kaon Factory," to be published as a Los Alamos National Laboratory informal report.


D. M. Manley, “Measurement and Isobar-Model Analysis of the Doubly Differential Cross Section for the $\pi^+$ Produced in $\pi^-p \rightarrow \pi^+\pi^-n$,” submitted to Phys. Rev.


C. M. Hoffman, “On the Possibility of Studying $\nu_e$ and $\overline{\nu}_e$ Interactions,” Los Alamos National Laboratory report LA-8760-MS.

LAMPF Experimental Program Reports and Publications


(Exp. 492) M. W. McNaughton, “Absolute Polarization Standards at Medium and High Energies,” Los Alamos Scientific Laboratory report LA-UR-80-2395.


IV. FACILITY AND EXPERIMENTAL DEVELOPMENT

Research Support at LAMPF
(Second in a Series)

Keeping the mechanical, electrical, and hydraulic systems of the LAMPF accelerator in operation, and designing and implementing upgrades of equipment are the functions of the Accelerator Support Group, MP-11. These activities span the accelerator space from ion sources and injectors to power and water supplies for magnets in experimental areas. Figure 1 shows schematically the locations of the group's activities.

One current major project is an ion source which will provide high-current H⁻ capability to the WNR Storage Ring upon its completion. Development activities are almost continuous in all of the activities shown in Fig. 1.

Beam availability currently approaches a remarkable 90% as compared to the design figure of 75%. Much of the credit for this high performance goes to members of MP-11, who are, by turns, on call during machine operation. When the machine suffers unscheduled outages, MP-11 is on the job to restore operation.

Figures 2-8 show some of the activities of the Accelerator Support Group.

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Fig. 1.
Accelerator support, MP-11.
Fig. 2.
Bobby Poe (above) and Allen Herring perform a residual gas analysis on 201-MHz tank.

Fig. 3.
Bill Boedeker inspects beam boxes.
Fig. 4.
Bill Halloran machines parts for the intense $H^-$ source that is under development.

Fig. 5.
Don Rader wires a sample-and-hold chassis for emittance-measuring apparatus.

Fig. 6.
The 805-MHz rf crew. Left to right: Don Patton, Chester Higgins, Bob Newell, David Trudell, and Don Rader.
Fig. 7.
Harry Williams, Phil Chamberlin, and Rob York (top to bottom) inspect the polarized ion source.

Fig. 8.
Joe Primeaux wires a LAMPF standard module.
The LAMPF Radiation Effects Facility —
A New Stringer

Introduction

The radiation-effects facility (REF) at LAMPF was built to allow study of radiation damage produced by spallation neutrons, which are generated by the main proton beam in the isotope production targets and the copper beam stop. Access to the neutron flux is via three stringers that penetrate 8 m of shielding around the beam stop. Previous stringers allowed insertion of samples having diameters to 50 mm, but sample lengths were restricted because of bends in the tubing required to reduce radiation streaming. In addition, samples had to be inserted and removed in the pit region, access to which required a lengthy machine shutdown for personnel safety. To overcome these problems, a stringer design was sought that would allow samples to be inserted and removed from outside the isotope production facility building and that would increase the available sample volume.

Stringer Design

To allow easy sample insertion and removal, we decided on the concept of a wheeled cart pulled through a rectangular tube by a come-along. A disposable sample box (inside dimensions are 295 mm long, 73 mm wide, and 50 mm deep) was designed to slip inside the cart. Provision has been made for instrumentation wiring between the samples and the outside. During irradiation, the sample box is cooled by contact with a water-cooled copper plate.

To reduce the radiation streaming through the rectangular tube, it was necessary to place a movable shield block between the pit and the neutron source. The constraints imposed by the stringer housing dictated the use of a vertically moving shield block, which in its upper position covers the rectangular tube opening and, when down, allows the cart to ride on its top surface while being inserted or withdrawn. The shield block is 1.8 m long, and is raised and lowered by end wedges moved by a motor-driven lead screw. The shield block's vertical position is monitored by microswitches interlocked with the radiation safety system, which allows the proton beam to be on only if the block is in the raised position. Operation of the stringer is illustrated in Fig. 1.

Fig. 1.
(a) Sample cart positioned to irradiation position. (b) As above but shield door raised. (c) View shows guide tube extended across the pit as the cart is withdrawn. (d) Guide tube has been pulled outside the building with cart in position for transfer of samples to cart. (e) Sample cart.

Operation — Neutron Spectrum

The new stringer was placed in operation during Cycle 30. The initial runs were used to study the neutron flux vs energy and position in the sample box, with the results shown in Fig. 2. It should be noted that the neutron spectrum and flux will vary with the type and location of the isotope production targets. It has previously been suggested that the spallation neutron spectrum available at the REF is suitable for studying (at low fluence) radiation damage produced by neutrons at fusion reactors. Samples have already been irradiated in the new stringer in conjunction with Exp. 545, “Fusion Materials Neutron Irradiations.” Several runs have been instrumented, indicating peak sample temperatures of 140°C.
The variation in neutron spectrum between the front location (~300 mm from the beam line) and the back location (~533 mm from the beam line) in the new REF stringer sample box.

Acknowledgment
We would like to thank J. E. Vasquez for his design contributions.

REFERENCE

Special Target Holders

It is a common enough challenge in nuclear physics to fabricate pure isotopic targets with a minimum of wall material. Recently, two special challenges were met: a vessel to hold powdered $^{14}$C in vacuum, and a high-pressure gas target. We describe both targets here to illustrate the special engineering services available to experimenters at LAMPF.

The $^{14}$C target dimensions are 30 by 72 by 3 mm. The material is similar to lampblack and would be loaded in the container at Oak Ridge at atmospheric pressure and used under vacuum at EPICS. To prevent distortion of the container and possible shifting of the carbon powder, provision had to be made to permit the internal pressure to reach environmental pressure (atmospheric or vacuum).

The target holder was made as a frame wrapped with 1 mil (25 μm) stainless steel foil, as shown in Fig. 1. One narrow end is plugged with a porous filter to permit passage of gas; the filter is sintered stainless steel. The components were assembled with a polyurethane adhesive. Tests showed that the pressure change should be less than 1/2 psi per minute to prevent stretching of the window foil.

The filling and shipping operation required fabrication of containers for shielding and protection against rapid pressure changes, and to protect the foil while loading the $^{14}$C. The filled targets as received at LAMPF required decontamination but were otherwise generally in satisfactory shape. Six targets were selected and mounted on a holder for the target ladder at EPICS. At the conclusion of the experiment, no $^{14}$C leakage was found.

Thin-walled vessels for tritium gas targets pose additional challenges of greater radiation hazard and pressure containment. The latter requirement constrains the vessel geometry to spherical if wall thickness is to be
minimized. Five-inch-diam (127-mm) hemispheres of stainless steel with 0.62-mm wall thickness, and aluminum with 0.8-mm wall thickness, were found commercially available. The attempt to use aluminum spheres was dropped at a later stage.

A technique to assemble the spheres evolved through trial and error and under safety constraints to ensure adequate strength and reliability. The hemispheres were machined to have matching lip-and-groove at the equator, then welded. The welded spheres were annealed and radiographed, and the voids repaired. The best five spheres were selected for targets; the remainder were used for testing.

A laboratory safety committee set forth assembly and testing methods to ensure safety. The permitted working pressure would be the lower of 200 psia or 1/3 yield; the yield pressure would be determined using four spheres. Each sphere selected for use as a target would be copper plated and tested at 400 psia or 2 times working pressure. The spheres destined to hold tritium would be gold plated to prevent tritium diffusion. Finally, material analysis would be required. An assembled sphere is shown in Fig. 2 before finishing and plating to show the equatorial electron-beam weld.

The yield and ultimate pressure tests, conducted by Laboratory group WX-11, showed that the yield pressure exceeded 660 psi and ultimate pressures of 1500-2500 psi. Material analysis from the supplier of the hemispheres was accepted. Eight Laboratory groups in H, MP, MEC, CMB, WX, and M Divisions were involved in target fabrication, filling, and handling.

—J. Van Dyke

**H⁻ Ion Source Program**

**Introduction**

The requirement for high-intensity H⁻ ion beams for the WNR Proton Storage Ring has necessitated the development of a new H⁻ ion source. The present H⁻ ion source at LAMPF is a charge exchange source and is limited to low-intensity operation. Although the development of a higher intensity charge exchange source is certainly possible, such a source would have fundamental limitations on beam brightness and would be marginal at best for LAMPF operations. Various types of direct-extraction H⁻ ion sources have been developed in the past few years for other accelerator applications, such as the magnetron sources at the Fermi National Accelerator Laboratory and at the Brookhaven National Laboratory. These sources have adequate peak current, but are presently limited to low duty factor operation. A different approach is needed to provide an adequate quality source for the proton storage ring, and it is necessary for LAMPF to undertake a development program to provide such a source.

Fortunately, high-current H⁻ sources have recently been developed in the Lawrence Berkeley Laboratory fusion program to provide intense neutral-beam injection. Additional development required for the accelerator application is in the area of high-voltage extraction of high-brightness beams. A similar development program has been carried out at LAMPF in improving the brightness of the proton beams from the LAMPF duoplasmatron. It was decided to develop a scaled down version of a suitable neutral-beam injector ion source to provide a relatively low-current but high-brightness beam. The initial goal of this program is to obtain an ion source that will produce H⁻ beams with the same intensity and beam...
quality as the H\(^+\) beams now used for production at LAMPF.

**Ion-Source Concept**

The ion-source concept most closely meeting our requirements is the self focused, cusped-field source developed at Berkeley by Ehlers and Leung.\(^1\) A schematic diagram of our prototype based on the Berkeley concept is shown in Fig. 1. A cusped-field magnetic bucket is used for confinement of a low-density hydrogen plasma. A converter electrode in the form of a spherical cap is immersed in this plasma and biased several hundred volts below plasma potential. The production of H\(^-\) ions is effected at the surface of the converter electrode mainly by desorption of hydrogen atoms by positive ion bombardment. These H\(^-\) ions are self-focused by the spherical plasma sheath at the converter surface into a converging beam. This beam propagates through the plasma to an exit aperture in the magnetic bucket and is then accelerated by a high-voltage extraction system to the desired operating potential. For these beams to be useful in an accelerator application, the extraction system must suppress the high electron flux with a minimum distortion of the H\(^-\) beam. A static dipole magnetic field and a biased-exit electrode, termed a plasma-repeller electrode, are used to effect this electron suppression. The development of these concepts is now being pursued both at Berkeley and Los Alamos and is expected to produce an accelerator-quality H\(^-\) ion source.

**Experimental Program**

An experimental program was undertaken at LAMPF to demonstrate the feasibility of using this ion source concept for the proton storage ring. A small cusped-field ion source and a ground-level test stand, which had been previously used in the development of intense H\(^+\) ion beams, were obtained. The ion source was modified to accept a converter electrode, a standard duoplasmatron beam-extraction system, and a plasma-repeller electrode. The aperture in the plasma-repeller electrode, together
with the size of the converter, was chosen to produce a small-emittance ion beam, a choice that subsequently has been found to be too restrictive for optimum operation. Nevertheless, these modifications and design choices did permit a low-current prototype source to be built.

The ground-level test stand was refurbished and the necessary modifications were made to test the prototype H⁻ ion source. The ion source produced an 8-mA dc beam of H⁻ ions at 200 eV, which was the current expected for this prototype design. The source was then mounted on a high-voltage test stand and H⁻ beams were extracted at energies up to 100 kV. These beams were momentum analyzed and emittance data taken with a standard LAMPF emittance-scanning system. In the initial high-voltage tests, problems were encountered in obtaining proper cooling to the accelerating structures on the test stand. This constraint limited the arc power that could be safely run in the ion source and thus the H⁻ beam current that could be obtained from the source. Nevertheless, H⁻ beams up to 4 mA were successfully extracted and transported to the emittance scanners. Emittance measurements taken with the scanners (see Fig. 2) confirmed that the emittance of these beams is indeed within the designed geometrical admittance of the prototype ion source. Stable, quiet operation of this source was achieved in these first tests.

Experimental Results

The initial results obtained with this first prototype ion source demonstrate the feasibility of using an H⁻ cusped-field type ion source for accelerator applications. High-quality beams at 100 kV of 4 mA were obtained and further tests with a cooled version of this design are expected to yield beam currents up to 8 mA. The emittance of the extracted beam can indeed be defined by the geometrical admittance of the ion source, which was 0.08 cm-mrad (normalized*) in these first tests. The H⁻ beam fraction is typically 95% of the total extracted ion beam. Electron loading was small as evidenced by current drain on the high-voltage power supply but certainly was not completely eliminated since there was significant x-ray production. The rise time of the extracted H⁻ beams was several microseconds. No other significant transients in beam current were observed with unanalyzed beam. Voltage modulation of the converter electrode permitted rapid (several microseconds) current modulation of the extracted beam. We expect that further development of this self-focusing, cusped-field type of ion source will result in an ion source that will produce the desired beam currents for the proton-storage-ring application with the high brightness required for high-duty accelerator operation.

Fig. 2.
Horizontal emittance distribution for a 4 mA H⁻ ion beam.

REFERENCE


*Normalized = multiplied by Lorentz factor (βγ = ρ/m).

—R. R. Stevens, Jr.
V. ACCELERATOR OPERATIONS

This report covers operating Cycles 30, 31, and 32. The accelerator was in operation from early July through late November, providing beams for research use for 111 days and for facility development for 13 days. A summary of information on beams provided for experimental use is given in Table I.

Machine operation continued to be reliable and stable. A new Δt solution, with reduced power settings for most of the 805-MHz klystrons, was used successfully. Approximately 1/4 MW was saved in total power consumption; in addition, klystron lifetimes may be extended.

Significant degradation in beam-current-monitor toroids and beam profile monitors at A5 and A6 was observed. The toroid damage is especially worrisome because it impairs the beam transmission interlock system which serves to protect beam-line components in that region. Average $H^+$ beam current was limited to 500 μA during Cycle 32 because of large cooling-water leaks in the A6 beam stop shielding. A summary of unscheduled facility downtime during research shifts is given in Table II. Because some of the outages were concurrent, the total is greater than the beam downtime.

Accelerator development efforts addressed dual-beam steering problems associated with future operation of the Proton Storage Ring. The work concentrated on improving computer modeling capability and on detection and replacement of several suspect quadrupole magnets.

—J. Bergstein

| TABLE I |

| BEAM STATISTICS FOR CYCLES 30, 31, AND 32 |

<table>
<thead>
<tr>
<th></th>
<th>Cycle 30</th>
<th>Cycle 31</th>
<th>Cycle 32</th>
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<tr>
<td>No. of experiments served</td>
<td>40</td>
<td>28</td>
<td>34</td>
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<tr>
<td>$H^+$ scheduled beam hours</td>
<td>898</td>
<td>815</td>
<td>837</td>
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<tr>
<td>$H^-$ scheduled beam hours</td>
<td>148</td>
<td>--</td>
<td>--</td>
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<tr>
<td>$P^-$ scheduled beam hours</td>
<td>710</td>
<td>791</td>
<td>829</td>
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<td>$H^+$ beam availability, %</td>
<td>86</td>
<td>89</td>
<td>90</td>
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<tr>
<td>$H^-$ beam availability, %</td>
<td>84</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>$P^-$ beam availability, %</td>
<td>79</td>
<td>82</td>
<td>85</td>
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<tr>
<td>$H^+$ average current, μA</td>
<td>565</td>
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<td>500</td>
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<tr>
<td>$H^-$ average current, μA</td>
<td>3</td>
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<td>--</td>
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<tr>
<td>$P^-$ average current, nA</td>
<td>~5</td>
<td>~5</td>
<td>~5</td>
</tr>
<tr>
<td>$H^+$ beam duty factor, %</td>
<td>6-7.5</td>
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<td>6-7.5</td>
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<tr>
<td>$H^-$, $P^-$ beam duty factor, %</td>
<td>3-7.5</td>
<td>3-7.5</td>
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### TABLE II

**UNSCHEDULED MACHINE DOWNTIME**

<table>
<thead>
<tr>
<th>Category</th>
<th>Downtime (h)</th>
<th>Percent of Total</th>
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<tbody>
<tr>
<td>201-MHz amplifiers and transmission lines</td>
<td>50</td>
<td>11</td>
</tr>
<tr>
<td>805-MHz amplifier systems</td>
<td>35</td>
<td>8</td>
</tr>
<tr>
<td>Vacuum</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>Magnets and magnet power supplies</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>Interlocks</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Injectors</td>
<td>135</td>
<td>30</td>
</tr>
<tr>
<td>Water</td>
<td>78</td>
<td>17</td>
</tr>
<tr>
<td>Computer control and data acquisition</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Beam stops, plugs, targets, strippers, scrapers</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td>Miscellaneous (utilities, etc.)</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>445</strong></td>
<td></td>
</tr>
</tbody>
</table>
CLINTON P. ANDERSON MESON PHYSICS FACILITY

MILESTONES

Official Ground Breaking
Spinoff: Adoption of LAMPF Accelerating Structure for X-Ray Therapy and Radiography Machines
5-MeV Beam Achieved
Adoption of a LAMPF Standard Data-Acquisition System
100-MeV Beam Achieved
211-MeV Beam Achieved
800-MeV Beam Achieved
Spinoff: First Use of Electrosurgical Forceps in Open-Heart Surgery (University of New Mexico)
Discovery of $^{236}$Th (Experiment Zero)
Dedication to Senator Clinton P. Anderson
Spinoff: First Hyperthermic Treatment of Animal Tumors
First H$^+$ Injector Beam
First Simultaneous H$^+$ and H$^-$ Beams
Beam to Area B
First Experiment (#6) Received Beam
First Meson Production, Beam to Area A
Beam to Area A-East
First Medical Radioisotope Shipment
Usable 100-μA Beam to Switchyard
Pi-Mesic Atoms with "Ticklish" Nuclei
First Experimental Pion Radiotherapy
First Tritium Experiment (80 000 Ci)
Start of Great Shutdown
New Precise Measurements of Muonium Hyperfine Structure Interval and μ$^+$ Magnetic Moment
Q Data-Acquisition Software Operational
Spinoff: First Use of $^{82}$Rb for Myocardial Imaging in Humans (Donner Laboratory, Lawrence Berkeley Laboratory)
Spinoff: First Hyperthermic Treatment of Human Cancer (University of New Mexico)
Accelerator Turn On Starts
Acceptable Simultaneous 100-μA H$^+$ and 3-μA H$^-$ Beams to Switchyard
Production Beam to Area B
First Pions Through EPICS Channel
Production Beam in Area A and Area A-East:
End of Great Shutdown
Muon Spin Rotation Program
Spinoff: First Hyperthermic Treatment of "Cancer Eye" in Cattle (Jicarilla Reservation)
100-μA Production Beam in Area A

February 15, 1968
ca 1968
June 10, 1970
August 1970
June 21, 1971
August 27, 1971
June 9, 1972
September 13, 1972
September 25, 1972
September 29, 1972
October 1972
March 28, 1973
May 4, 1973
July 15, 1973
August 24, 1973
August 26, 1973
February 6, 1974
July 30, 1974
September 5, 1974
October 13, 1974
October 21, 1974
November 1974
December 24, 1974
1975-77-80
June 1975
June 1975
June 1975
July 11, 1975
August 1, 1975
September 14, 1975
October 7, 1975
March 18, 1976
April 5, 1976
June 1976
June 3, 1976
August 1976
MILESTONES

(Continued)

Experiment in Atomic Physics (H\(^-\) + laser beam):
  Observation of Feshbach and Shape Resonances in H\(^-\)
Double Charge Exchange in \(^{16}\)O: LEP Channel
Startup of Isotope Production Facility
HRS Operation Begins
Maintenance by "Monitor" System of Remote Handling
Proton Beam to WNR
Polarized Proton Beam Available
Spinoff: First Practical Applications Patent
  Licensed to Private Industry
Pion Radiotherapy with Curative Intent
Proton Computed Tomography Program
Experimental Results at Neutrino Facility
Cloud and Surface Muon Beams: SM\(\xi\) Channel
EPICS Operation Begins
300-\(\mu\)A Production Beam in Area A
AT Division Established
\(\pi^0\) Spectrometer Begins Operation
Operation of Polarized Proton Target
Successful Water-Cooled Graphite Production Target
Spinoff: First Thermal Modification of
  Human Cornea (University of Oklahoma)
600-\(\mu\)A Production Beam in Area A
New Limit on \(\mu \rightarrow e\gamma\)
Commercial Production of Radioisotopes
Spin Precessor Begins Operation
Data-Analysis Center Operational
Variable-Energy Operation
Single Isobaric Analog States in Heavy Nuclei
Spinoff: First Use of \(^{82}\)Rb for Brain Tumor Imaging in
  Humans (Donner Laboratory, Lawrence Berkeley Laboratory)
Double Isobaric Analog States in Heavy Nuclei
Focal Plane Polarimeter Operational at HRS
Safety Award to LAMPF Users Group, Inc., for Working
  One Million Man-Hours Since 1975 Without a
  Disabling Injury
New Measurement of Pion Beta Decay —
  Improved Test of Conserved Vector Current

October 1976
October 5, 1976
October 15, 1976
November 1976
Fall 1976
March 12, 1977
April 1977
April 12, 1977
May 1977
June 1977
July 1977
July 1977
August 1977
Fall 1977
January 1, 1978
February 1978
Spring 1978
November 1978
July 11, 1979
November 1979
December 1979
January 1980
February 1980
April 1980
June 1980
June 1980
September 1980
October 1980
October 1980
October 27, 1980
November 1980
## APPENDIX A

### EXPERIMENTS RUN

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<td>A Study of Neutrino-Electron Elastic Scattering</td>
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<td>The (p,n') Reaction on ²He with 800-MeV Protons</td>
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<td>267</td>
<td>Preparation of Radioisotopes for Medicine and the Physical Services Using the LAMPF Isotope Production Facility</td>
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<td>Therapy Beam Development — Biomedical Channel Tuning</td>
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<td>Therapy Beam Development — Microdosimetry</td>
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<td>Pion Radiobiology</td>
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<td>Pion Clinical Trials</td>
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<td>303</td>
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<td>An Attempt to Make Direct Atomic-Mass Measurements in the Thin Target Area</td>
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<td>Inclusive π⁺ and π⁻ Double Charge Exchange on ¹⁶O and ⁴⁰Ca</td>
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<td>High-Resolution Study of the (π⁺,2p) Reaction</td>
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<td>Analyzing Power and Cross-Section Measurements for Inelastic Proton Excitation of Simple States</td>
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<td>386</td>
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<td>A Measurement of the Triple-Scattering Parameters D, R, A, R' and A' for Proton-Proton and Proton-Neutron Scattering at 800 MeV</td>
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<td>Excitation of Giant Multipole Resonances by 200-400-MeV Protons</td>
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<td>Search for the Rare-Decay $\mu^+ \rightarrow e^+e^+e^-$</td>
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<td>416</td>
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<td>Magnet Resonance Studies of $\mu^+$ Electron-Defect Complexes in Nonmetals</td>
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<td>High-Precision Study of the $\mu^+$ Decay Spectrum</td>
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<td>Radiochemical Study of Pion Single Charge Exchange</td>
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<td>The Analyzing Power for $\bar{p} + ^{24,26}$Mg at 500 and 800 MeV</td>
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<td>Dibaryon Resonances in Pion Production</td>
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<td>Polarized Beam and Target Experiments in the p-p System. Phase 1. ( A_\gamma ) and ( A_{\nu} ) for the ( \Delta n^+ ) Channel and ( A_{\nu} ) for the Elastic Channel from 500-800 MeV</td>
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<td>Study of the Reaction ( p(\text{Polarized}) + (\text{^4He}) \rightarrow (p,d,n,\ldots) + X ) to Measure the Analyzing Power Structure Functions for Backward Particles</td>
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<td>538</td>
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<td>541</td>
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<td>773.7</td>
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<td>543</td>
<td>A Product Recoil Study of the ( (n^+,n^+N) ) Reaction</td>
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<td>Search for a Fast Fission Process</td>
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<td>545</td>
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<td>Radiation Damage</td>
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<td>P^3, LEP</td>
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<td>591</td>
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<td>Exp. No.</td>
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<td>Beam Hours</td>
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<td>594</td>
<td>Precision Determinations of Some Relative Muonic Coulomb Capture Ratios in Oxides of Different Valences</td>
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<td>597</td>
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<td>Transverse and Longitudinal Field μSR Measurements in Selected Ternary Metallic Compounds</td>
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<td>Structure of States in the Oxygen Isotopes via Measurements of the Spin Depolarization and Spin Rotation Observables</td>
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## APPENDIX B

### NEW PROPOSALS

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<th>Institution</th>
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<td>B. Budick</td>
<td>New York Univ.</td>
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<td>698</td>
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<td>R. M. Steffen, E. B. Shera</td>
<td>Purdue Univ., Los Alamos</td>
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<td>699</td>
<td>Measurements of Spin Flip and Depolarization Parameters for $^{58}$Ni(p,p')$^{64}$Ni* $(5^+,T = 0)$ - a Test of the Spin-Orbit Force in Nuclei at 500 MeV</td>
<td>N. M. Hintz</td>
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<td>700</td>
<td>Double Charge Exchange on $^{40}$Ar</td>
<td>H. T. Fortune, C. L. Morris</td>
<td>Univ. of Pennsylvania, Los Alamos</td>
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<td>701</td>
<td>Pion Double Charge Exchange on Self-Conjugate Nuclei</td>
<td>C. L. Morris, H. T. Fortune</td>
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<td>702</td>
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<td>J. R. Comfort</td>
<td>Arizona State Univ.</td>
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<td>Study of M4 Strength in $^{15}$N by $\pi^+$ and $\pi^-$ Inelastic Scattering</td>
<td>D. B. Holtkamp, S. Seestrom-Morris</td>
<td>Univ. of Minnesota, Los Alamos</td>
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<td>704</td>
<td>Pion Inelastic Scattering From $^{20}$Ne</td>
<td>C. F. Moore, H. T. Fortune</td>
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<td>D. Ashery</td>
<td>Tel Aviv Univ., Israel</td>
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<td>706</td>
<td>Unpolarized $p-p$ Differential Cross Sections at 90° c.m.</td>
<td>B. W. Mayes, M. Furic</td>
<td>Univ. of Houston, Univ. of Zagreb, Yugoslavia</td>
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<td>J. J. Reidy, R. L. Hutson</td>
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<td>708</td>
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<td>C. L. Hollas</td>
<td>Univ. of Texas, Austin</td>
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<td>709</td>
<td>Measurements of $A_{NN}$, $A_{SS}$, and $A_{SL}$ in the Coulomb Interference Region at 650 and 800 MeV</td>
<td>M. Gazzaly, G. Pauletta, N. Tanaka</td>
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<td>710</td>
<td>A Measurement of the Triple Scattering Parameters D, R, A, R', and A' for Quasi-Elastic Scattering at 800 MeV</td>
<td>M. L. Barlett, G. W. Hoffmann</td>
<td>Univ. of Texas, Austin, Univ. of Texas, Austin</td>
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July-December 1981

Los Alamos National Laboratory
711 Reactive Content of the Optical Potential at 500 MeV
G. W. Hoffmann
Univ. of Texas, Austin

712 Inelastic Proton Scattering on \(^{40}\text{Ca}\) and \(^{50}\text{Ti}\): An Attempt to Identify Mesonic Effects as the Cause of M1 Quenching
R. E. Segel
Northwestern Univ.

713 M1's, Deltas, and Medium Effects in Cross Sections for \(^{88}\text{Sr}(p,p')^{88}\text{Sr}^*\) at 400 MeV
C. Glashausser
Rutgers Univ.

714 A Search for the Giant Isovector Monopole Resonance in Inelastic Proton Scattering at Zero Degrees
C. Glashausser
Rutgers Univ.

715 Analysis of Chemical Composition of Archeological Artifacts by Way of Muonic X Rays
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D. H. Snow
Oklahoma Univ.
Museum of New Mexico

716 Pion Double Charge Exchange on Heavy Nuclei
K. K. Seth
Northwestern Univ.

717 Pion Scattering to Collective States in Selenium Isotopes
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C. L. Morris
S. J. Greene
Univ. of Pennsylvania
Los Alamos
New Mexico State Univ.

718 Energy Dependence of the Two-Nucleon Effective Interaction
J. Kelly
M. V. Hynes
MIT
Los Alamos

719 Production of Neutron Rich Radon Isotopes and Determination of Their Cross Sections and Half Lives by a Radiochemical Technique
A. L. Turkevich
Univ. of Chicago

720 Recoilless Delta Production in the Reaction \(^{12}\text{C}(p,d)^{12}\text{C}^\Delta\)
C. L. Morris
J. A. McGill
Los Alamos
Rutgers Univ.

721 Measurement of the Proton Polarization Observables in the 'Li(p,p')'Li and the Test of the Reaction Theory at Intermediate Energies
B. Aas
E. Bleszynski
UCLA

722 Measurement of Cross Sections and Analyzing Powers for Elastic and Inelastic Scattering of 400- to 500-MeV Protons from \(^{12}\text{C}\)
C. J. Harvey
S. Seestrom-Morris
Univ. of Texas, Austin
Los Alamos
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## APPENDIX C

### ACTIVE AND COMPLETE EXPERIMENTS BY CHANNEL

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* FEASIBILITY STUDY.
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USE OF LAMPF BEAM STOP TO OBTAIN $^{60}$Fe

FEASIBILITY OF HELIUM-JET TECHNIQUES FOR STUDYING SHORT-LIVED NUCLEI PRODUCED AT LAMPF

A RADIOCHEMICAL STUDY OF THE $^{209}$Bi(p,$\pi^0$)$^{210}$Po, $^{209}$Bi(p,$\pi^-$Xn)$^{210}$Po, AND $^{209}$Bi(p,2$\pi^-$Xn)$^{210}$Po PION PRODUCTION REACTIONS AT 500-800 MeV

PRODUCTION OF NEUTRON-RICH RADON ISOTOPES AND DETERMINATION OF THEIR CROSS SECTIONS AND HALF LIVES BY A RADIOCHEMICAL TECHNIQUE

BIOMEDICAL PION CHANNEL (BIOMED)

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**BEAM STOP A RADIATION (BSA-RAD)**

Los Alamos National Laboratory

July-December 1981
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EXCITATION OF HIGH-SPIN PARTICLE-HOLE STATES IN \(^{56}\text{Fe}\) AND \(^{58}\text{Ni}\)

INVESTIGATION OF THE STRUCTURE OF \(^{16}\text{O}\) WITH PION INELASTIC SCATTERING

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\(n^2\) ELASTIC SCATTERING FROM DEUTERIUM AT 237 MeV

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PROGRESS AT LAMPF
Los Alamos National Laboratory

July-December 1981
625  INELASTIC SCATTERING OF PIONS TO GIANT RESONANCES
KING  1  162.0
ANDERSON
PETerson

651  MEASUREMENT OF A LOWER LIMIT FOR THE SUBTHRESHOLD PRODUCTION OF KAONS WITH 800-MeV PROTONS
MORRIS  1  0.0

655  \pi^± INELASTIC SCATTERING FROM \(^{4}\text{He}) — AN EXAMINATION OF ISOSPIN SYMMETRY BREAKING
HOLTKAMP  1  0.0
COTTINGAME

657  INELASTIC \pi^± SCATTERING FROM THE N = 26 ISOTONES
SEIDL  1  0.0
MOORE

659  SPIN-FLIP GIANT RESONANCE EXCITATION
BLAND  1  0.0
MOORE

661  GOOD-RESOLUTION STUDY OF \(^{18}\text{O}(\pi\pi')
MORRIS  1  0.0
BLAND

662  ELASTIC AND INELASTIC \pi^- AND \pi^+ SCATTERING FROM \(^{32}\text{S}, \(^{31}\text{P} AND \(^{90}\text{Zr, \(^{90}\text{Y}
KRAUSHAAR  1  0.0
PETerson

671  EXPERIMENTAL INVESTIGATIONS OF ISOVECTOR PROPERTIES OF COLLECTIVE TRANSITIONS
SAHA  1  0.0
SETH

672  STUDY OF GIANT RESONANCES IN \(^{90}\text{Zr, \(^{116}\text{Sn, AND \(^{208}\text{Pb WITH \pi^- AND \pi^+ INELASTIC SCATTERING}
CAREY  1  0.0
MOSS

677  A DETERMINATION OF \Delta S = 1 CONTRIBUTIONS IN INELASTIC PION SCATTERING FROM ODD-A NUCLEI
HOLTKAMP  1  0.0
FUNSTEN

678  STUDY OF THE M1 TRANSITION IN \(^{44}\text{Ca BY INELASTIC SCATTERING OF \pi^- AND \pi^-
DEHNHARD  1  0.0
MORRIS

681  MEASUREMENTS OF LARGE-ANGLE PION-NUCLEUS SCATTERING WITH EPICS
BURLESON  1  0.0

694  ISOSPIN MIXING IN \(^{4}\text{He}
SETH  1  0.0

700  DOUBLE CHARGE EXCHANGE ON \(^{40}\text{Ar}
FORTUNE  1  0.0
MORRIS

701  PION DOUBLE CHARGE EXCHANGE ON SELF-CONJUGATE NUCLEI
MORRIS  1  0.0
FORTUNE

702  NUCLEAR STRUCTURE EFFECTS IN PION SCATTERING FROM \(^{92}\text{Mo}
COMFORT  1  0.0

703  STUDY OF M4 STRENGTH IN \(^{19}\text{N BY \pi^+ AND \pi^- INELASTIC SCATTERING}
HOLTKAMP  1  0.0
SEESTROM-MORRIS

704  PION INELASTIC SCATTERING FROM \(^{20}\text{Ne}
MOORE  1  0.0
FORTUNE

716  PION DOUBLE CHARGE EXCHANGE ON HEAVY NUCLEI
SETH  1  0.0

717  PION SCATTERING TO COLLECTIVE STATES IN SELENIUM ISOTOPES
BLAND  1  0.0
MORRIS
GREENE

723  MEASUREMENT OF THE NEUTRON AND PROTON CONTRIBUTIONS TO EXCITED STATES IN \(^{38}\text{K BY \pi^+\ AND \pi^- INELASTIC SCATTERING}
HARVEY  1  0.0
FORTUNE

July-December 1981
### HIGH-RESOLUTION SPECTROMETER (HRS)

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ELASTIC-SCATTERING SURVEY USING POLARIZED PROTONS

HOFFMANN 1 * 715.3
2 * 245.6

STUDY OF HIGH-MOMENTUM COMPONENTS IN NUCLEI USING A POLARIZED PROTON BEAM

FRANKEL 1 * 209.8

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HINTZ 1 * 209.3

DETERMINATION OF NEUTRON-MASS DISTRIBUTION FROM ELASTIC PROTON MEASUREMENTS [P(t) AND d(2)dt] ON ISOTOPES IN THE CALCIUM REGION

WHITTEN 1 * 204.6

SCATTERING OF 800-MeV PROTONS FROM 12C AND 14C AT MOMENTUM TRANSFER >4 F-1

BLANPIED 1 * 324.1

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HOFFMANN 1 * 130.0
2 * 55.0

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GLASHAUSSER 1 * 199.9
BAKER 2 88.1
SCOTT

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HOFFMANN 1 * 140.6
2 * 108.8

TOTAL REACTION CROSS SECTIONS FOR p NUCLEI AT 800 MeV

HOFFMANN 1 * 256.1
BURLESON 2 * 118.2
YOKOSAWA 3 * 30.0

THE (p,n) REACTION ON 16O AND 40Ca

BAUER 1 * 195.8
HOISTAD
NANN

EXCITATION OF GIANT MULTIPOLAR RESONANCES BY 200-400-MeV PROTONS

BERTRAND 1 * 40.0
2 0.0

THE (p,n) REACTION ON 12C AND 13C

HOISTAD 1 * 162.7
BAUER
SETH

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MOSS

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HOFFMANN

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GLASHAUSSER 1 * 181.0
MOSS

CROSS SECTION FOR EXCITATION OF UNNATURAL PARITY STATES IN 12C AT E < 800 MeV

GLASHAUSSER 1 * 148.9
MOSS

PROGRESS AT LAMPF
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**Spokesman:** BOWMAN
**Phase No.** 1 *
**Beam Hours** 1341.4

**LINE X BEAM STOP (Line-X-BS)**

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**Spokesman:** O'BRIEN
**Phase No.** 1 *
**Beam Hours** 0.0

**NEUTRINO AREA (Neutrino A)**

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**Spokesman:**
- NEMETHY
- CHEN
- REINES
- CHEN
- FIREMAN
- DUONG-VAN
- PHILLIPS

**Phase No.**
- 1 *
- 2 *
- 1 *
- 1 *
- 1 *
- 1 *

**Beam Hours**
- \(\approx 133.2\)
- 1097.4
- 0.0
- 1132.0
- 47.0
- 1026.0
- 0.0
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2 118.7

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NUCLEAR EXCITATION FOLLOWING MUON CAPTURE ON MEDIUM AND HEAVY NUCLEI

GROUND-STATE QUADRUPOLE MOMENTS OF DEFORMED NUCLEI

STUDY OF TRANSFER EFFECTS IN MUON CAPTURE IN GAS TARGETS

ANALYSIS OF CHEMICAL COMPOSITION OF ARCHAEOLOGICAL ARTIFACTS BY WAY OF MUONIC X RAYS

MEASUREMENT OF THE LAMB SHIFT IN MUONIUM

SEARCH FOR THE C-NONINVARIANT DECAY \( \nu^p \rightarrow 3\nu \)

MEASUREMENT OF THE EFFICIENCY OF MUON CATALYSIS IN DEUTERIUM-TRITIUM MIXTURES AT HIGH DENSITIES

SWITCHYARD LINE A BEAM STOP (SWY-LABS)

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THIN TARGET AREA (TTA)

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## APPENDIX D

### ACTIVE SPOKESMEN, INSTITUTIONS, AND EXPERIMENTS

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APPENDIX E

VISITORS TO LAMPF DURING THE PERIOD
JULY 1 — DECEMBER 31, 1981

Bjarne Aas .................................. UC, Los Angeles
Gary S. Adams ............................. Massachusetts Inst. of Tech.
Suman K. Agarwal ............................ Purdue Univ.
Richard C. Allen ............................ UC, Irvine
John C. Allred .............................. Consultant
Aharon Amitay .............................. Yale Univ.
Richard E. Anderson ........................ Univ. of North Carolina
Sharon W. Anderson ........................ UNM Cancer Center
Barbara L. Anstey ............................ UNM Cancer Center
Richard A. Arndt ............................. Virginia Poly. Inst./State Univ.
Mary Jean Arntzen ........................... UNM Cancer Center
Jeffrey E. Arrington ........................ Abilene Christian Univ.
Daniel Ashery ............................... Tel Aviv Univ.
Nader A. Atari ............................... Kuwait Univ.
Alireza Azizi ............................... UC, Los Angeles
Andreas Badertscher ........................ Univ. of Berne
F. Todd Baker ............................... Univ. of Georgia
Mike W. Ballard ............................. Abilene Christian Univ.
Martin L. Barlett ............................. Univ. of Texas
David B. Barlow ............................. Northwestern Univ.
Charles A. Barnes ........................... California Inst. of Tech.
Peter D. Barnes .............................. Carnegie-Mellon Univ.
Bernd Bassalleck ............................. Carnegie-Mellon Univ.
Curtis E. Bemis, Jr. ........................ Oak Ridge
Barry L. Berman ............................. Lawrence Livermore Lab.
Aron Bernstein ............................. Massachusetts Inst. of Tech.
William Bertozzi ............................. Massachusetts Inst. of Tech.
Tariqchan S. Bhatia ........................ Texas A&M Univ.
Ewart W. Blackmore ........................ TRIUMF
Leslie C. Bland .............................. Univ. of Pennsylvania
Gary S. Blanpied ............................ Univ. of South Carolina
Marvin Blecher ............................. Virginia Poly. Inst./State Univ.
Elizabeth H. Bleszynski ....................... UC, Los Angeles
Marek Bleszynski ............................ UC, Los Angeles
Carolyn A. Blies .............................. UNM Cancer Center
Charles L. Billie ............................. Univ. of Minnesota
Fred O. Borcherding ........................ UC, Los Angeles
Jonathan S. Boswell ........................ Univ. of Virginia
Dale E. Boyce ............................... Univ. of Chicago
Kenneth Boyer .............................. Univ. of Texas
James A. Bridge ............................. Consultant
William J. Briscoe ............................ UC, Los Angeles
Howard C. Bryant ............................. Univ. of New Mexico
Douglas Bryman .............................. TRIUMF
William J. Burger ........................... Massachusetts Inst. of Tech.
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Steven E. Bush .............................. UNM Cancer Center
Jeanne L. Butler ............................. UNM Cancer Center
Kenneth B. Butterfield ........................ Univ. of New Mexico
Michael A. Carchidi ........................ Univ. of Pennsylvania
Nicholas S. Chant .............................. Univ. of Maryland
Herbert H. Chen ............................. UC, Irvine
Yonghyun Cho ............................... Stanford Univ.
Connel L. Chu ............................... M. D. Anderson Hospital
David A. Clark .............................. Univ. of New Mexico
Nance L. Colbert ............................. UC, Irvine
Joseph R. Comfort ........................... Arizona State Univ.
Joseph J. Comuzzi ........................... Massachusetts Inst. of Tech.
David C. Cook ............................... Univ. of Minnesota
William Cottingham ........................ New Mexico State Univ.
Mary L. Courtright ........................ UNM Cancer Center
Donna J. Cremans ............................. Univ. of Texas
Gourisankar Das ............................. Univ. of Virginia
Sobhendranath Datta ........................ UNM Cancer Center
Kincaid Davidson ........................... UNM Cancer Center
Glen H. Daw ................................. UNM/New Mexico State Univ.
Dietrich Dehnard ............................ Univ. of Minnesota
Peter P. Denes ............................... Univ. of New Mexico
Arthur B. Denison ........................... Univ. of Wyoming
Satish Dhawan ............................... Yale Univ.
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W. Rodney Ditzler ........................... Argonne
Stanley A. Dodds ............................. Rice Univ.
Peter J. Doe ................................. UC, Irvine
Mohan Doss ................................. Univ. of Washington
Robert W. Dunn ............................. Univ. of New Mexico
Minh V. Duong-Van ........................ Rice Univ.
Steven A. Dytmam ........................... Massachusetts Inst. of Tech.
Thanasis E. Economou ......................... Univ. of Chicago
David A. Edrich ............................. UC, Irvine
Patrick O. Egan ............................. Yale Univ.
Andrew D. Eichon ............................ UC, Los Angeles
Richard J. Ellis ............................. College of William & Mary
Stephen F. Eiston ............................ Univ. of Texas
July-December 1981

Los Alamos National Laboratory

PROGRESS AT LAMPF

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INFORMATION FOR CONTRIBUTORS

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*Progress at LAMPF* is published semiannually on April 1 and October 1. This schedule requires that manuscripts be received by December 1 and June 1, respectively.

Published material is edited to the standards of the *Style Manual* of the American Institute of Physics. Papers are not refereed, hence presentation in this report does not constitute professional publication of the material nor does it preempt publication in other journals.

Contributors can expedite the publication process by giving special care to the following specifics:

1. Drawings and figures submitted should be of quality suitable for direct reproduction after reduction to single-column width, 83 cm (3-1/4 in.).

2. Figure captions and table headings should be furnished.

3. References should be complete and accurate.

4. Abbreviations and acronyms should be avoided if possible (in figures and tables as well as text), and when used must be defined.

5. All numerical data should be given in SI units.

6. Authors are reminded that it helps the reader to have an introduction, which states the purpose(s) of the experiment, before presentation of the data.

Research reports should be brief, one printed page or less, including figures (approximately three double-spaced typed pages). A list of recent publications relating to the experiment, for separate tabulation in this report, is much appreciated.

Contributors are encouraged to include as authors all participants in experiments so that they may receive credit for authorship and participation.

Questions and suggestions should be directed to John C. Allred, Los Alamos National Laboratory, MS 850, Los Alamos, NM 87545.
ERRATUM

In the Los Alamos National Laboratory report LA-8994-PR, *Progress at LAMPF*, January-June 1981, on p. 38, the spokesmen for Exp. 225 were incorrectly given. The spokesman for this experiment is H. H. Chen (University of California at Irvine).