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FOREIGN TRIP REPORT

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SUBJECT: Report of Foreign Travel by Melvyn L. Halbert, Research Staff,
Physics Division, January 6-13, 1991

TO: Alvin W. Trivelpiece

ORNL/FTR--3862

FROM: Melvyn L. Halbert

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PURPOSE

To attend and present invited paper at the XIV Nuclear Physics Symposium; to visit two accelerator laboratories in and near Mexico City.

SITES VISITED

1/7-10/91	XIV Nuclear Physics Symposium, Cuernavaca, Mexico	M. E. Brandan
1/11/91	ININ (National Institute for Nuclear Investigations), Sálazar, Mexico	E. Aguilera
1/11/91	IFUNAM (Institute of Physics, University of Mexico), Mexico City, Mexico	A. Dacal and M. E. Ortiz

ABSTRACT

This report includes background material on the long-standing series of annual symposia presented by the Mexican nuclear physics community, summarizes the highlights of the fourteenth symposium in the series, and records items learned by the traveler in subsequent visits to two research laboratories in Mexico.

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A. XIV Nuclear Physics Symposium

This conference was the fourteenth in a series organized annually in January by nuclear physicists from three institutes in or near Mexico City, namely the Institute of Physics of the National Autonomous University of Mexico (IFUNAM), the Institute of Nuclear Sciences of the National Autonomous University of Mexico (ICNUNAM), and the National Institute of Nuclear Investigations (ININ). Financial support was provided also by about six other Mexican and international physics societies. Among these was the ICTP at Trieste, Italy, which requested participants to fill out a post-conference questionnaire rating the physical facilities and general usefulness of the Symposium. Evidently the virus of performance appraisal is beginning to infect international scholarly organizations.

Traditionally this Symposium has been held in a government-owned resort in the town of Oaxtepec, about 50 miles south of Mexico City. This year it had to be moved to a private hotel in Cuernavaca, a few miles from Oaxtepec because of repeated failures of the newly appointed administrator (now fired) to respond to inquiries by the conference chairperson, Maria Ester Brandan.

The XIV Symposium included two other changes from tradition. The Symposium Proceedings are to be published by World Scientific Publishing (Singapore) rather than by the Mexican Physical Society. This should allow for a speedier appearance and a wider distribution of the Proceedings. Secondly, a poster session was held for the first time to give students an opportunity to discuss their work with the visiting scientists. This session included the showing of an interesting videotape of collisions between droplets of mercury. The images show many phenomena familiar to scientists studying heavy-ion nuclear reactions, such as vibrations, rotations, neck formation, and ternary fission, for various relative kinetic energies and impact parameters. Of course, phenomena due to Coulomb effects were absent. The images were digitized and then analyzed quantitatively by undergraduates under the direction of A. Menchaca-Rocha.

The major part of the Symposium consisted of twenty-two 40- to 50-minute talks on a wide variety of topics in nuclear physics. Since total attendance was only about 35, well over half of the attendees gave talks, which resulted in an atmosphere very different from the usual one at large international conferences in which only a select few experts dominate the oral presentations and discussions.

B. Highlights of the Symposium

The opening talk, by M. Moshinsky (IFUNAM), discussed the basic problem of two charged particles fusing to form a compound nucleus. Rather than introduce an optical potential and solve numerically, he considered the problem from the point of view of the wave functions and the Schrödinger equation and went as far as possible with analytic expressions. This work, which has just appeared in *Phys. Rev. C* (Jan. 1991), is an extension of a similar calculation he had done 40 years ago for uncharged particles. To allow for a clearer understanding of the essential features, the problem was restricted to elastic scattering and one $\ell = 0$ resonance only, with a boundary condition between the elastic channel and the fused system at the point of touching. Moshinsky then worked out the phase shift due to this boundary condition and gave expressions for the S matrix and the cross section, showing in closed form how the charged system differed from the

uncharged one. In the charged system the lifetime is much longer than for the uncharged, which opens the possibility of using "nuclear transients" to study properties of nuclei, in analogy with electric circuit theory where the transient response of a black box tells as much about the box as does frequency variation. He also mentioned the possibility of solutions by use of the powerful technique of Laplace transforms. Extension of the model to additional resonances is simple and to $\ell > 0$ is also possible. While Moshinsky does not claim his method is complete, it does appear to be instructive and actually useful in some reactions -- as an example, he applied it to $^{238}\text{U} + ^{238}\text{U}$ collisions. He mentioned that application to simple systems such as $\alpha + \alpha$ might be even more useful since these have many fewer internal degrees of freedom which are not included at present in his treatment.

N. Benczer-Koller (Rutgers) surveyed the current status of measurements of magnetic moments in nuclei at high spin, high temperature, near the limits of stability, and with exotic shapes (e.g., superdeformed). There exist at present few such measurements, but they can be very useful. For example, the 14^+ level of ^{160}Yb has a negative moment, which implies immediately that an odd-neutron orbital is active. Koller described collaborative experiments underway at Argonne in which information on the γ -ray continuum as well as discrete states is being obtained.

Eric Norman (LBL) reported on two measurements of beta spectra which suggest the existence of a weak ($\sim 1\%$) component corresponding to a neutrino with mass about 17 keV. Such a massive neutrino was proposed by J. J. Simpson in 1985 from measurements of tritium decays, and again in 1989 from Simpson's measurements of the ^{35}S beta spectrum. Since 1985 ten or more papers have been published which do not see evidence for such a massive neutrino. Norman's first experiment used a germanium detector whose Ge crystal was grown with a small atomic fraction (10^{-10}) of carbon enriched to 10% in ^{14}C . With this detector, he could measure the ^{14}C beta spectrum without any complications of surface effects (as might occur with an external source) or crystal damage (as might result if radioactive atoms had been implanted in the crystal by use of an accelerator). After counting for 122 days in a low-background facility, with 52 additional days of background checks from a similar crystal without ^{14}C , Norman examined a 60-keV portion of the spectrum near the endpoint. Although no "kink" at 17 keV can be seen in the data, a least-squares fit to the theoretical shape including such a component revealed a slight dip in χ^2 (9 out of 420, which corresponds to a 3σ confidence limit) for a neutrino mass of (17 ± 2) keV and an intensity of $(1.4 \pm 0.5)\%$. This result was checked in several ways, such as using subsets of the data. Also, data synthesized with Monte Carlo simulations and subjected to the same analysis were found to give similar results, with a small dip in χ^2 . Norman believes the dip in χ^2 is statistically significant, but remains cautious at this time in claiming a positive result. In a study of the spectrum of the internal bremsstrahlung of ^{53}Fe , he obtained somewhat weaker evidence for a neutrino with mass (21 ± 2) keV with an intensity of $(0.85 \pm 0.45)\%$ of the main spectrum; this measurement is continuing. In the next year, Norman expects to measure spectra with a ^{63}Ni -doped Ge and another ^{14}C -doped crystal; the latter should provide a count rate 10 to 25 times higher than the existing one and, Norman hopes, a definitive answer. One of the reasons he remains cautious is that all of the positive evidence for a massive neutrino has come so far from Si or Ge detectors; one would like to see the effect also in spectra taken with other types of detectors such as magnetic spectrographs or gas counters.

A. Menchaca-Rocha reported on singles measurements at Grenoble of emission of intermediate-mass fragments from carbon bombarded by 38-MeV/nucleon ^{16}O . Thirty percent of the yield at back angles appears in a low-energy peak. A similar peak has been seen at forward angles for lower bombarding energies (10-15 MeV/nucleon) and can be satisfactorily accounted for by Hauser-Feshbach calculations, but at 38 MeV/nucleon it is hard to believe that the compound nucleus can play a significant role because 400 MeV is being pumped into a system of only 28 nucleons. Likewise, one doesn't expect incomplete fusion to be important because large fragments (e.g., ^7Li , ^{12}C) are observed despite the very high excitation energy. With a simplified cascade model, Menchaca-Rocha has succeeded in showing that the backward low-energy peak is due to evaporation of nucleons from the target. He plans to improve the program and do some fitting of parameters. However, someone commented that not much can be learned about nuclei from singles spectra at these energies. Measurements of particle correlations and a program to model such data are required for real progress.

T. Fortune (University of Pennsylvania) surveyed data taken at LAMPF for the past 5-6 years on pion double charge exchange reactions [e.g., (π^+, π^-)] and related the experimental data to nuclear states with special structure such as the double isobaric analog state (DIAS) or the giant dipole resonance built on the isobaric analog state (GDR $\otimes$ IAS). The latter excites mainly the T-1 state, especially if $T \gg 1$. The energy of the GDR $\otimes$ IAS is always 2-3 MeV less than for the photonuclear GDR on the ground state, and its width is $(54 \pm 8) \text{ A}^{-1/2} \text{ keV}$ (except for In, which is only half as broad for reasons still unknown; Fortune speculates that it is related to α decay of the T-1 states). He also surveyed data on the double giant dipole resonance, GDR $\otimes$ GDR. The data are more easily interpreted if it is excited by (π^-, π^+) rather than (π^+, π^-) since the former leads to a single isospin. The price paid for this simplicity is poorer statistics because the π^- beam is about five times weaker at LAMPF than the π^+ beam. The 2^+ member of the GDR $\otimes$ GDR has been observed, but its intensity is three times what was expected. Many other aspects of the double GDR are puzzling and more experiments are planned.

A. Lepine-Szily (Pelletron laboratory, São Paulo) spoke about the successful application of the so-called algebraic scattering theory (AST) of Alhassid and Iachello to her scattering and reaction data for $^{12}\text{C} + ^{24}\text{Mg}$ ($E_{\text{lab}} = 37.9 \text{ MeV}$) and $^{18}\text{O} + ^{10,11}\text{B}$ ($E_{\text{lab}} = 52.6 \text{ MeV}$). The first system shows a back-angle anomaly (increase in yield and onset of oscillations) and the second shows features characteristic of orbiting (e.g., $1/\sin \theta$ angular distribution); these are related phenomena. The AST replaces the coupled Schrödinger differential equations for the various channels with a set of coupled linear algebraic equations, which makes it relatively easy to take into account large numbers of channels. The AST calculations indicate that the back-angle rise in elastic cross section for the ^{12}C reaction is mainly due to coupling to transfer channels, especially transfer to excited states. For the ^{18}O reactions, coupling of 11 inelastic and 11 transfer channels to the ground state and a smaller number of couplings to excited states were included. The observed $1/\sin \theta$ angular distribution magically appears when the different highly structured direct-reaction components are summed. These calculations are incomplete at present because the maximum ℓ value was 150, far too low for the Coulomb excitation part, and the cross sections are consequently underpredicted. In a comment after this talk, K. McVoy (Wisconsin) emphasized that the AST is not actually a theory, although it may be a useful way to parametrize reaction data since unitarity and Coulomb excitation are properly built into it.

A. Aprahamian (Notre Dame) introduced her talk with a survey of what is known about multi-phonon vibrations in spherical and deformed nuclei. Although hundreds of one-phonon vibrations are known in the latter, there is only scant evidence for two-phonon vibrations. Theoretical predictions vary: some theories do not predict the existence of multi-phonon states while others predict them but differ in the properties of these states. Working with H. Börner's group at ILL (Grenoble), she studied levels in ^{168}Er excited by the reactor flux of 5×10^{14} neutrons/cm²sec on an internal target. The detection technique is Gamma-Ray-Induced Doppler broadening (GRID), in which bent-crystal diffraction is used to measure the incredibly small broadening of a γ -ray line due to the nuclear recoil from prior emission of another γ ray. In this case the recoil velocity is only 5×10^{-6} c, and the Doppler broadening is on the order of only 10 eV! The method requires very careful calibration and alternating measurements in a dispersive and nondispersive geometry to guard against spurious broadening effects. The lifetimes deduced from these data are $\tau \approx 440$ fs for the 1234-keV line from the 4^+ member of the $K^\pi = 4^+$ band to the 2^+ member of the $K^\pi = 2^+$ band, and $\tau \approx 260$ fs for the 1274-keV transition from the 5^+ level of the $K^\pi = 4^+$ band to the 3^+ level of the $K^\pi = 2^+$ band. Both of the corresponding $B(E2)$ values are of the same order of magnitude as those for a $2^+ \rightarrow 0^+$ transition known to be collective. The energies show that the levels are definitely anharmonic. These facts are in agreement with predictions from the multi-phonon method of Pipenbring *et al.* and the contracted symplectic model developed at IFUNAM.

A paper by E. Hernández and A. Mondragón (IFUNAM) in the poster session deduced the existence of three very broad negative-parity states in ^6Li at about 25 MeV excitation; one of them, with $J^\pi = 2^-$ has not been reported previously. Later Dr. Mondragón pointed out to me the possible connection of this work to the solar neutrino puzzle. The isobaric analogue of such states in ^6Be would be formed by $^3\text{He} + ^3\text{He}$ radiative capture which would deplete the ^3He in the solar interior and thereby reduce the formation of ^7Be by $^3\text{He} + ^4\text{He}$. The beta decay of ^7Be produces the high-energy neutrinos to which the ^{37}Cl detector of R. Davis *et al.* is most sensitive. This was of particular interest to me. In 1973 I was involved in an experiment with ORIC designed to set a limit on the amount of solar ^3He that could be removed by a sharp, positive-parity resonance in $^3\text{He}(^3\text{He}, \alpha 2p)^6\text{Be}$. Our group found no evidence for such a resonance; our experiment was not sensitive to broad negative-parity states such as Dr. Mondragón is considering.

C. Visit to ININ

ININ (National Institute for Nuclear Investigations) was originally devoted to development of practical uses of nuclear energy, but the nuclear power section there is now inactive; at present, all major activity in this field takes place in the ministry for electricity. The emphasis at ININ has shifted to environmental studies. The laboratory is located near the town of Salazar, state of Mexico, in the mountains about 20-30 miles southeast of the capital. I was shown the EN tandem installation where a group of about 10 physicists carries out research on nuclear reactions and does certain service work such as analyzing air-pollution samples from Mexico City with particle-induced x-ray emission (PIXE) for the state Department of the Environment. A second PIXE setup is sometimes used for studies of purity of milk and for some work in archeology and geology.

The tandem operates only Monday through Friday, with most of Monday devoted to pump down and cold trap preparations. Operation at 5.0 MV is routine; the machine can go to 5.5 MV with difficulty. Two magnetic spectrographs are in place, the famous MIT multigap spectrometer donated to ININ long ago, and a single-gap instrument built locally, I believe. Neither spectrograph is now in use. Some work on neutron scattering and polarization are done. However, it appears that most of the significant basic research is now done elsewhere, when staff members go to foreign laboratories for brief or long-term stays. A strong collaboration exists with Notre Dame University (U.S.A.) in studies of heavy-ion fusion and of depolarization, and with Legnaro (Padua, Italy) for the neutron cross section work.

E. F. Aguilera is deeply involved in the fusion work at Notre Dame and is principal investigator for near-barrier measurements of $^{27}\text{Al} + ^{70,72,73,74,76}\text{Ge}$ and $^{17}\text{O} + ^{12,13}\text{C}$. In some cases, there are large differences in fusion from one isotope to the next which may be traceable to angular momentum effects. He and I had a long discussion about measuring angular momenta in fusion, the subject of my talk at the Symposium.

D. Visit to IFUNAM

The National Autonomous University of Mexico, located on an ancient lava flow in the southern portion of Mexico City, appears to be the nation's principal center of research in many fields. On driving to the Institute of Physics (IFUNAM), one passes many research institutes one after another, devoted to chemistry, engineering, social sciences, philosophy, biology, various branches of medical science, and so on. The character of the Institute of Physics, once primarily a nuclear physics research center, has changed to heavier involvement in condensed matter and other fields of physics. Nevertheless, many of the members of the Institute working in nuclear physics are young, well trained, and productive. The experimental facilities for nuclear studies consist of the 5.5 MV van de Graaff accelerator donated to IFUNAM in 1984 by Rice University, for which a large new building was constructed in 1986, a 2 MeV electron accelerator, and a 0.7 MV van de Graaff accelerator used extensively for PIXE and surface studies, the latter by proton and alpha-particle backscattering. The 5.5 MV machine has been in operation in the past, but at the moment is down for minor repairs.

As at ININ, however, I noticed that the major research projects in nuclear reactions seem to be done by staff members visiting other laboratories such as Texas A&M, LBL, ORNL, and SARA (Grenoble). I spoke at length with M. E. Brandan, who has made a significant contribution in the past few years in analyzing elastic scattering data on $^{12}\text{C} + ^{12}\text{C}$ and $^{12}\text{C} + ^{16}\text{O}$ obtained by others. By fitting the data above 10 MeV/nucleon first, she has shown that a potential with a shallow imaginary well (18-25 MeV) and a deep real well with depth that increases slowly with bombarding energy can provide excellent fits without the ambiguities that are usually encountered below 6 MeV/nucleon. From this start, she has been able to tie onto the extensive lower-energy data. She has shown that only one of the many potentials that reproduce the low-energy data is actually suitable for all energies. Her work was done first with six-parameter Woods-Saxon wells but more recently with four-parameter, density-dependent folding potentials (in collaboration with G. R. Satchler at ORNL). Brandan's recent work (with K. McVoy) has shown that the sharp dips in the 90° excitation functions are due to the Airy minima of the far-side rainbow scattering passing through 90° as the energy increases. Furthermore, she can predict at what energy

what energy the last Airy minimum can be seen; above this energy there can be no additional deep minima in the excitation function if the correct potential has been chosen. The same considerations apply to the 90° excitation function for $^{16}\text{O} + ^{16}\text{O}$ obtained at ORNL in 1974: she believes that our data has revealed the last Airy minimum in this system as well; this provides an important constraint on the potential. Additional data on $^{16}\text{O} + ^{16}\text{O}$ at 90° would be easy to obtain at IHIRF, although in McVoy's opinion angular distributions at selected energies would be of much greater value.

APPENDIX

A. ITINERARY

1991

January 6	--	Travel en route from Oak Ridge to Mexico City, Mexico
January 7	--	Travel from Mexico City to Cuernavaca, Mexico
January 7-10	--	XIV Nuclear Physics Symposium, Cuernavaca
January 10	--	Travel from Cuernavaca to Mexico City
January 11	--	ININ (National Institute of Nuclear Investigations), Sálazar, Mexico
	--	IFUNAM (Institute of Physics, University of Mexico), Mexico City
January 12	--	Weekend
January 13	--	Travel from Mexico City to Oak Ridge

B. PERSONS CONTACTED

M. E. Brandan	--	Symposium Chairperson
E. Aguilera	--	Tandem Accelerator Laboratory, ININ, Sálazar, Mexico
A. Dacal and M. E. Ortiz	--	5.5 MV Van de Graaff Accelerator Laboratory, IFUNAM, Mexico City

C. LITERATURE ACQUIRED

Reprints on fusion reactions, negative-parity levels in ${}^6\text{Li}$, and analyses of elastic scattering of ${}^{12}\text{C} + {}^{12}\text{C}$ and ${}^{16}\text{O} + {}^{12}\text{C}$.

END

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