# SECTION IV

# ABSTRACTS OF PAPERS IN PRESS

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Excitation of M1 resonances in $^{90}Zr$, $^{92}Zr$, $^{94}Zr$ and $^{120}Sn$ by inelastic scattering of 201 MeV protons.

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The location of M1 strength in others than light nuclei has been the subject of many discussions. Very recently inelastic electron scattering experiments have shown three small M1 components in $^{90}Zr$ near 9 MeV excitation energy (1). In contrast (pn) charge exchange experiments excite broad spin-flip, isospin flip Gamow-Teller resonances (2). This resonances are strongly enhanced when the energy of the projectile is increased from 45 to 160 MeV.

Taking advantage of the 201 MeV proton beam of the Orsay synchrocyclotron we have searched for these $\Delta T = 1$ $\Delta S = 1$ transitions in $^{90}Zr$, $^{92}Zr$, $^{94}Zr$ and $^{120}Sn$. The experimental set up allows measurements at very small angles with an energy resolution of 60 to 80 keV. In the three Zr isotopes a resonance centered near 9 MeV is clearly seen (fig. 1 abc). In $^{120}Sn$ a small bump centered at 8.3 MeV is superimposed on a large continuum due to the tail of the elastic peak (fig. 1d). The characteristics of these resonances are given in the table. Their angular distribution is forward peaked and is well fitted by a L = 0 DWBA angular distribution (fig. 2) as the (pn) GT resonances.

The strength exhausted by these M1 resonances will be discussed.

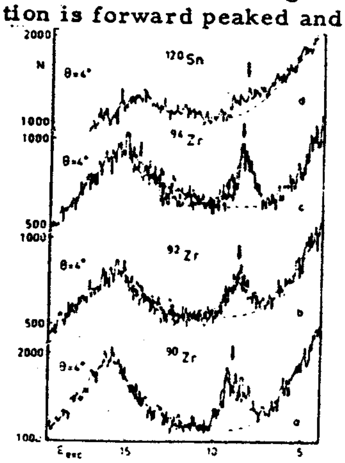

fig. 1

| Target | $E_{exc}$(MeV) | (MeV) |
|---|---|---|
| $^{90}Zr$ | 8.95 ± 0.1 | 1.7 ± 0.1 |
| $^{92}Zr$ | 8.75 ± 0.1 | 1.6 ± 0.1 |
| $^{94}Zr$ | 8.6 ± 0.1 | 1.5 ± 0.1 |
| $^{120}Sn$ | 8.3 ± 0.15 | 1.75 ± 0.15 |

Table

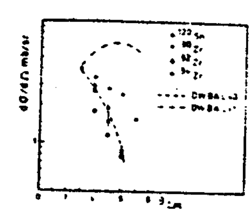

fig. 2

(1) D. Meuer et al. Nucl. Phys. A349(1980) 309
(2) D. J. Horen et al. Phys. Let. 95B(1980) 27
(3) A. Willis et al. Nucl. Phys. A344(1980) 137

Presented at the European Physical Society Conference on Nuclear and Atomic Physics with Heavy Ions, Bucharest, Romania, June 1981.

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# INTERMEDIATE ENERGY HEAVY ION COLLISIONS

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Abstract: Intermediate energy nuclear collisions between 20 and 200 MeV/nucleon are discussed. Various transitional phenomena occur in this region which acts as a bridge between low energy and relativistic heavy-ion reactions. The change from mean field to hydrodynamical phenomena, the onset of the participant-spectator description, and of high multiplicity events are all likely to be accessible at intermediate energies. The study of heavy fragments in peripheral reactions to measure zero point motion, and of light particle emission to probe properties of the participant zone in more central collisions are discussed. Exotic aspects of explosion, entropy production, of phase transitions and of nuclei far from stability can also be investigated at intermediate energies.

## 1. Introduction

The subject of intermediate energy, heavy-ion collisions has so far enjoyed a symbiotic relationship with its low and high energy hosts, drawing liberally from both. The reasons are partly practical and partly philosophical. Largely as a result of developments in accelerator technology, the study of nuclear collisions has been concentrated on two decades of incident energy: from 1 to 20 MeV/ nucleon by the numerous electrostatic and cyclotron accelerators throughout the world, and from 200 to 3600 MeV/nucleon by modifications to existing synchrotrons. By driving these accelerators to their high and low energy limits, some initial results in the intermediate energy regime from 20 to 200 MeV/nucleon are now available.[1-5]) In like fashion, the theoretical interpretations are mainly extrapolations of ideas developed at much lower and higher energies. However the major emphasis of the new accelerators coming into operation in the next few years will be on nuclear collisions at intermediate energies, which are now known to contain important transitional features. Within the span from 20 to 200 MeV/nucleon, several thresholds can be surpassed, for example at the sound velocity, the Fermi energy and the pion mass. Instead of a mean field description, one may find that the mean free path becomes short before nuclei lose their cohesiveness; hydrodynamic features may therefore come into play. From the perspective of general physics, the region is also very interesting because of the lack of relevant, small, characteristic parameters. The situation is neither classical nor quantal, neither in the one-body nor the two-body extreme, neither close to the adiabatic nor to the sudden approximation; the energy is neither so low that the interaction might be dominated by the mean field, nor so high that individual few nucleon collisions might make the major contribution. This paper will deal with our present knowledge of intermediate energy, heavy-ion collisions and their relation to phenomena at low and at relativistic energies.

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MSUCP-364
December 1981

EXTREME STATES IN NUCLEAR SYSTEMS

*" Les extrêmes se touchent..."*
*L.-S. Mercier, Tableau de Paris*

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ABSTRACT: Extreme states in nuclear systems are discussed in terms of limiting phenomena. Eight limits are described, viz. of angular momentum, reaction mechanisms, nuclei, space and time, temperature, density and matter. These limits have become accessible mainly through collisions of heavy nuclei, at incident energies ranging from a few MeV/nucleon up to energies of TeV/nucleon.

## INTRODUCTION

It is probably no exaggeration to say that there are few, if any, extreme states in nuclear systems (1). Rather there exist extreme points of view. Many of these are familiar and, indeed, have played a pivotal role in the development of nuclear science. For many years our ideas about nuclear reactions were dominated by compound and direct processes—extremes of time scale ranging from $10^{-16}$ to $10^{-23}$ sec. The coexistence of the shell and liquid drop models demonstrates the extremes of single particle and collective aspects. More recently we have seen both time-dependent Hartree Fock and nuclear hydrodynamical theories applied with some success to the dynamics of nuclear collisions, although the two theories start from paradoxically opposing hypothesis, the extremes of infinite and zero mean free path of a nucleon in the nucleus, and the extremes of few and many particle collisions. There is, however, a danger in associating these extreme viewpoints with extreme states, just as there is a danger in associating God with singularities in the solution of differential equations. With improved mathematics the singularities sometimes disappear. Similarly with improved nuclear theory, the extreme viewpoints disappear; complete extended shell model calculations, for example, exhibit collective features. As expressed succinctly by L.-S. Mercier in Tableau de Paris, "Les extrêmes se touchent". But before the extremes meet, they

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# The Pulse-Height Correction Technique for Improving γ-Ray Spectra from Coaxial Ge Detectors

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Abstract:

We demonstrate that the pulse-height correction technique can be used for coaxial as well as planar Ge γ-ray detectors. Pulses from the detectors are analyzed according to their rise-times, and an improved spectrum is obtained by correcting the incompleteness of charge collection, using the relation between rise-time and pulse-height defect. Geometrical effects in coaxial detectors require at least a three-parameter correlation, in which the rise-times of the pulses are analyzed for two time segments. We have been able to improve the energy resolution of neutron-damaged Ge detectors by more than 50% and their peak-to-Compton ratios by almost as much, all without significant loss in detector efficiency.

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# Pairing Model Predictions for (p,t) Experiments on the Cadmium Isotopes*

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## ABSTRACT

The even-even cadmium isotopes have been studied by the (p,t) reaction at 42 MeV. A broad resonance-like structure is observed between 6 and 7 MeV excitation energy which has similar properties to the feature observed in (p,t) reactions in the tin isotopes. A second smaller bump at higher excitation energy appears to arise from pickup of two particles from deep orbits.

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The distribution of one-hole strength in a large number of nuclei has been studied both experimentally (see ref. 1 and references therein) and theoretically.[2,3] Recently, a broad resonance has been observed near 8 MeV excitation energy in two particle pickup reactions on the tin isotopes.[4,5] These structures appear to arise from pickup of one neutron from a deep lying orbit ($g_{9/2}$) and one from a valence orbit.[6,7]

In order to gain further insight into these broad structures the (p,t) reaction was carried out on the even-even isotopes of cadmium, viz $^{106}$Cd, $^{110}$Cd, $^{112}$Cd, $^{114}$Cd, $^{116}$Cd using the 42 MeV proton beam from the MSU K50 cyclotron. The tritons were detected on the focal plane of the Enge split pole spectrograph using a position sensitive proportional counter backed by a plastic scintillator. Triton spectra measured at a laboratory angle of 20° are shown in Fig. 1. Broad structure is observed in all the cadmium isotopes as in the tin case, but there appears to be somewhat more varied and fragmented structure in the cadmium spectra particularly for the higher isotopes.

Another important feature observed in the cadmium spectra is the appearance of a second broad bump at an even higher excitation energy. This second peak is marked with an arrow in the spectra in Fig. 1.

In the $^{104}$Cd spectra it is possible to resolve individual levels which have been previously reported.[8] Using the $^{62}$Ni(p,t)$^{60}$Ni reaction and $^{108}$Cd(p,t)$^{106}$Cd reactions (from the $^{108}$Cd impurity on the $^{106}$Cd target) as calibrations, the Q-value for the $^{106}$Cd(p,t)$^{104}$Cd reaction was measured as $-10.802 \pm 0.015$

Abstract of Talks for Bormio and Hirschegg Conferences, Jan. 1982

# Subthreshold Pion Production by Heavy Ions

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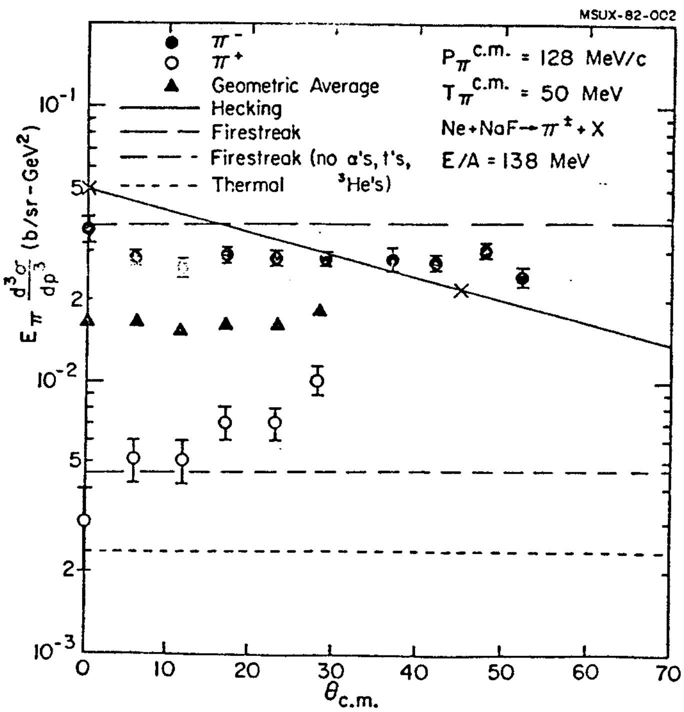
The most recent data on pion production below the nucleon-nucleon threshold with heavy ions consist of an angular distribution at E/A = 138 MeV for $^{20}$Ne+NaF. The data were taken at the LBL Bevalac by a MSU-LBL-Orsay-Tokyo collaboration. The results can be summarised as follows: 1) There is a very large $\pi^-/\pi^+$ ratio at $0^\circ$ indicating that cold charged projectile fragments still exist after the collision even at this low energy.
2) The angular distribution is isotropic in the center of mass frame, which may indicate a predominance of thermal production rather than first collision nucleon-nucleon production.
3) The magnitude of the cross section is in good agreement with previous work[1] and is smaller than the full firestreak calculation[2] with all composite particles and resonances as can be seen in the figure.




Angular distributions at E/A = 138 MeV and $P_T^{cm}$ = 128 MeV/c. The data are given for $\pi^-$, $\pi^+$ and the geometric mean of the cross sections.

The amount and type of composite particles included affects the pion cross section very strongly because of the very strong temperature dependence. This can be seen on the figure by comparing firestreak calculations with and without α's, t's and $^3$He's. The curve labelled thermal comes from the model of Kapusta[3] and the curve labelled Hecking[4] is a first collision + thermal calculation.

This work supported in part by the U.S. N.S.F. under grant No. 78-22696.

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3) J.I. Kapusta, Phys. Rev. C16, 1493 (1977).
4) P. Hecking, LBL-12671 and private communication.

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# Energy Dependence of Nuclear Matter Disassembly in Heavy Ion Collisions

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ABSTRACT

Measurements of light charged particle spectra from $^{20}$Ne+Au at 100 and 156 MeV/nucleon are compared with results for similar systems at 9,13,20,42,241,393, and 800 MeV/nucleon. Spectra at each energy are fitted with a single moving source model to extract the temperatures and cross sections for protons and light nuclei in the intermediate rapidity region. The $^{4}$He/p production ratio decreases drastically with incident energy, whereas the d/p and t/p ratios are almost constant.

PACS: 25.70.z



An important concept in relativistic nuclear collisions concerns the formation of an excited, localized region of participant nucleons moving with a velocity intermediate between those of the projectile and target.[1,2] In this letter we present a new approach to the study of this region over a wide range of incident energies through its dissassembly into nucleons and light composite nuclei. The relative abundance of these emitted fragments as a function of temperature in the zone is characteristic of the detailed mechanism of its disassembly.[3,4,5] Within a thermodynamic model temperature and relative numbers of nucleons and light nuclei are predicted to vary smoothly with incident energy, whereas a hydrodynamical model,[6] incorporating compression, could lead to a discontinuity in the temperature and a sudden decrease in the production of light composite nuclei as a function of incident energy. We report new measurements of p,d,t, and $^{4}$He energy spectra and angular distributions from $^{20}$Ne-induced reactions on a Au target at incident energies of 100 and 156 MeV/nucleon. Our results for production cross sections and temperatures, when combined with those extracted from previous measurements for $^{16}$O or $^{20}$Ne-induced reactions on heavy targets, give a consistent picture of an intermediate velocity source with a temperature that varies smoothly with incident energy. We also observe that the deuteron to proton ratio (d/p) is almost independent of energy whereas the $^{4}$He to proton ratio ($^{4}$He/p) varies from 1.9 at 9 MeV/nucleon to 0.05 to 800 MeV/nucleon. These observations lend support to models that describe these reactions in terms of a localized, thermalized, expanding interaction zone.[3,4,5]

Presented at the Workshop on Isovector Resonances
Los Alamos, February 8, 1982

# Splitting of the Dipole and Spin-Dipole Excitations

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Dipole (L=1) transitions in a (p,n) reaction can be accompanied by spin transfer S=0 or S=1. The nature of these excitations is shown in Fig. 1. All S=0 strength is concentrated in a $J^{\pi}=1^{-}$ state located at $E_0$ , while for S=1 , there are states with $J^{\pi}=0^{-}$, $1^{-}$, $2^{-}$ with centroid at $E_1$ . Near $E_p$ = 40 MeV, S=0 transfer is dominant, but transfer of S=1 becomes more and more probable (relative to S=0) as the proton bombarding energy increases toward 200 MeV[1]; one then expects the centroid of the L=1 strength to move from $E_0$ toward $E_1$ with increasing energy.

This behavior has been observed experimentally for all heavier ($A \gtrsim 90$) nuclei investigated, and is shown for the isotopes of Zr[2,3] in Fig. 2.

The position of the L=1 centroid at bombarding energy $E_p$ is given by

$$C(E_p) = \frac{\sigma_1 E_1 + \sigma_0 E_0}{\sigma_1 + \sigma_0} = E_0 - \frac{\sigma_1/\sigma_0}{1 + \sigma_1/\sigma_0} \Delta \qquad (1)$$

where $\Delta \equiv E_0 - E_1$ and $\sigma_1(\sigma_0)$ is the cross section for S=1(S=0) transfer. For the ratio $\sigma_1/\sigma_0$ we use the value found for L=0 transitions by Taddeucci, et al.,[1] namely $\sigma_1/\sigma_0 = a^2 E_p^{\,2}$ where a = 0.00183 ± 0.00018 $\text{MeV}^{-1}$. (Our use of this value of a involves the assumption that the spin operator is quenched as it is for Gamow-Teller Transitions in heavier nuclei.) Then

$$C(E_p) = E_0 - \frac{a^2 E_p^{\,2}}{1 + a^2 E_p^{\,2}} \Delta \qquad (2)$$

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# Observation of M1 strength in zirconium isotopes by proton inelastic scattering

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Abstract

A broad resonance has been observed by inelastic scattering of 200 MeV protons from $^{90}Zr$, $^{92}Zr$, $^{94}Zr$ and $^{96}Zr$. This resonance has a sharply forward peaked angular distribution and an excitation energy and strength which strongly suggest that it is the M1 giant resonance. Microscopic distorted wave impulse approximation calculations match the shape of the angular distribution reasonably well. The strength, however, is only about 30% of that predicted.





## I. INTRODUCTION

The study of M1 states in nuclei allows the exploration of the nuclear spin degrees of freedom, which is interesting for a number of reasons[1]. The shell model predicts that there should be M1 states ($1^+$ in even-even nuclei) made when the spin of a particle in a j-unsaturated shell is flipped, i.e., $j=l+1/2 \rightarrow j=l-1/2$. The M1 strength is therefore a measure of the extent to which unsaturated spin-orbit-partner orbits are occupied in the nuclear ground state. Secondly, the M1 strength gives a check on the renormalization (due to core polarization and mesonic effects) of the magnetic charge (effective g-factors).[2] This renormalization, until now, has been determined mainly from the study of magnetic moments. Thirdly, in scattering experiments the M1 strength allows, in principle, the determination of the spin-dependent components of the effective interaction between the nucleons in the projectile and the target. At small angles and at bombarding energies above 100 MeV/nucleon, where the $V_{\sigma\tau}$ component is dominant[3,4], the strength should be particularly sensitive to this one component. Finally, since the one pion exchange potential involves spin and isospin transfer of one, and since the $V_{\sigma\tau}$ operator involves spin flip and isospin flip, the magnitude of this operator at large momentum transfers is important in determining the pionic interactions with nuclei and in particular whether or not a phase transition to a pion condensed phase can take place[5,6].

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# OBSERVATION OF M1 STRENGTH IN MEDIUM-HEAVY NUCLEI VIA THE (p,p') REACTION

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ABSTRACT

A broad resonance has been observed by inelastic scattering of 200 MeV protons from $^{51}V$, $^{58/60/62}Ni$, $^{68}Zn$, $^{90/92/94/96}Zr$, $^{92/94/96/98/100}Mo$, $^{120/124}Sn$ and $^{140}Ce$. The resonance occurs between 8 and 9 MeV in most of the nuclei and has a width of around 2 MeV. In all cases, the angular distribution is very sharply forward peaked and is consistent with an orbital angular momentum transfer of zero. The excitation energy, angular distribution and strength of the resonance suggest that it is the giant M1 resonance. In the nickel isotopes, and in $^{51}V$, both the $T_o$ and $T_o+1$ components of the resonance are observed.

## I. INTRODUCTION

The study of spin excitations in nuclei has been pursued by a number of different yet complementary techniques including electron scattering, (γ,n) reactions, β-decay and, more recently, (p,n), ($^3$He,t) and (p,p') reactions. The program of this conference is proof of the richness and diversity of this field. Both the beautiful (p,n) results showing the excitation of the Gamow-Teller (G-T) resonance in many nuclei[1,2] and the very nice high resolution inelastic electron scattering work[3,4,5] have stimulated renewed interest in this subject. In addition, improvements in the theoretical formulation of the effective interaction used in direct reaction calculations at high energy[6] and the resulting ability to predict the absolute magnitudes of the cross sections, confirm that magnetic transitions are substantially quenched.[7] The quenching has apparently two components, one being configuration mixing and the other more exotic mesonic effects such as the mixing of the M1 state with a Δ particle-nucleon hole configuration excited through the Δ-nucleon interaction[8,9].

In spite of the strong excitation of the G-T resonance in the (p,n) reaction, until last year there was no corresponding clear observation of the M1 state in the parent nucleus either by inelastic proton scattering[10] or inelastic electron scattering[5,11,12] in nuclei heavier than the nickel isotopes. However, the (p,n) data did suggest to us that the appropriate kinematic region to search for the M1 state in (p,p') would be at high bombarding energies (>120 MeV) and at very forward angles. The (p,n) reaction to the G-T state is very forward peaked and the similarity of the reaction mechanism suggested a similar behaviour for the (p,p') reaction. Of course, the measurement of inelastic scattering cross sections at very forward angles is experimentally challenging, primarily because of the background from scattered particles and the Landau tail of the elastic peak.

## II. EXPERIMENTAL METHOD

The experiments reported here were carried out using 201 MeV protons from the synchocyclotron at the IPN, Orsay. The spectrometer attached to this facility is ideal for forward angle measurements because of its large size. In addition, a counter system consisting of two multiwire detectors and two plastic scintillators measures the trajectory of the particles emerging from the spectrometer.[13] Such measurements serve to minimize the background from scattered particles. However one problem with this counter was that it had small differential non linearities which gave rise to spurious fine structure in the spectra. For this reason each spectrum was taken with two slightly different settings of the magnetic field to clearly identify any spurious structure. An example of such overlapping spectra is shown for $^{51}V$ in Fig. 3a. In addition, since the fine structure was found to be very stable during a week long run, a correction function was obtained which could then be applied to all the spectra to further reduce the effect of the non linearities in the counter.

The absolute cross section was obtained in two ways. First, the cross section was measured by a comparison with the known p-p scattering cross section and second by a comparison with elastic scattering calculations at angles forward of $10^o$. The two methods agreed to better than 10%.

MSUCP-39
March 1982

# On the feasibility of axial injection in superconducting cyclotrons

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## Abstract

In connection with the superconducting cyclotron program at M.S.U. a feasibility study of axial injection, aimed mainly at the K-800 cyclotron, has been carried out.

The results encompass all major aspects of a working system, i.e. center region, injection trajectories and phase space matching. It is shown that axial injection is indeed feasible, although problems exist not ordinarily encountered in conventional A.V.F. cyclotrons.

The possible solutions and limitations are presented and discussed in detail.

# Anomalons as Pineuts Bound to Nuclear Fragments: A Possible Explanation

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Abstract:

We suggest that the properties of anomalons, the highly reactive heavy-ion reaction fragments observed in emulsions, can be explained by considering them to be "pineuts", i.e., a $\pi^-$ bound hadronically to a neutron cloud extending out from the nuclear fragment.

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MSUCP-40
April 1982

# Neutron Shielding Calculations for Phase II Operations of the National Superconducting Cyclotron Laboratory

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Second Indo-U.S. Joint Symposium on

# NUCLEAR PHYSICS AT CYCLOTRON AND INTERMEDIATE ENERGIES

May 24-28, 1982

Bombay, India

MSUCL-374
May 1982

## M1 EXCITATION OF NUCLEI BY INELASTIC PROTON SCATTERING

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Abstract

The giant M1 excitation has been observed in the inelastic scattering of 200-MeV protons from 23 medium-heavy nuclei between $^{40}$Ca and $^{140}$Ce. The M1 identification is based upon the excitation energies (between 8 and 9 MeV in most of the nuclei) and angular distributions (very forward peaked) of structures observed in the proton spectra. Microscopic distorted wave impulse approximation calculations match the shapes of the angular distributions quite well but predict cross sections about 4 times too large. Comparisons with (e,e') and (p,n) results are presented.

# OBSERVATION OF ℓ=0, SPIN-FLIP TRANSITIONS IN $^{48}$Ca AND OTHER N=28 NUCLEI*

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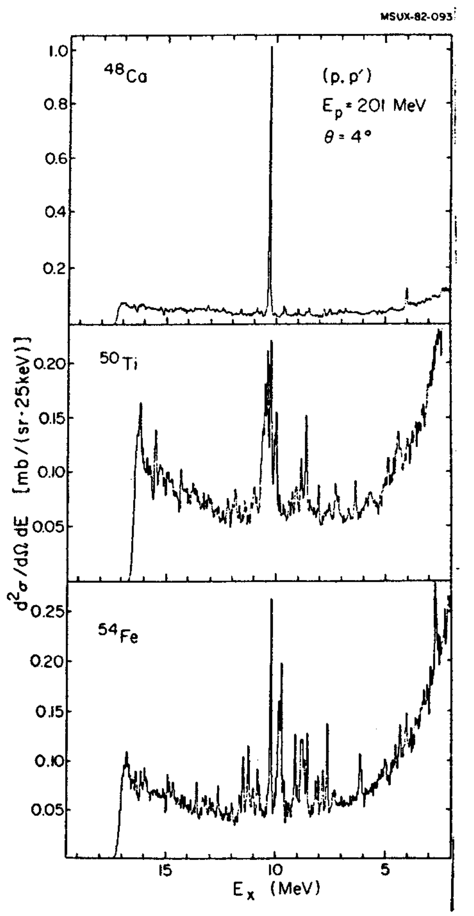
The nucleus $^{48}$Ca has been a particularly interesting test case for the study of ℓ=0, spin-flip transitions mainly because of the simplicity of its structure. A strong sharp transition to a $1^+$ state has been observed with this target in a number of reactions.[1,2,3] In the present experiment, 200 MeV protons from the Orsay synchrocyclotron were used to study the $^{48}$Ca(p,p') reaction from 2° to 16°. In the spectrum at 4° shown in the top panel of the figure, the 10.2 MeV, $1^+$ state, stands out very clearly above the background. In contrast, by 10° many states are observed in the spectrum with comparable intensity. The angular distribution for this state is very sharply forward peaked and has been compared to microscopic distorted wave Born approximation calculations using the code DWBA70. Both a simple $\{\nu f_{5/2}\nu f_{7/2}^{-1}\}$ and a more realistic full f-p shell wave function[4] have been used in these calculations. Both calculations reproduce the shape of the measured angular distribution reasonably well. The ratio of experimental to predicted cross sections for these two cases are 0.27 and 0.36 respectively. These values are somewhat lower than the ratio of experimental to theoretical BM1 values extracted from the (e,e') measurements.




In addition, it is interesting to observe the effect of adding protons to the $f_{7/2}$ shell keeping a neutron number of 28. Spectra for $^{50}$Ti and $^{54}$Fe are shown in the lower panels of the figure where the single sharp peak in $^{48}$Ca has become a more widely spread cluster of levels. In $^{50}$Ti, the states tend to cluster in two groups centered at energies near 10.2 MeV and a little below 9 MeV. It has been suggested[5] that this lower energy cluster corresponds to proton excitations. These results agree with the (e,e') observations.[5] In contrast, a broad feature is also observed in $^{51}$V(p,p') in the present experiment but no corresponding strength was observed in the (e,e') measurements on this same nucleus.

* Work supported in part by NSF under grants PHY-78-22696 and INT-8116064.

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MSUCL-377
June 1982

# Low energy particles produced in heavy ion reactions

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## Abstract

A model is presented for the low energy spectrum of nucleons produced in small impact parameter heavy ion reactions. Special attention is paid to the effects of the Coulomb force which not only gives rise to an energy shift but also to a sideward focussing. Calculated angular distributions are compared with high multiplicity selected events in the Ne on U reaction at 393 MeV/nucleon.

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# Isospin dependence of pion absorption by nucleon pairs

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ABSTRACT

We calculate the relative absorption ratio of a pion by nucleon pairs measured recently by Ashery, et al. Standard theory based on Δ-isobar intermediate excitations agrees with the experimental observation that pion absorption by a $T = 1$ nucleon pair is strongly suppressed.

*Research sponsored by the Division of Basic Energy Sciences, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

# SHELL-MODEL CALCULATIONS OF NUCLEAR CHARGE RADII

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Abstract Shell-model calculations of charge radius differences in the Pb isotopes are discussed. Core quadrupole oscillations are found to be significant factors in the calculations. Existing data on the $^{210}$Pb isotope shift and the B(E2) strengths in $^{210}$Pb are shown to be inconsistent. Ground-state correlation effects in light nuclei (i.e., O and Ca isotopes) introduce odd-even staggering effects and other qualitative features in agreement with existing data.

## INTRODUCTION

At this conference we have heard about a number of beautiful experiments which produce extremely precise measurements of nuclear sizes, as extracted from isotope shift measurements. An obvious question is what can we learn from such measurements. Historically, there are two distinct classes of nuclear models. One is the collective model, wherein the nucleus is treated as some sort of liquid which can assume a shape, rotate, vibrate, etc. Bill Myers has discussed here the application of such

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# LIQUID-GAS PHASE INSTABILITIES IN NUCLEAR SYSTEMS

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## Abstract

The conventional approach to composite fragment production in heavy ion collisions from a single gaseous phase may require modification at temperatures below 20 MeV due to the onset of a liquid-gas phase instability. Clusters heavier than the $\alpha$-particle are necessary for an unambiguous experimental signature.

PAC NOS. 25.70.Fg, 05.70.Jk, 24.90.+d

In high energy nuclear collisions, a localized zone of participant nucleons can be created at excitation energies greater than the binding energy of the nucleons. The disassembly of the hot transient system into many different final channels is a problem of current interest.[1] Thermodynamic models have been developed to account for the emission of light composite fragments by treating the participant zone as a single gaseous phase in thermal and chemical equilibrium. However, under certain combinations of density and temperature the system may develop an instability toward division into liquid and gas phases which could influence the production of composite fragments. In this paper we discuss the conditions for this instability to develop and we suggest how this effect might be observed experimentally.

To derive the condition for a liquid-gas instability, we start from the relation[2]

$$\rho = \frac{4}{(2\pi)^3} \int d^3k \, [1 + \exp(\frac{k^2}{2m} - \mu)/T]^{-1}$$

from which the chemical potential, $\mu$, is determined as a function of the density $\rho$ and the temperature T. The thermal contribution to the internal energy is given by

$$\frac{E_T}{V} = \frac{4}{(2\pi)^3} \int d^3k \, \frac{k^2}{2m} \, [1 + \exp(\frac{k^2}{2m} - \mu)/T]^{-1}$$

Gamow-Teller strength at high excitations

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Abstract

A perturbative calculation is reported for the mixing of Gamow-Teller strength with 2-particle 2-hole configurations at high excitation energies. We find that roughly 50% of the Gamow-Teller strength is shifted into the region of 10-45 MeV excitation for the nucleus $^{90}$Zr. This would explain a substantial part of the continuum background seen in the 200 MeV (p,n) reaction.



[Nuclear Structure, $^{90}$Zr, Gamow-Teller strength function, $E_{ex}$ = 10-45 MeV, theory]

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The recent elucidation of the giant Gamow-Teller state in heavy nuclei by the (p,n) reactions presents a paradox. There is a well-defined peak whose energetics is reproduced by the TDA shell model theory,[1] but the strength is apparently less than half of the predicted value.[2,3] Part of the suppression can be ascribed to the Δ-isobar admixtures in the nuclear wave functions,[4-6] but part is undoubtedly due to conventional nuclear mixing.[6,7] For example in the case of $^{41}$Sc, Towner and Khanna[6] found that more strength was depleted by ordinary nuclear configuration mixing than by the Δ amplitudes in the wave functions.

In this article, we will examine in some detail the distribution of strength that is lost to the Gamow-Teller peak due to configuration mixing. Our motivation is the presence of excitation strength in the (p,n) reaction at 0°, for excitation energies ranging up to ∿50 MeV above the Gamow-Teller peak.[3] We anticipate that much of this excitation strength is due to Gamow-Teller strength for the following reasons. The main other possibilities are multistep excitation, and excitation by operators with orbital dependence, e.g., $(Y_L(r)\sigma)^J_{t_-}$. Multistep reaction cross sections characteristically rise with increasing excitation energy, due to the greater number of intermediate states possible for higher energy losses. However, the (p,n) reaction cross section falls with energy loss up to excitation energies beyond 50 MeV. This is clearly seen in the data of Gaarde, et al.,[3] which we reproduce in Fig. 1. Furthermore, explicit calculation of multistep reaction cross sections indicates that single step should dominate at forward angles when the excitation energy is less than half the beam

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# DAMPING OF NUCLEAR EXCITATIONS

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# Intrinsic Fragment Spins Generated in the Reactions of $^{20}Ne$ with $^{197}Au$ and $^{238}U$ at 12.6 MeV/Nucleon

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Abstract

The average magnitude and alignment of the intrinsic spin of the heavy partner from the reaction of 252 MeV $^{20}Ne$ with $^{197}Au$ and $^{238}U$ were determined as a function of Q-value. These spin values were extracted from sequential fission angular distributions obtained in coincidence with projectile-like products. For all Q-values, a large out-of-plane anisotropy was observed, while for large negative Q-values an in-plane anisotropy was observed. A very large entrance-channel mass-asymmetry was chosen to provide a stringent test of equilibrium statistical model predictions for the spin alignment. The importance of determining the direction of the line-of-centers of the dinuclear system at scission is discussed. Large values of $P_{ZZ}$ were deduced for all Q-values. $P_{XY}$ was observed to be positive in the quasielastic region and negative in the deep-inelastic region. The extracted alignment data are compared to equilibrium statistical model calculations.

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Submitted to Physics Review C

# Theoretical interpretation of the Gamow-Teller strength in the $^{42}Ca(p,n)^{42}Sc$ reaction

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Abstract

We have calculated the Gamow-Teller strength of the $^{42}Ca(p,n)^{42}Sc(1^+)$ reaction using the Kuo-Brown wave function. This shell model calculation together with the Δ isobar quenching mechanism accounts for the GT strength.

[Nuclear Structure, Shell-Model, Reaction Matrix, GT-strength, Δ isobar Polarization]

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# Relations among the quenching strengths of magnetic transitions due to the Δ isobar excitation in N ≠ Z nuclei

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## Abstract

A possible excitation scheme of particle-hole states in N ≠ Z nuclei is worked out within the isospin formalism. Particle-hole states with a definite isospin are decomposed into 1p - 1h (particle-hole), 2p - 2h and 3p - 3h states. This decomposition enables us to relate transition strengths from the ground state to the excited states and those in the adjacent nuclei. The same thing is done for Δ isobar-hole states. Using these results, we obtain the relations among the quenching strengths of magnetic transitions in N ≠ Z nuclei. In particular, we apply these relations to the M1 states around $^{48}$Ca and $^{90}$Zr and compare the results with experimental data obtained by (p,n), (p,p') and (e,e') experiments on $^{48}$Ca and $^{90}$Zr.

RGM Kernels for the 9-quark 3-nucleon system

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The RGM norm kernel for the 9-quark 3-baryon system is evaluated in analytic form. The space-symmetry content of the RGM wave function of the NNN system is given in a form which makes it possible to include NΔΔ, ΔΔΔ, and hidden color states. The norm kernel is used to investigate the role of quark Pauli effects on the central density of $^3$He.

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†Work supported by the U.S. National Science Foundation.

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# Do quark Pauli effects account for the central depression in the $^{3}He$ density?

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Analytic expressions for the RGM norm kernel of the 9-quark NNN system make it possible to examine the role of Pauli effects among quarks. The conclusion is that Pauli effects alone do not account for the central dip in the $^{3}He$ density.

[NUCLEAR STRUCTURE 9-quark model of $^{3}He$]

# Microscopic Calculation of the Parameters of the Interacting Bose-Fermi Approximation for Nondegenerate Orbits

by

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Abstract

Microscopic calculations of the parameters of the quadrupole operator of the Interacting Bose-Fermi Approximation are reported for the realistic case in which the valence orbits are nondegenerate. The results of these exact calculations are compared with those of an approximate formalism and in general reasonable agreement is found.

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** Work supported in part by National Science Foundation - Grant No. PHY-8015342.

# Gamow-Teller strength in the continuum

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Abstract

We present the results of a decomposition of the angular distribution of the continuum observed in the $^{90}Zr(p,n)$ reaction at 200 MeV into different angular momentum transfers. We found significant amounts of $L = 0$ strength over a wide range of excitation energies in the continuum, which sums up to more than half of the missing GT strength.

# The effective quadrupole force between like IBA-bosons

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In the Interacting Boson Approximation[1] (IBA) model the structure of even-even nuclei is described in terms of a system of interacting s- and d-bosons. A boson is regarded as a collective pair of two neutrons or two protons. From the spectra of semi-closed shell nuclei there is strong evidence that there is no, or at most a very weak, quadrupole force between like particles[2] and consequently no quadrupole force between like bosons. It is the strong neutron-proton quadrupole-quadrupole force that gives rise to the collective features of the spectra of medium heavy and heavy nuclei that have both valence neutrons and protons. In a recent paper, however, Dieperink and Bijker,[3] give strong evidence, on phenomenologic grounds, for a strong quadrupole force between like bosons in nuclei where the SU(3) or O(6) limits of the IBA model apply. In this letter it will be shown that this paradox can be resolved by considering the effective interaction which arises from the truncation of the full shell model space to the S-D pair subspace[4] which corresponds to the IBA boson space.

The consequence of the space truncation has been considered by Sage and Barrett,[5] where the effects of the G-pair are studied in a perturbative approach. The G-pair state is a collective $v = 2$, $J = 4$ state and is obviously outside the S-D fermion pair space. A parameter of the IBA-model that has been considered in Ref. 5

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# NEUTRON-HOLE STRENGTH DISTRIBUTIONS IN HEAVY NUCLEI.

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UNIVERSITÉ PARIS-SUD

# Beta-Decay Half-lives of Isotopes Produced in Projectile Fragmentation

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ABSTRACT

Beta-decay half-lives have been measured for eight neutron-rich isotopes produced in the fragmentation of 11.4 GeV $^{40}Ar$ on $^{9}Be$. The experiment used a new measurement technique designed to observe very short half-lives. The previously unknown half-lives of $^{22}O$ (910 $\pm$ 350 ms) and $^{32}Al$ (35 $\pm$ 5) have been obtained, as well as six known half-lives to provide a check of the procedure.

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This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

# (p,n) Reactions on $^{13}C$, $^{14}C$, and $^{14}N$ and The Effective Nucleon-Nucleon Interaction

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# SYSTEMATICS OF THE EXCITATION OF M1 RESONANCES IN MEDIUM HEAVY NUCLEI BY 200 MeV PROTON INELASTIC SCATTERING

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Abstract

In a series of seventeen nuclei ranging from $^{51}V$ to $^{140}Ce$ broad resonance structures are observed at energies between 8 and 10 MeV, nearly mass independent. These resonances have very forward peaked angular distributions which imply that they are populated by an angular momentum transfer of zero. This together with the observed excitation energies suggests an M1 character for these resonances. In $^{51}V$, $^{58}Ni$, $^{60}Ni$, $^{62}Ni$, a sharp peak located at an excitation energy above the threshold for neutron emission is interpreted as a part of the $T_o+1$ component of the M1 resonance. Cross sections are given for all the M1 resonances. For $^{58}Ni$, $^{90}Zr$, $^{120}Sn$ and $^{140}Ce$, an "attenuation" factor for the cross sections is extracted in a DWIA calculation assuming a simple shell model structure for these resonances.

Nuclear reactions : $^{51}V$, $^{58,60,62}Ni$, $^{68}Zn$, $^{90,92,94,96}Zr$, $^{92,94,96,98,100}Mo$, $^{120,124}Sn$, $^{140}Ce(p,p')$, Ep = 200 MeV ; measured $E_x$, $\sigma(\theta)$ for M1 resonances. DWIA calculations.

# Spallation Processes in Astrophysics

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Two major areas were discussed: (1) The creation of the light ($A < 12$) elements and (2) The nature of the processes and sources that produce the galactic cosmic rays (GCR). In addition, techniques for measuring spallation cross sections were reviewed. Some more details:

## 1) Creation of the light elements[1)]

A simple picture of light element creation is consistent with the available abundance of these elements (known, except for $^4He$, to within about a factor of two). $^6Li$, $^9Be$ and $^{10,11}B$ are produced by galatic cosmic ray bombardment of the interstellar medium. (To reproduce the abundance ratio $^{11}B/^{10}B$ apparently requires additional production of $^{11}B$, perhaps by a flux of so far unobserved low energy cosmic rays). Only about 15% of the observed $^7Li$ is produced in this way and a negligible fraction of $^2H$, $^3He$ and $^4He$. These isotopes, however, are produced naturally by the big bang at a density corresponding to a present value of about $5 \times 10^{-31} g/cm^3$. This density implies that the Universe is not closed by baryons as one could also conclude from virial theorem estimates of the masses of small groups of galaxies. Other implications were presented by Dave Schramm.

## 2) The nature of the GCR process and sources[5,6)]

Recently, measurements of the isotopic composition of the GCR have beome available up through mass 30. For example,

Submitted to Nulcear Physics

# Nucleon Scattering from Light Nuclei

# I. The Targets $^{6}Li$ and $^{7}Li$*

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## Abstract

New data for the elastic and inelastic scattering of 24.4-MeV protons from $^{6,7}Li$ are presented and a summary of all the available data for the elastic, inelastic, and charge exchange scattering of 24-50 MeV protons from these same targets is given. The cross section data for $E_p \simeq 25$ and 50 MeV are examined theoretically within the framework of the microscopic folding model and the distorted wave approximation. Standard p-shell wave functions, supplemented by renormalization factors deduced from electromagnetic and β-decay data, are used to describe the target nuclei in these calculations. Results obtained using a phenomenological 1-fm range Yukawa interaction provide information on proton-neutron differences in the quadrupole transitions in $^{7}Li$ and differences in the energy dependence of the spin-flip and non-spin-flip isovector central components of the effective interaction. Results obtained with the more realistic G matrix interaction of Bertsch et al. give a reasonable description of the overall features of the experimental data after 20-60%

Submitted to NIM

# Techniques for Measuring Neutron Scattering Cross Sections With a Beam Swinger

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## Abstract

Techniques have been developed for measuring neutron elastic and inelastic scattering cross sections using a beam swinger based time-of-flight system. The use of the beam swinger has significant advantages at high neutron energies because of the simplification of shielding arrangements and the possibility of using long flight paths to obtain high resolution. Applications have been made to neutron scattering at 30.3 and 40 MeV.

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CONFERENCE SUMMARY*

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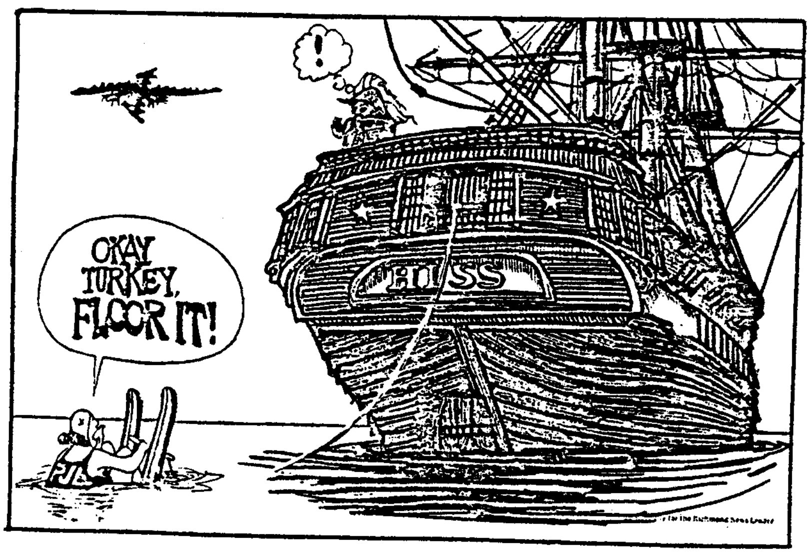
## 1. Introduction

My feelings--and probably yours--at this point are very much like that of the would-be water skier in Fig. 1. He is keen to race off towards the exciting prospects ahead, but at the same time has a sinking feeling at the sheer magnitude and inertia of the driving force. We also should race back to our laboratories to tackle the enormous range of research possibilities we have heard about, but here too the extent is almost overwhelming. For our conference has truly been a massive one. It was also an epic occasion by narrating the heroic exploits in nuclear and atomic physics, in nuclear structure and reactions, in pure and applied aspects, in dealing with some old, but unsolved, problems as well as tackling some of the very latest developments in theory and experiment. These themes of the Conference remind me a little of Romania. On my first night here in Magurele, I observed a striking contrast. Motionless under the stark new




*European Physical Society Conference on Nuclear and Atomic Physics with Heavy Ions (Bucharest, Romania, June 1981): Prepared from tape transcript.

# Isovector E2 Matrix Elements from Electromagnetic Transitions in the s-d Shell: Experiment and Shell-Model Calculations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NUCLEAR STRUCTURE: $17 \leq A \leq 39$ nuclei: comparison of experimental E2 isovector matrix elements with shell-model predictions; extraction of the isovector effective charge; full basis $0d_{5/2} - 1s_{1/2} - 0d_{3/2}$ shell-model wavefunctions; Chung-Wildenthal-Hamiltonians.



ABSTRACT

All available B(E2) values in the mass region $8 \leq Z, N \leq 20$ relevant to the isovector electric quadrupole operator are compared to the theoretical B(E2) values based on Chung-Wildenthal $0d_{5/2} - 1s_{1/2} - 0d_{3/2}$ shell-model wavefunctions with harmonic oscillator radial wavefunctions, and some selected cases are compared with local and energy dependent Woods-Saxon potential wavefunctions. The empirical effective charges deduced from these comparisons are insensitive to differences in mass, state and dominant single-nucleon orbit. The value for the effective charge parameter $e_p - e_n$ extracted in the harmonic oscillator approximation is consistent wiht 1.0e. The values extracted with local and energy-dependent Woods-Saxon potentials, which are more meaningfully related to the underlying structure of the isovector polarizability, are consistent with 0.7e and 0.6e respectively. Some inadequacies in the experimental data and theoretical models are discussed and improvements are suggested.