

SECTION IV

ABSTRACTS OF PAPERS IN PRESS

Inelastic Scattering of  ${}^6\text{Li}$  from  ${}^{58}\text{Ni}$  at 71 MeV

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ABSTRACT

Nine excited states of  ${}^{58}\text{Ni}$  were studied via the  ${}^{58}\text{Ni}({}^6\text{Li}, {}^6\text{Li}')^{\prime}$  reaction at 71.2 MeV. Five sets of optical model parameters for a complex potential of the Woods-Saxon form which gave good fits to the elastic scattering were used to describe the reaction. Two methods were employed to analyze the data. They were the distorted wave Born approximation (DWBA), and the method of coupled channels. A comparison of their predictions and the information they provide about the nuclear deformation lengths is presented. It was anticipated that comparison of the experimental inelastic angular distributions with the theoretical predictions would produce an unambiguous choice of optical model parameters to describe the elastic scattering process. This was not possible, however, because each set of parameters gave equally good fits to the data.

[NUCLEAR REACTIONS  ${}^{58}\text{Ni}({}^6\text{Li}, {}^6\text{Li}')^{\prime}$  for  ${}^{58}\text{Ni}^*$  energies  $E^*$   
= 1.45 , 2.46, 2.78, 3.04, 3.26, 3.62, 3.90, 4.48, and  
4.75 MeV. Angular distributions measured, deformation  
lengths extracted.]

Systematics of Deep Hole States Observed in One and  
Two Particle Transfer Reactions\*

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Abstract

One hole states in orbits below the valence orbits have been observed in a variety of isotope chains using  $(p,d)$ ,  $(d,t)$ , and  $(^3\text{He},\alpha)$  reactions. Broad enhanced structure has also been observed by means of  $(p,t)$  reactions at 42 and 88 MeV on many isotope chains including tin, samarium, and zirconium. The excitation energies, widths, and angular distributions of these structures will be discussed.

\* Paper presented at the International Conference on the Structure of Medium-Heavy Nuclei, Rhodes, Greece, 1-4 May, 1979.

Multipole moments of  $^{154}\text{Sm}$ ,  $^{176}\text{Yb}$ ,  $^{232}\text{Th}$ , and  $^{238}\text{U}$  from proton inelastic scattering

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ABSTRACT

We have measured the inelastic scattering of 35 MeV protons from the nuclei  $^{154}\text{Sm}$ ,  $^{176}\text{Yb}$ ,  $^{232}\text{Th}$ , and  $^{238}\text{U}$ . Angular distributions were extracted for  $J^\pi = 0^+ - 8^+$  members of ground state rotational bands. These data were analyzed using coupled channels calculations for scattering from a deformed optical potential. Searches were made on some of the parameters of this potential, including the deformation parameters  $\beta_2$  and  $\beta_4$ . The multipole moments of the potential distribution were calculated from the parameter values and are compared to the results of Coulomb excitation, electron scattering, and inelastic alpha particle scattering studies. In general, those moments deduced in our investigation agree better with those from Coulomb excitation and electron scattering than with moments deduced from  $\alpha$ -particle scattering. But, we also find the moments from our study to be systematically smaller than those from Coulomb excitation.

NUCLEAR REACTIONS  $^{154}\text{Sm}(p,p')$ ,  $^{176}\text{Yb}(p,p')$ ,  $^{232}\text{Th}(p,p')$ , and  $^{238}\text{U}(p,p')$ ,  $E_p = 35$  MeV; enriched targets, nuclear emulsion plates (7 keV FWHM) and position-sensitive proportional counter (15 keV FWHM), magnetic spectrograph; measured  $\sigma(E_{p'}, \theta)$ ; coupled channels calculations, rotational model; deduced optical model and deformation parameters, quadrupole and hexadecapole moments; comparisons to Coulomb excitation,  $(e,e')$  and  $(\alpha,\alpha')$ , comparisons to Hartree-Fock calculations.

The Mass and Excited States of the New Nucleus  $^{89}\text{Mo}$

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Abstract

The mass excess of  $^{89}\text{Mo}$  has been measured using the  $^{92}\text{Mo}(^3\text{He}, ^6\text{He})$  reaction at 70 MeV bombarding energy. The mass excess was determined to be  $-75.008 \pm 0.015$  MeV. The excited states observed are also reported.

The (p,n) reaction for  $89 < A < 130$  and an anomalous  
optical model potential for sub-Coulomb protons

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Abstract

The (p,n) cross sections were measured from about 2.5 to 5.8 MeV with about 100 keV target resolution for natural Pd, Ag, Cd, In and Te and for  $^{89}\text{Y}$ ,  $^{93}\text{Nb}$ ,  $^{103}\text{Rh}$ ,  $^{105,106,108,110}\text{Pd}$ ,  $^{107,109}\text{Ag}$ ,  $^{111,112,113,114,116}\text{Cd}$  and  $^{125,126,128,130}\text{Te}$ . Systematic uncertainties are about  $\pm 2\%$  for  $^{89}\text{Y}$ ,  $^{93}\text{Nb}$  and the natural targets and about  $\pm 4\%$  for the other nuclei. The isotopic  $\sigma_{p,n}$  are fitted by adjustment in the depth  $W_D$  and diffuseness  $a_D$  of the surface imaginary part of a proton optical model potential (OMP) that was chosen previously to describe precision (p,n) data for isotopes of Sn. The diffuseness  $a_D$  is found to be nearly constant, about 0.4 fm, but the depth  $W_D$  shows a large and systematic A-dependence. A study of the parameter space indicates that at least one OMP parameter must have a strong A-dependence and that  $W_D$  is probably the only such single parameter that will suffice. The explanation of this anomaly is presently unclear.

Pion Production with Heavy Ions from 125 to 400 MeV/nucleon

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LIGHT ATTENUATION IN LIQUID ORGANIC SCINTILLATORS\*

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Abstract

Measurements of the attenuation length of monochromatic light in NE 213 and NE 224 and of the wavelength-averaged attenuation length in NE 213 are given in order to provide the designer of large-volume detectors with information necessary in deciding how large a detector can be constructed without excessive loss of light. In particular, the attenuation length of scintillation light in NE 213 is found to be  $2.16 \pm 0.24$  m.

\*This material is based upon work supported by the National Science Foundation under Grant No. Phy-7822696.



The  $^{194,196,198}\text{Pt}(p,t)$  Reactions at 35 MeV

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ABSTRACT

The  $^{194,196,198}\text{Pt}(p,t)$  reactions have been studied at a proton energy of 35 MeV using nuclear emulsion plates and a high-resolution position-sensitive proportional counter. Fifty states were observed in  $^{194}\text{Pt}$  and  $^{196}\text{Pt}$  and sixty-five in  $^{192}\text{Pt}$ , many for the first time. Angular distributions were measured for many of these levels from  $7^\circ$  to  $60^\circ$  and the results were compared with zero-range DWBA calculations. Several new  $J^\pi$  assignments were made using DWBA and empirical shapes of transitions to well-known levels in Pt and Pb. No new levels, in particular no new  $0^+$  levels, were seen below 1.5 MeV excitation. A new  $0^+$  level at 1.628 MeV was found in  $^{192}\text{Pt}$  and new levels tentatively assigned to be  $4^+$  were seen in all three final nuclei near 1.9 MeV with 15% of the ground state strength at  $7^\circ$  in the  $^{196,198}\text{Pt}(p,t)$  reactions. Enhancement factors were calculated for simple two-neutron pickup configurations. A comparison is made between experimental (p,t) strengths and those calculated in the  $0(6)$  limit of the interacting boson approximation model for  $L = 0, 2$  transitions.

NUCLEAR REACTIONS  $^{194}\text{Pt}(p,t)$ ,  $^{196}\text{Pt}(p,t)$ , and  $^{198}\text{Pt}(p,t)$ ,  $E_p = 35$  MeV; measured  $\sigma(E_t, \theta)$ ; deduced energies,  $J^\pi$ , and strengths; DWBA calculations, comparison with experiment; enhancement factors. Enriched targets, 7 keV resolution (plates); Interacting Boson Approximation Model.

Observation of Particle Alignment in the Octupole Band of  $^{172}\text{Yb}$

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Abstract

Members of the octupole band up to spin  $14^-$  have been identified following the  $^{170}\text{Er}(\alpha, 2n)^{172}\text{Yb}$  reaction. The band is strongly perturbed by Coriolis effects and has a high moment of inertia with variations characteristic of particle alignment. Vibrational alignment is insufficient to explain the data.

THE OCTUPOLE STATES IN  $^{63}\text{Cu}$  AND THE  
PARTICLE-CORE-COUPLING PICTURE

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Abstract

A high-resolution experiment of proton inelastic scattering by  $^{63}\text{Cu}$  at  $E_p = 40$  MeV has resolved three octupole states at  $E_x = 3.81, 3.84,$  and  $3.89$  MeV for the first time, thus showing the existence of seven strong octupole states in  $^{63}\text{Cu}$ . Possible ways of explaining the experimental data are discussed in the particle-core-coupling picture. It is shown that the weak-coupling picture for the octupole states contradicts the ground-state wave function of the conventional particle-core-coupling model.

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\*This material is based upon work supported by the National Science Foundation under Grant No. Phy 78-01684.

THE ENERGY DEPENDENCE OF THE DIFFERENTIAL CROSS SECTIONS  
FOR THE (p,t) REACTION

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Abstract: It is shown that the zero-range DWBA theory is able to reproduce the experimental energy dependence of the differential cross sections for the  $L = 0$  ground-state transition in the reaction  $^{65}\text{Cu}(p,t)^{63}\text{Cu}$  over the incident energy range from 12.6 to 51.9 MeV within a factor of about 2. Use is made of an energy-independent triton optical potential. There is only a very narrow range of choice for the radius parameter of the real central well of the proton optical potential to obtain good fits to experimental angular distributions over the wide energy range. This indicates an inadequacy of the common practice of using standard (average)-fixed-geometry optical potentials in DWBA analyses of individual direct transfer reactions.

\* This material is partly based upon work supported by the National Science Foundation under Grant No. Phy 78-01684.

A SINGULAR PROPERTY OF THE VOLUME-ABSORPTIVE OPTICAL  
POTENTIAL AS USED IN THE ZERO-RANGE DWBA CALCULATION  
OF THE  $(p, t_0)$  ANGULAR DISTRIBUTION\*

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Abstract

Extensive series of zero-range DWBA calculations have shown that the real central well of the volume-absorptive optical potential conventionally used for the triton has characteristically different effects on the calculated  $(p, t_0)$  angular distribution, depending on the relative magnitudes of its radius parameter  $r_{ot}$  and the radius parameter of the neutron-binding potential. Implications of the revealed phenomenon are discussed. A consequence among others is that  $r_{ot}$  cannot be fixed at an arbitrarily chosen value.

\*This material is based upon work supported by the National Science Foundation under Grant No. Phy 78-01684.

Methods for the Production and Use of  
<sup>13</sup>N in Studies of Denitrification<sup>1</sup>

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<sup>1</sup>Contribution from the Dep. of Crop and Soil Sciences, Dep. of Microbiology and Public Health, and the Heavy Ion Laboratory, Michigan State Univ., E. Lansing, MI, 48824. Published as Journal Article No. \_\_\_\_ of the Michigan Agric. Exp. Stn. This work was supported by NSF Grants DEB-77-19273 and PHY-78-01684 and USDA Regional Research Project NE-39. Received \_\_\_\_ Approved \_\_\_\_

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Running head: Use of <sup>13</sup>N in Denitrification Studies

Additional Index Words: nitrous oxide, nitrogen gas, soil nitrogen metabolism

The Influence of Nitrate, Nitrite and Oxygen on  
the Composition of the Gaseous Products of Denitrification in Soil<sup>1</sup>

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<sup>1</sup> Contribution from the Dept. of Crop and Soil Sciences, Dept. of Microbiology and Public Health, and the Heavy Ion Laboratory, Michigan State University, E. Lansing, MI 48824. Journal Article No. 8808 of the Michigan Agric. Exp. Stn. This work was supported by NSF Grants DEB-77-19273 and PHY-78-01684 and USDA Regional Research Project NE-39.

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Running head: Nitrate, nitrite and oxygen influence on nitrous oxide evolution.

Additional Index Words: nitrous oxide, nitrogen gas, soil nitrogen metabolism

Shell-Model Predictions of Alpha-Spectroscopic Factors Between  
Ground States of  $16 \leq A \leq 40$  Nuclei \*

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Abstract

Shell-model wave functions in the complete  $0d_{5/2} - 1s_{1/2} - 0d_{3/2}$  basis space are used to calculate the alpha spectroscopic factors for ground state to ground state transitions in the  $16 \leq A \leq 40$  region. The results are compared to various families of experimental data and to predictions of the SU(3) approximation.

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\*This material is based upon work supported in part by the National Science Foundation.



**Comment on  $\alpha$ -transfer Spectroscopic Factors in  $^{23}\text{Na}$** 

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NUCLEAR STRUCTURE  $^{23}\text{Na}$ ; Calculation of  $\alpha$   
spectroscopic factors in full sd basis;  
comparison with experiment and SU(3).

**Abstract:** Alpha-transfer spectroscopic factors computed from shell-model wave functions for  $^{19}\text{F}$  and  $^{23}\text{Na}$  generated in the full sd-shell model space with the Chung-Wildenthal interaction are in good agreement with experimental  $^{19}\text{F}(^6\text{Li},d)^{23}\text{Na}$  results, contrary to previous SU(3)-type calculations.

## Isobaric Quartets in Nuclei

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### Abstract

The present experimental evidence on  $T = 3/2$  states in nuclei is presented with particular attention to quartets in which the properties of all four members are known. A relation between the masses of the quartet, the isobaric multiplet mass equation, is shown to hold extremely well. The significance of the coefficients of the equation is also discussed.

Ratios of Cross Sections for Elastic Scattering of 30.3 MeV Protons from  $^{40,44,48}\text{Ca}$  - A New Method

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ABSTRACT

Ratios of cross sections for elastic scattering of 30.3 MeV protons from  $^{40,44,48}\text{Ca}$  have been measured using a new method which should be free of most systematic uncertainties. Protons scattered from a mixed metallic target with a thickness of  $100\mu\text{g}/\text{cm}^2$  were detected by a position-sensitive proportional counter in the focal plane of an Enge split-pole spectrograph. Resolution of 8-10 keV (full width at half maximum) permitted identification of the scatterer by the kinematic shift for angles as small as  $30^\circ$ . A standard optical model successfully reproduces the data.

NUCLEAR REACTIONS  $^{40,44,48}\text{Ca}(p,p)$ ,  $E = 30.3$  MeV; measured ratios of  $\sigma(\theta)$ . New technique using mixed target, kinematic shift in spectrograph. Performed optical model analysis.

## THE DECAY OF $^{201}\text{Pb}$

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and

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### Abstract:

$\gamma$  rays emitted in the decay of 9.4-h  $^{201}\text{Pb}$  were studied with Ge(Li) and NaI(Tl) detectors in singles, anti-Compton, anticoincidence, and integral coincidence configurations. The construction of a consistent decay scheme including 66 of the 74  $\gamma$  rays observed in the decay of  $^{201}\text{Pb}$  was also aided by a two-dimensional  $\gamma$ - $\gamma$  coincidence experiment of 4096  $\times$  4096 channels using two Ge(Li) detectors. The proposed levels in  $^{201}\text{Tl}$  lie at 0, 331.15, 692.40, 1098.4, 1134.8, 1157.4, 1238.8, 1277.1, 1290.0, 1330.4, 1401.2, 1420.0, 1445.8, 1479.9, 1575.1, 1617.4, 1639.5, 1672.0, and 1755.3 keV with possible additional levels at 1550.5 and 1712.5 keV. Using existing conversion-electron data, conversion coefficients were calculated and multipolarity assignments proposed for 25 transitions. Based on these multiplicities, photon branching ratios, and  $\log_{10}ft$  values, unique spin and parity assignments have been made for several states and limits placed on others. The resulting decay scheme is compared with recent theoretical calculations of level energies and  $\gamma$  transition probabilities, using the intermediate-coupling unified model.

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†Supported in part by the U.S. Energy Research and Development Administration.

‡Supported in part by the U.S. National Science Foundation.

Production of A=6 and 7 Isotopes in the  
 $\alpha + \alpha$  Reaction

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ABSTRACT

Cross sections have been measured for the production of  ${}^6\text{He}$ ,  ${}^6\text{Li}$ ,  ${}^7\text{Li}$  and  ${}^7\text{Be}$  in the  $\alpha + \alpha$  reaction between 61.5 and 158.2 MeV. The significance of these measurements for theories of lithium nucleosynthesis is discussed.

## THE MSU SUPERCONDUCTING CYCLOTRON PROJECT \*

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The Cyclotron Laboratory at MSU is in the process of designing and constructing a large double cyclotron system for the purpose of providing high quality beams of heavy ions with energies up to 200 MeV per nucleon for lighter heavy ions such as calcium and up to 20 MeV per nucleon for the heaviest particles such as uranium. The 500 MeV first stage cyclotron is at present in the final year of its construction phase; funding for the second stage cyclotron and for a large expansion of experimental facilities and building is expected in fiscal year 1980. The project has been described in a number of previous publications.<sup>1-13</sup> In this paper we restrict ourselves to presenting a broad overview of the project in a brief form along with a statement of project status as of July 1979.

The long-range goals of the project are shown in Figure 1, which gives anticipated beam intensity as a function of energy per nucleon and projectile mass number. The operating range covers interesting new phenomenological regions corresponding to the expected onset of compressional waves in nuclei ("sound") and the expected region of coherent mesic phenomena and doubling of the nuclear density. Operation of the complete facility is expected in late 1983.

In the years 1980 to 1983, the first stage 500 MeV cyclotron will be used as an independent nuclear research instrument; expected intensity contours for operation in

Charge Dependence of Pion Production in  
Heavy Ion Collisions

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In a recent experiment on pion production in heavy ion collisions, Benenson, et al. [1] observed an unexpectedly strong dependence on the charge of the pions. At the highest energy studied, 400 MeV/n, many more  $\pi^-$  than  $\pi^+$  were produced in the forward direction. At the lowest energy studied,  $\sim 100$  MeV/n, the relative yields are reversed, with more  $\pi^+$  produced. The experimental ratios of  $\pi^-$  to  $\pi^+$ ,

$$R_{-/+} = \frac{d\sigma_{\pi^-}/d^3p}{d\sigma_{\pi^+}/d^3p}$$

are quoted in Table I. In ref. (1) the  $\pi^-$  enhancement is explained in terms of the Coulomb distortions of the pion wavefunctions. In this note I include in the same framework an explanation of the low energy result.

My starting point for the pion production rate is the formula

$$W = \sum_f \langle i | H_{\pi N} | f \rangle^2 \rho_f$$

where  $\rho_f$  is the density of final states and  $H_{\pi N}$  is the pion creation part of the nuclear Hamiltonian. The  $\rho_f$  is a product of density of pionic states  $\rho_f^\pi$ , and density of nucleonic states  $\rho_f^N$ . Normalizing the pion wavefunction to plane waves at infinity, the pionic density of states is the usual  $\rho_f^\pi = \frac{d^3p}{(2\pi)^3}$ . The transition

$^{14}\text{C}(p,n)^{14}\text{N}$  AND THE ISOVECTOR TENSOR COMPONENT  
OF THE EFFECTIVE TWO-NUCLEON INTERACTION

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NUCLEAR REACTIONS  $^{14}\text{C}(p,n)^{14}\text{N}$ ,  $E = 35$  MeV; measured  $\sigma(\theta)$ . DWBA analysis,  
deduced tensor force.

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NEUTRON ANGULAR AND ENERGY DISTRIBUTIONS  
FROM 710-MeV ALPHAS STOPPING IN  
WATER, CARBON, STEEL AND LEAD  
AND 640-MeV ALPHAS STOPPING IN LEAD

by

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Elastic Scattering of  ${}^6\text{Li}$  at 73.7 MeV

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ABSTRACT

Angular distributions for  ${}^6\text{Li}$  elastic scattering at 73.7 MeV from targets of  ${}^{58}\text{Ni}$ ,  ${}^{90}\text{Zr}$ ,  ${}^{124}\text{Sn}$ , and  ${}^{208}\text{Pb}$  have been measured. Optical-model parameters for Woods-Saxon real and imaginary volume potentials have been found which describe the data well and exhibit both discrete and continuous ambiguities. For a fixed geometry, the dependence of the optical potentials on Z and A of the target and on the bombarding energy was investigated.

[ NUCLEAR REACTIONS:  ${}^{58}\text{Ni}$ ,  ${}^{90}\text{Zr}$ ,  ${}^{124}\text{Sn}$ ,  ${}^{208}\text{Pb}({}^6\text{Li}, {}^6\text{Li})$ ,

E = 73.7 MeV; measured  $\sigma(\theta)$ ; deduced optical-model parameters.]

SECTION V

THESIS TITLES

(JULY 1978-JUNE 1979)

Department of Physics

Ph.D. Thesis

DeVito, R.P.

Determination of the Coulomb Correction  
and Isovector Term of the Nucleon-Nucleus  
Optical Model Potential From Neutron Elastic  
Scattering at 30.3 and 40 MeV

Department of Chemistry

Ph.D. Thesis

Deason, Paul Jr.

A Study of  $^{192,194,196,198}\text{Pt}$  Using the (p,t)  
and (p,p') Reactions and the Interacting  
Boson Approximation Model

Department of Physics

M.S. Thesis

Williamson, Cecil L.

Elastic and Inelastic Scattering of  $^6\text{Li}$   
from  $^{58}\text{Ni}$

Yurkon, John

Neutron/Gamma-Ray Pulse Shape Discrimination  
in Liquid Organic Scintillators