Section III

Abstracts of Papers Submitted for Publication but not yet published

September 1969

The Michigan State University Cyclotron Computer Facility*

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Abstract

The Michigan State University Cyclotron Computer facility consists of a Scientific Data Systems Sigma-7 computer with a laboratory designed multi-purpose interface. The operating system is a time-sharing supervisor called JANUS which permits safe real-time operation. The computer is available to the laboratory staff 24 hours a day, and it is often serving as many as six users simultaneously. FORTRAN jobs including compiling can be run anytime and have an effective memory of 128k locations. On-line use of the computer is mainly particle identification or one to four parameter pulse height analysis.

Production of the Light Element Lithium, Beryllium, and Boron by Proton Spallation of ^{12}C*

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ABSTRACT

Measurements of the production of the light elements lithium, beryllium, and boron by the proton bombardment of ^{12}C were measured for proton energies between 21.7 and 44.0 MeV. Time-of-flight methods were used to identify the masses of ions recoiling from a thin target into a semiconductor detector. The results are related to current models on the origin of these light elements, and are consistent with a suggestion that the $^{11}B/^{10}B$ isotopic ratio has remained unaltered at its formation value.

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* Work supported in part by the National Science Foundation

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A Single Crystal Ge(Li) Conversion-Coefficient Spectrometer*

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R. E. Doebler and Wm. C. McHarris

Michigan State University

ABSTRACT:

We discuss the design and operation of a conversion-coefficient spectrometer in which a single small Ge(Li) crystal serves as the detector both for γ-rays and conversion electrons. We show a calibration curve for our detector and discuss both its advantages and faults as compared with a spectrometer that uses separate detectors for γ-rays and electrons.

*Work supported in part the U.S. National Science Foundation, by the National Aeronautics and Space Administration, and by the U.S. Atomic Energy Commission.

Neutron-Deficient Members of the A=139 Decay Chain:

II. 4.5-hour Pr^{139}*

D. B. Beery, W. H. Kelly, & Wm. C. McHarris
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ABSTRACT

The γ-rays emitted following the decay of 4.5-h Pr^{139} have been investigated with Ge(Li) and NaI(Tl) detectors in singles and anti-coincidence configurations. Twelve transitions having the following energies (and relative intensities) were observed: 254.7 (53), 1320.0 (13), 1347.4 (100), 1375.7 (33), 1563.6 (9), 1596.6 (10), 1630.6 (70), 1653.3 (8), 1730.2 (1.6), 1818.4 (7.0), 1907.9 (3.5), and 2015.9 keV (3.0). Using energy sums and the anti-coincidence results, we placed states in Ce^{139} at 0 (3/2+), 254.7 (1/2+), 1320.0 (3/2,5/2,7/2), 1347.4 (7/2+), 1596.6 (3/2,5/2, 7/2), 1630.6 (3/2,5/2+), 1818.4 (3/2,5/2+), 1907 (3/2,5/2+), 1984.9 (3/2,5/2+), and 2015.9 keV (3/2,5/2,7/2+). The assignments were made on the basis of log ft values and relative photon intensities. The single-particle vs collective behavior of the states is also discussed.

*Supported in part by the National Science Foundation and the Atomic Energy Commission.

Neutron-Deficient Members of the A=139 Decay Chain:
I. 5.5-Hour Nd^{139m} and 30-Minute Nd^{139g}*

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ABSTRACT

We have studied the γ-rays emitted following the decays of 5.5-h Nd^{139m} and 30-min Nd^{139g} with Ge(Li) and NaI(Tl) detectors in singles, coincidence, and anti-coincidence configurations. Our study has indicated 51 γ-rays accompanying Nd^{139m} decay and 21 that follow Nd^{139g} decay. Of these, 56 have been placed in decay schemes containing a total of 22 excited states. The decay scheme of 3/2+ Nd^{139g} has much in parallel with those of similar nuclei in this region, and states are populated in Pr^{139} at 0 (5/2+), 113.8 (7/2+), 405.0 (3/2+,1/2+), 589.2 (5/2+), 916.8 (1/2+,3/2+), 1074.4 (1/2+,3/2+), 1311.8 (1/2+,3/2+,5/2+), 1328.2 (5/2+), 1405.5 (1/2+,3/2+,5/2+), 1449.5 (1/2+,3/2+,5/2+), and 1501.2 keV (1/2+,3/2+). On the other hand, 11/2- Nd^{139m} decays only 12.7% via a 231.2-keV M4 isomeric transition and independently decays by electron capture to a set of almost completely different states in Pr^{139}. These are at 0 (5/2+), 113.8 (7/2+), 821.9 (11/2-), 828.1 (7/2+,9/2+), 851.9 (9/2+,7/2+), 1024.0 (7/2+, 9/2+,11/2+), 1396.6 (9/2,11/2,13/2), 1523.2, 1624.5 (9/2-,11/2-), 1834.1 (9/2-,11/2-), 1927.1 (9/2-,11/2-), 2048.8 (9/2-,11/2-), 2174.3 (9/2-11/2-), and 2196.7 keV (9/2-,11/2-). Some 80.7% of its decay goes to the last six, and we interpret them as being three-quasiparticle states. It appears that Nd^{139m} is one of a few nuclides whose intrinsic structure forces the preferred mode of decay to go into a three-quasiparticle multiple, i.e. $(\pi d_{5/2})^2(\nu d_{3/2})^{-2}(\nu h_{11/2})^{-1} \rightarrow (\pi d_{5/2})(\nu d_{3/2})^{-1}(\nu h_{11/2})^{-1}$. The three-quasiparticle states are depopulated by numerous enhanced γ-transitions between states in their multiplet and fewer apparently highly hindered transitions to lower states. Thus, the potential exists for extracting information about states near 2 MeV in this nucleus that normally is available only for states near the ground state.

*Work supported in part by the U.S. National Science Foundation and the U.S. Atomic Energy Commission.

A High Precision Goniometer for Charged Particle Spectroscopy*

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ABSTRACT

A high precision goniometer capable of positioning Ge(Li) charged particle detectors with a precision of ±0.02° has been built. This device consists of a 4 foot radius, detector support which rotates outside of a central target vacuum chamber. The main features of the system are described and a summary of the tests to verify its operational capabilities is presented.

A description is also given of the installation of the unit on the beam line, illustrating the precautions which were taken to insure alignment. The performance of this apparatus in studying Ni(p,p') reactions at 40 MeV is discussed.

* Work supported in part by the National Science Foundation.

** In partial requirement for Ph.D. thesis. Present address Argonne National Laboratory.

INELASTIC DEUTERON SCATTERING FROM ^{56}Fe and ^{58}Fe

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ABSTRACT

Angular distributions of inelastically scattered deuterons from ^{56}Fe and ^{58}Fe have been measured at incident deuteron energies of 11.5 and 11.8 MeV respectively using a broad-range spectrograph. The experimental angular distributions have been compared with the results of DWBA calculations using complex coupling and including the contribution from Coulomb excitation. Values of B(E1) have been extracted and in general the spin and parity assignments agree well with previous work.

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Energy Dependence and Spectroscopy in the $^{16}O(p,d)^{15}O$ Reaction*

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Received______________

ABSTRACT

A systematic study of the extraction of spectroscopic factors for the (p,d) reaction on light nuclei and the difficulties encountered in obtaining reasonable DWBA fits to the shapes of the angular distributions has been made. Deuteron spectra and angular distributions were measured for the $^{16}O(p,d)^{15}O$ reaction for 21.27, 25.52, 31.82, 38.63, and 45.34 MeV incident protons. The elastic scattering of protons from ^{16}O was measured over the same energy range and used to obtain proton optical model parameters. Present results indicate that consistent spectroscopic information can be obtained from DWBA calculations when the deuterons in the exit channel have an energy greater than 20 MeV. Approximately 30% of the $1p_{3/2}$ strength appears to be missing from the 6.18 MeV, $3/2^-$ level of ^{15}O and a large fraction of that strength appears in the 9.60 MeV and 10.46 MeV levels. Small 2s-1d admixtures were observed in the ground state of ^{16}O, and excitation of a $7/2^+$ level through a two-step process is indicated.

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*Reserach supported by the National Science Foundation.

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The $^{15}N(p,d)^{14}N$ Reaction at 39.8 MeV*

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Abstract

Energy spectra and angular distirbutions were obtained for the $^{15}N(p,p)^{15}N$ and $^{15}N(p,d)^{14}N$ reactions at 39.8 MeV. Spectroscopic factors were extracted for the levels in ^{14}N populated by ℓ_n=1 pickup and were found to be in excellent agreement with intermediate coupling predictions, which for this nucleus differ only slightly from j-j coupling. A width of 210 ± 30 keV was measured for the $J^\pi = 1^+$, T = 1 level at 13.72 MeV. Angular distributions for other levels populated in the $^{15}N(p,d)^{14}N$ reaction are shown.

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A NaI(Tl) Split Annulus for Coincidence Anticoincidence, Triple Coincidence, and Pair Spectrometry*

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ABSTRACT

An 8x8-in. NaI(Tl) split annulus has been used at MSU more or less routinely for the past three years as an efficient and versatile partner for Ge(Li) detectors in various coincidence experiments. It has been used for Compton suppression, straightforward anticoincidence experiments, triple-coincidence experiments, and for obtaining pair spectra. During these years we have accumulated a rather extensive amount of data illustrating its worth, and we present spectra demonstrating the following uses: a) Compton suppression, both with and without an additional 3x3-in. NaI(Tl) detector inserted in one end of its tunnel to reduce Compton edges further; also with internal vs. external sources. b) Simple anticoincidence experiments, performed routinely at the outset of study of a new decay scheme. c) Efficient triple-coincidence experiments, especially with short-lived activities. d) Double-escape spectra, for very clean separation of weak higher-energy peaks from their backgrounds. e) β^+ feeding, including the study of weak β^+ feedings in the heavy elements. f) More exotic uses, such as with duode Ge(Li) detectors. The advantages of such an annulus and also its limitations and pitfalls (problems from summing and stemming from the extreme differences in efficiency between it and Ge(Li) detectors) will also be discussed.

*Work supported in part by the National Science Foundation and the U.S. Atomic Energy Commission.

Data Acquisition from Simultaneous Experiments Using the MSU Sigma-7 Computer*

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ABSTRACT

The Sigma-7 computer at the Cyclotron Laboratory at Michigan State University forms the basis of a flexible real-time, time-sharing system. The interfacing hardware and time-sharing software are both products of our laboratory and permit simultaneous data taking by as many as four experiments. A typical situation would be an extended multiparameter Ge(Li)-Ge(Li) coincidence experiment running at the same time as a scattering experiment using the computer to identify multiple particles. While these experiments are running one can simultaneously analyze data using a scope, plot data, and run several computations. The computations can be as large as 128K words, permitting such programs as the DWBA code JULIE. Computer control of the Michigan State University Sector-Focussed Cyclotron is partially operational and will be completed in the fall of 1969. Descriptions of the programs of most interest for the acquisition and analysis of spectra resulting from radioactivity will be given, including those for collecting multiparameter spectra and those for spectrum analysis. Programs currently in use for scattering experiments, including ΔE-E and time-of-flight identification, will be discussed in terms of their applicability to on-line spectroscopy.

*Supported in part by the National Science Foundation.

Three-Quasiparticle Multiplets in Nuclei below N=82*

D. B. Beery, R. Muthukrishnan, W. H. Kelly and Wm. C. McHarris
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ABSTRACT

The ε decay of Nd^{139m} has been found to populate a multiplet of six high-lying, high-spin, odd-parity states in Pr^{139}. We interpret this as the configuration of Nd^{139m} being peculiarly suited for populating three-quasiparticle states in its daughter and suggest other nuclei below N=82 that do the same.

*Supported in part by the National Science Foundation and the U.S. Atomic Energy Commission.

The Nuclear Surface and Inelastic Proton Scattering*

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ABSTRACT

Comparisons of the electromagnetic and inelastic proton scattering reduced transition probabilities for the even nickel isotopes are made. It is found that the values obtained for high multipole transitions in the inelastic scattering are extremely sensitive to the nuclear density distribution. This sensitivity is investigated for various phenomenological models of the nuclear density distribution.

*Work supported in part by the National Science Foundation.

Optimization of the Cyclotron Central Region for the Nuclear Physics User*

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The energy spread and emittance of the external beam of a modern cyclotron are largely due to time fluctuations in dee voltage amplitude and to the substantial phase width of the beam—contributions from magnetic field fluctuations or from rf frequency variations are usually much smaller reflecting the high precision with which these latter two quantities can be stabilized. For high resolution applications ($\Delta E/E$ = 1/10,000), nearly all of the beam reaching the users target can be shown to come from a narrow range of rf phase (∿2°) and only at times when the dee voltage matches the "central ray" value to the same accuracy as the energy precision requirement. Background, activation, and thermal dissipation problems are of course all enormously eased if "bad" beam (the beam which will fail to reach the users target) is eliminated at an early stage of the acceleration process which implies that the rf must be accurately stabilized and the beam phase width restricted to a narrow interval. As regards the phase width, a system of slits now in routine use in the MSU cyclotron yield a phase spread of only 1.5° for currents up to 15μa—if the cyclotron is carefully tuned to minimize the energy spread (correcting longitudinal space charge effects) the contribution of the phase width to the energy spread is about 1 in 20,000. With such narrow phase groups the energy spread is dominated by rf fluctuations; experimentally this is vividly evidenced by the transmission thru a 1 in 10,000 analysis which is observed to be twice as high for 0.07% rf ripple as for 0.14%. (The percentage energy spread of the whole beam is also observed to closely match the rf ripple percentage.) Interestingly the gross radial emittance of the external beam is also observed to vary approximately linearly with rf ripply indicating that the normally employed measurement procedure does not actually measure the true emittance but rather a combination of emittance and dispersion. Procedures have been developed to separate these two pheonomena—the resulting true emittance is typically 0.7 mm-mr radially by 5.0 mm-mr axially for the MSU cyclotron. A further interesting by-product of the narrow phase group system is the ability to ex post facto correct data by reading the rf voltage each time a scattering chamber count is recorded, computing the Q value ($=E_{counter}-aV_{rf}$) and thus obtaining high resolution spectra even when the analysis system is set to transmit a much broader energy interval.

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*Supported by the National Science Foundation.

Proposed Michigan State University
Trans-Uranic Accelerator Facility*

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To produce nuclear reactions between uranium and uranium a laboratory bombarding energy approaching 2 GeV is required. The most effective presently known procedure for obtaining the required energetic ions is a two stage process of (1) acceleration in an initial charge state, (2) foil or gas stripping to a higher charge state and (3) final acceleration to the desired energy. As the design charge state for the final acceleration is increased, the size of the pre-accelerator increases and the size of the final accelerator decreases. If the pre-accelerator is a large Tandem VandeGraff, its costs can easily exceed that of the final acceleration and hence both the total cost and many other major characteristics of the facility are strikingly influenced by the choice of transition energy from pre-accelerator to final accelerator. Michigan State University studies indicate the optimum transition point to be at a much lower energy than proposed by other laboratories. The envisaged Michigan State University facility involves a 9 MV Tandem injecting into a 6 sector ring cyclotron with 40 kilogauss-meter maximum bending capability. In such cyclotron uranium ions in charge state 24 will have a final energy of 1.92 GeV. In addition, with appropriate trimming coils, intense, precise, variable-energy beams of protons (600 MeV max), deuterons (360 MeV max), alphas, etc. will be available for nuclear structure research. (The present MSU cyclotron would be used as the "light" ion injector.) The customary objection to such a broadly variable cyclotron—the trim coil power—has already been investigated in detail and found tractable. A total connected power 1.2×10^6 watts will accomplish the necessary trimming. Several novel resonances ($Q_z = 1$, $Q_r = Q_z$, etc.) are involved in the proposed design. These have been investigated including both determination of field tolerances and preliminary design of simple correcting elements.

*Supported by the National Science Foundation.

High Resolution Nuclear Studies using Cyclotron Beams

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The role of high resolution beams and detection systems in the study of the nucleus has been apparent for many years, especially in nuclear spectorscopy, ie the classification of nuclear levels by exictation energies, decay properties, spin, parity, etc. More recently high resolution beams have proved to be essential in the study of Coulomb analog levels. These studies up to now have been the exclusive domain of Electrostatic accelerators, mostly the VandeGraff type which have in many ways the most desirable beam properties. However, as the energy of these machines has been increased, as in the tandem accelerators, the achievement of high resolution has become more difficult for a number of reasons, one of which is the spatial stability of the beam as it emerges from the accelerator.

In this paper it is shown that cyclotrons like the MSU sector focused cyclotron when used with a highly dispersive beam analyser such as the one presently in use in the MSU Cyclotron Laboratory[1] can compete successfully in a field previously reserved to electrostatic machines, and in some instances improve upon such machines. Data will be shown taken at resolution of 1 keV (at 5.2 MeV) resolution[2] and results of an experiment presently in progress to achieve 400 ev resolution at 6 MeV will be shown[2]. The problems of achieving such resolution (ie, aberration in analysing elements) and the quantity of beam available will be indicated. Results of measurement which use dispersion matching with an Enge-type[3] spectrograph will also be shown.

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[1] G. H. Mackenzie, E. Kashy, M. M. Gordon and H. G. Blosser, IEEE Trans. on Nucl. Sci., 450 NS15 (1967).

[2] E. Kashy, R. K. Jolly, F. Trentelman and P. Plauger, to be published.

[3] J. E. Spencer and H. A. Enge, Nucl. Instr. and Methods 49, 181 (1967).

The Longitudinal Space Charge Effect and Energy Resolution*

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ABSTRACT

Considerable interest has developed recently in the construction of Separated Turn Isochronous Cyclotrons for producing high-energy ultra-heavy ions as well as the traditional cyclotron ions. The longitudinal space charge effect in such machines will ultimately limit the currents which can be achieved. An analysis of this effect reveals the existence of a vortex motion within the space charge cloud which decreases the turn separation. Results of detailed calculations on this effect, which include image forces and realistic charge distributions, will be presented and compared with measurements made on the MSU cyclotron internal beam.

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* M. M. Gordon, Nucl. Instr. & Meth., 58 (1968) 245.

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To be submitted to the International Cyclotron Conference

Computer Control of the MSU Cyclotron*

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ABSTRACT

All of the settings needed to run the MSU cyclotron for a given particle and energy are at present calculated in the laboratory's Sigma-7 computer by a program called SETOP. This program also has built into it the ability to turn the knobs on the console to the calculated values. Conventional hand turned Helipots are being replaced by motorized ten-turn Helipots, computer control of which can be bypassed by a switch. The Sigma-7 can control the cyclotron without affecting other computer users. The cyclotron control monitor becomes another of the several tasks which can share the computer's resources. Differential beam current as a function of radius can be taken by the computer and analyzed to give information of the beam properties.

*Research supported by the National Science Foundation.

Cyclotron Beam Pulser for Particle Time-of-Flight Experiments*

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The energy resolution in time-of-flight experiments performed on a cyclotron is limited by the reaction product flight times of approximately 60 nsec associated with the beam microstructure. A scheme for eliminating N-1 out of every N micropulses from the external beam has been developed for the Michigan State University cyclotron. The internal beam is stopped on a collimator on the first one-half turn by applying a DC voltage to a radially deflecting plate located in the dee between the ion source and collimator. A 60 nsec wide pulse, synchronized with the dee voltage, but with $1/N^{th}$ the repetition rate cancels the DC deflection voltage allowing single micropulses through the collimator. Beam currents of 1 μ amp time-average have been obtained with pulse widths of 0.4 nsec at one-tenth the RF repetition rate. By removing a set of phase selecting slits inside the cyclotron, time-average currents of 10 μ amp have been obtained at 10% duty cycle with pulse-widths of approximately 1 nsec. The signal-to-noise ratio of the micropulses is greater than 1000 to 1.

* Work supported in part by the National Science Foundation.

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IV. PhD Theses Completed - July 1968-June 1969

(1) John Kopf - "JANUS: A Realtime Timesharing Computer System for use in Nuclear Physics Experiments"

(2) James Kolata - "Proton Spin Flip in the Reactions $^{12}C(p,p')$ $^{12}C^{*}$ (4.44) and $^{120}Sn(p,p')^{120}Sn^{*}$ (1.17)"

(3) James Snelgrove - "Energy Dependence and Spectroscopy in the $^{16}O(p,d)^{15}O$ and $^{15}N(p,d)^{14}N$ Reactions"

(4) Kenneth Thompson - "Inelastic Proton Scattering at 40 MeV from Even Nickel Isotopes"

V. List of Personnel (Sept. 1969)

A. Faculty

Thelma Arnette
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Henry Blosser
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Morton Gordon
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Charles Gruhn
Edwin Kashy
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