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Title: TANDEM VAN DE GRAAFF PRE-OPERATIONAL RESEARCH

Interim Report Period: 1 January 1968 - 1 October 1968

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October 1968

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INTRODUCTION

Both the nature of the scientific undertakings and the progress in these undertakings generally are proceeding as anticipated in the proposal submitted to the Atomic Energy Commission in October 1967 and revised in January 1968.

The undertakings are split between nuclear physics and atomic physics. Both undertakings involve in-beam experiments. Equipment assembled for atomic physics measurements has proven to be very useful. Theoretical interpretations of previously reported data, particularly in the relevant areas of atomic physics, have been undertaken with considerable success.

SIGNIFICANT RESULTS

Isomer Fission

(Leachman, Friedman ANL, and Graduate Assistants)

Through the cooperation of Associated Midwestern Universities (now Argonne Universities Association) considerable success has been obtained in this undertaking. Measurements are well along at the cyclotron at Argonne.

Although the proposal of October 1967 mentioned the possibility of observing gamma rays from prompt fission in preparation for studies of isomer fission, the availability of the Argonne accelerator for isomer measurements has allowed us to bypass this preliminary undertaking. The study at Argonne has been of the $^{242}\text{Pu}(d,2n)^{242}\text{Am}^m$ reaction leading to fission of the 14-msec isomer. Measurements are made of the energy of the two coincident fission fragments from each

fission. The data are then interpreted in terms of both energies of fission and masses of the fragments.

A very complex chamber to enable these measurements was constructed at Kansas State University and has been in operation at Argonne. Mechanical devices in this chamber enable shielding the detectors from prompt fissions during beam irradiation. Operation of the chamber has been very successful, and about 200 of these rare fission events have been recorded to date under good experimental conditions.

Preliminary results indicated that the isomer fission has a higher probability for symmetric division than does prompt fission. Furthermore, the kinetic energy associated with symmetric division seems anomalously low compared to prompt fission. These results should have considerable bearing both on theories of fission and on theories of nuclear structure at high deformations. To date, little effort has been expended under the contract on theoretical aspects.

Preparations are underway to measure properties of the fission modes of ^{242}Am prompt fission at low excitation energy so that comparison can be made with isomeric fission of the same nucleus at somewhat lower excitation energy. Back-to-back measurements will be made of fragment pairs with semiconductor detectors. For these prompt fission measurements, the reaction $^{241}\text{Am}(n,\gamma)^{242}\text{Am}^*$ will be used with thermal neutrons from the Kansas State University reactor to induce ^{242}Am prompt fission. Construction of a chamber for these measurements is starting in the machine shop.

Computer codes are in preparation for analyses of fission mode data for both the prompt and isomeric cases.

Particle Capture Gamma Ray Studies

Since this is an area of concentration in the proposed program for our tandem operation, considerable effort has been placed on various aspects of nuclear structure study by de-excitation gamma rays.

Gamma Rays From Neutron Capture (Legg, Seaman, Hechtl, Ellsworth, and Graduate Assistants)

Activity is underway at the Triga Mark II reactor of the Nuclear Engineering Department at Kansas State University. The multidimensional 4096 channel analyzer from the Physics Department has been moved to this location. Detectors have been put into operation. A beam collimator has been fabricated in our machine shop and has been placed in the tangential beam port of the reactor. The background radiation level has been reduced to an acceptable amount by proper shielding of the beam port and the gamma ray detectors.

A singles spectrum of gamma rays from ^{47}Ti produced by neutron capture in ^{46}Ti has been obtained. Statistics are low, so that more singles data will be taken. Measurements have been started on the $^{46}\text{Ti} (n,\gamma) ^{47}\text{Ti}$ reaction. It is anticipated that data on the γ - γ correlations resulting from thermal neutron capture by ^{48}Ti will also be obtained by January 1, 1969.

Procedures and programs have been developed for reading the magnetic tapes to print and punch data cards for further analysis.

Doppler Shift Experiment
(Seaman and Graduate Assistant)

Although this undertaking was not explicitly listed in the October 1967 and January 1968 proposals, it is an important part in the clear intention of using the appreciable momenta of accelerated particles, particularly heavy ions, in nuclear and atomic physics studies at the Kansas State University tandem Van de Graaff. The opportunity of starting these measurements now has been made possible by two developments. One is having Dr. G. G. Seaman join the contract after having done similar studies at Rutgers University. The other is the opportunity of collaboration with Dr. Francis Prosser at the University of Kansas 3-MeV Van de Graaff.

The goal is to measure the lifetimes of the states in ^{30}Si by the Doppler shift attenuation method. The first phase of this experiment has been started. Targets have been prepared. Existing equipment at the University of Kansas is scheduled for measuring the excitation functions for population of the first four excited states of ^{30}Si with the $^{27}\text{Al}(\alpha, p)^{30}\text{Si}$ reactions. Computer programs have been prepared for handling data.

(p, γ) Reactions on Analog Resonances in f-p Shell Nuclei
(Legg, Hechtl, Ellsworth, and Graduate Assistant)

An investigation of analog resonances in the $^{48}\text{Ti}(p, \gamma)^{49}\text{V}$ reaction has been made using the University of Kansas 3-MeV Van de Graaff accelerator. This work was temporarily curtailed following the publication by two European groups of the results of their study of this reaction. An investigation of an interesting result of this work has now instead been started. The $p_{3/2}$ analog resonance splits into two close-spaced resonances with

different gamma decay schemes. This has previously been observed in the $^{48}\text{Ca}(p,\gamma)^{49}\text{Sc}$ reaction. Investigations are underway to determine whether this splitting of the $p_{3/2}$ analog resonance into two parts with different decay schemes is a general characteristic of the $p_{3/2}$ analog for similar nuclei in the f-p shell. Grateful acknowledgement is made of the hospitality of the University of Kansas faculty, staff, and graduate students during this work.

(p, γ) Reaction on T = 3/2 Analog Resonances in ^{21}Na .
(Legg, Barse ANL, R. E. Segel ANL, and Morrison ANL)

This undertaking has been in cooperation with Associated Midwestern Universities (now Argonne Universities Association) at the Argonne National Laboratory.

The gamma decay of the first two T = 3/2 analog resonance in ^{21}Na have been observed in the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ reaction. These resonances are observed at proton bombarding energies of approximately 6.87 and 7.13 MeV by use of the ANL tandem Van de Graaff. The decay properties suggest 5/2 and 1/2 respectively for the spins of these resonances. A preliminary search for the analog to the ^{21}F 1.1-MeV state was unsuccessful. Further study of this reaction is planned.

Inelastic Proton Scattering from Odd-A Nuclei (Legg and Yntema ANL).

Inelastic proton scattering from ^{61}Ni , ^{63}Cu , ^{65}Cu , and ^{67}Zn has been studied at a bombarding energy of 14 MeV using the ANL tandem Van de Graaff. It was found that the $\ell = 2$ angular distributions

of the $1/2$ -states are distinctly different from the $\lambda = 2$ angular distributions for states with other spins ($3/2$, $5/2$, $7/2$). Work is continuing to determine whether this final state spin dependence of the angular distributions is a general feature of inelastic proton scattering and, if so, what its dependence on bombarding energy might be.

Atomic Channeling

(van Wijngaarden, Reuther, Bradford, and Graduate Assistants)

As was planned in the proposal, considerable emphasis has been placed on atomic physics studies with accelerators. This has been done both in experimental measurements and in theoretical interpretations of previous measurements.

Through great effort and skill, the group headed by van Wijngaarden and Reuther have assembled a small accelerator designed for studying atomic interactions in solids. This is called the Materials Study Accelerator, which is designed for 150-kV accelerating potential. Most parts have been made in the Physics Department machine shop. A heavy ion source has been designed and built, and the large currents obtainable are more than sufficient for the experiments planned.

The accelerator has been used with various ions at potentials up to 70-kV. An analyzing magnet has been used to assure the mass of the particles. A target chamber with a Vac-Ion pump has been prepared to assure adequate cleanliness of the target surfaces. Measurements have been completed for the sputtering yields from the atomic bombardment of single crystals of gold. By carefully controlling the angle of incident, the experiment allowed studies of the directional effects of sputtering from crystals. Results were obtained for the openness of the channel as a function of both mass

and energy of the particle. These results have been accepted by the Canadian Journal of Physics for publication. Measurements are now underway with single crystals of aluminum to supplement these measurements.

The effort in theoretical studies in this field has also been strong, and the results also have been successful. The experimentally observed oscillations in electronic stopping power, S_e , as a function of projectile mass have been shown to arise from charge distributions of orbital electrons. The Hartree-Fock-Slater model has been used in two approaches to reproduce accurately the oscillating structure. The first approach, based on the Lindhard fermi gas model has been completed. This has been reported at meetings and has been published (Phys. Letters A 27, 318 (1968) and submitted to Phil. Mag.). The second approach using the Firsov collision model is in final stages of computation. The IBM 360 computer in the Physics building has been used.

Charge-Changing Cross Sections and Ionization
(Macdonald, Connor, Betz, and Graduate Assistants)

As noted in the January 1968 revision of the proposal, two small accelerator facilities are more suitable and economical for conducting both the atomic physics studies and ion source developments desired for adequate Pre-Operational research in preparation for the tandem Van de Graaff. One accelerator, discussed above, is primarily for crystalline targets. The Atomic-Interaction Accelerator, which is the additional small accelerator, is primarily for study of interactions between free atoms and so is being instrumented for gaseous targets.

Emphasis was placed on bringing the previously mentioned Materials Study Accelerator into operation for early research. Following that, the Atomic-Interaction Accelerator has now been brought into very limited operation at the time when much of the heavy ion source equipment has just been received. Further modification of the accelerator is now necessary to accommodate this Diode Ion Source from High Voltage Engineering Corporation and the experimental equipment received from our machine shop. This Atomic-Interaction Accelerator is planned for 150-kV, but only a 60-kV voltage supply is now installed. It uses a $\pm 20^\circ$ inflector magnet to allow two different installations of ion sources. The following figure schematically shows the accelerator with one ion source installed, but the charge analysis chamber shown has not yet been constructed.

The Physics Department machine shop has completed two highly adaptable vacuum boxes to allow measurements of charge changing cross sections, ionization, and stopping power. These were designed by E. Feldl. Work is underway to complete instrumentation for measurements.

Theoretical studies of interpretation of experimental data have been undertaken in parallel with experimental preparations. Extensive computer calculations have been made for interpreting existing data of ionic charges as obtained at Heidelberg, Oak Ridge, and Burlington for 5 to 150 MeV. Some results on charge exchange cross-sections and equilibrium charge distributions have already been obtained. Considerable success has been met in deriving semi-empirical formulas as a first order approximation for the cross-sections, which are the basic quantities in heavy ion studies.

Heavy-Ion Source

Inflection
Magnet

Charge Exchange and
Ionization Chamber

Analyzer

Particle
Detector

Fig. 1. Use of the 150-kv heavy-ion facility for measurements of ionization and charge-changing cross sections.

Improved approximations for electron pick-up and loss cross sections are under way in order to understand more complicated charge changing collisions. Emphasis is being placed on obtaining predictions for ionic charge states under any experimental conditions at tandem energies.

Alignment Development with Lasers
(Betz)

Use of phase plates of special design with laser light has been developed to provide convenient and accurate methods of alignment of accelerator components and particularly of experimental apparatus. This activity has occupied a small fraction of one person's time.

PERSONNEL

Dr. G. G. Seaman and Dr. J. R. Macdonald joined the contract on 1 September 1968. Their vita follow. Dr. Macdonald succeeded Dr. A. van Wijngaarden, who returned to the University of Windsor following his sabbatical stay at Kansas State University. Dr. J. N. Bradford has extended his stay on the contract through the year.

PUBLICATIONS, REPORTS, AND TALKS

Worked Performed under this Contract

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4. Directional Effects of Sputtering of a Single Gold Crystal by Heavy Ions, A. van Wijngaarden, E. Reuther, J. N. Bradford, Accepted by Can. J. Phys. for publication (1968).
5. Charge Exchange Cross Sections of Fast Heavy Ions, H.-D. Betz, Bull. Am. Phys. Soc. 13, 614 (1968).
6. A New Technique for High Precision Alignment, H.-D. Betz, Proceedings of the Sixth Proton Linear Accelerator Conference, Brookhaven National Laboratory, May 1968.
7. High Precision Alignment with Laser Light, H.-D. Betz, Submitted to Applied Optics, July 1968.
8. Stopping Power of Gases for ^{127}I and ^{79}Br Ions, L. D. Ellsworth, L. B. Bridwell, L. C. Northcliffe, C. D. Moak, and B. R. Appleton, Bull. Am. Phys. Soc., 13, 703 (1968).
9. Inelastic Proton Scattering from ^{61}Ni , ^{63}Cu , ^{65}Cu , and ^{67}Zn , J. C. Legg and J. L. Yntema, Submitted to Bull. Am. Phys. Soc. for the Miami meeting of APS, 25-27 November, 1968.

Invited Talks on Work Performed under this Contract

1. "New Vistas for University Accelerators", R. B. Leachman, Kansas Academy of Sciences, Lawrence, 3 May 1968.
2. "Collisions of Energetic Heavy Ions with Matter", H.-D. Betz, Van de Graaff Laboratory of High Voltage Engineering Corp., 17 May 1968.
3. "New Calculations of Electronic Stopping Powers", J. N. Bradford, C. P. Bhalla, G. Reese, Presented by C. P. Bhalla at the International Conference on One and Two Electron Atoms, Munich, Germany, Sept. 1968.

1968 Publications by Investigators on other Work

1. "Energy of ^{242}Am and $^{242\text{m}}\text{Am}$ Fission Fragments", B. H. Erkkila and R. B. Leachman, Nucl. Phys. A108, 689 (1968).
2. "Lifetimes of 2+ States in ^{58}Ni ", M. C. Bertin, N. Benczer-Koller, G. G. Seaman and J. R. MacDonald, Phys. Letters 10, 623 (1968).
3. "Erzeugung Negativer Ion in einer Hochfrequenz-Ionenquelle", E. Reuther and K. Bethge, Zeit. f. Angewandte Physik 24, 227 (1968).
4. "Prazisionsjustierung mit Laserstrahlen", Hans D. Betz, Konstruktion, Elemente, Methoden, 5, 65 (1968).
5. "Equilibrium Charge Distributions of KeV Energy Hydrogen and Oxygen Atoms", J. R. Macdonald and H. E. Duckworth, Submitted to Can. J. Physics, 1968.
6. "Total Ionization in Gases of Heavy Ions with KeV Energies", J. R. Macdonald and G. Sidenius, Submitted to Physic Letters, 1968.
7. "Electron Capture and Loss of High Energy Oxygen Ions", F. W. Martin and J. R. Macdonald, Bull. Am. Phys. Soc. 13, 51 (1968).
8. "Three-Body Reactions Resulting from $^6\text{Li} + d$ ", J. C. Legg, W. D. Simpson, and S. T. Emerson, Submitted to Nucl. Phys. (1968)
9. "Elastic Scattering of Protons and Deuterons from Deuterium", J. C. Legg, Arthur Wilson, M. C. Taylor, and G. C. Phillips, Bull. Am. Phys. Soc. 13, 568 (1968).
10. "Effect of Nuclear Stopping on Doppler Shift Attenuation Lifetime Measurements", G. G. Seaman, M. C. Bertin, N. Benczer-Koller, and J. R. MacDonald, Bull. Am. Phys. Soc. 13, 105 (1968).
11. "Lifetimes of Spin 2 States of ^{58}Ni ", M. C. Bertin, N. Benczer-Koller, G. G. Seaman, and J. R. MacDonald, Bull. Am. Phys. Soc. 13, 105 (1968).
12. "Determination of the Reorientation Effect from Thick Target Yields of Natural Cadmium", S. G. Steadman, A. M. Kleinfeld, G. G. Seaman, and J. de Boer, Bull. Am. Phys. Soc. 13, 657 (1968).
13. "Lifetimes of States in ^{58}Ni ", M. C. Bertin, N. Benczer-Koller, G. G. Seaman, and J. R. MacDonald, Bull. Am. Phys. Soc. 13, 724 (1968).

14. "Properties of Low-Lying States of ^{48}Ca ", G. G. Seaman, M. C. Bertin, J. W. Tape, N. Benczer-Koller and J. R. MacDonald. Submitted to the Bull. Am. Phys. Soc. for the Miami Meeting of the APS, November 1968.
15. "Electromagnetic Transition Rates in ^{58}Ni ", M. C. Bertin, N. Benczer-Koller, G. G. Seaman, and J. R. MacDonald. Submitted to the Bull. Am. Phys. Soc. for the Miami Meeting of the APS, November 1968.

Name: James Robert Macdonald

Year Born: 1936

Title: Assistant Professor of Physics

Degrees: B. A. University of Toronto, 1958
Msc. McMaster University, 1964
Ph.D. McMaster University, 1966

Experience: Graduate Research Assistant, McMaster University, 1963-1966
Fellowship Appointment, Niels Bohr Institute, Copenhagen, Denmark, 1966-1968
Guest Physicist, Ioffe Physical Technical Institute of the Academy of Science, Leningrad, USSR, Two months summer 1968.
Assistant Professor of Physics, Kansas State University, Sept. 1968-

Fields of Research Competence:

Atomic Physics, Heavy Ion Research

Professional Publications:

Stopping Cross Sections in Boron, Msc. Thesis, McMaster University (1964)
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Equilibrium Charge Fractions of Hydrogen and Oxygen Atoms Emerging from Thin Films, Ph. D. Thesis, McMaster University, Canada (1966)
Electron Capture and Loss of High Energy Oxygen Ions, Bull. Am. Phys. Soc. 13, 51 (1968) (With F. W. Martin)
Equilibrium Charge Distributions of KeV Energy Hydrogen and Oxygen Atoms, Can. J. Phys. (In Press) (With H. E. Duckworth)
Charge Exchange Cross Sections of Oxygen Ions in Argon at MeV Energies, (In Press) (With F. W. Martin)
Total Ionization in Gases of Heavy Ions with KeV Energies (In Preparation) (With G. Sidenius)

1968

Name: Gregory G. Seaman

Year Born: 1938

Title: Assistant Professor of Physics

Degrees: B.A. College of Wooster, 1959
M.S. Yale University, 1960
Ph.D. Yale University, 1965

Experience: Researcher, Naval Research Laboratory, Summer 1959
Graduate Teaching Assistant, New Haven College, Summer 1961
Graduate Teaching Assistant, Yale University, Spring Semester 1964
Post-doctoral Fellowship, Los Alamos Scientific Laboratory,
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Post-doctoral Fellowship, Rutgers University, 1966-1968
Assistant Professor, Kansas State University, 1968-present

Honorary and Professional Societies:
Phi Beta Kappa
Sigma Xi
American Physical Society

Fields of Research Competence:

Experimental Nuclear Physics
Computer

Professional Publications:

- Emission of Alpha Particles from the System $^{12}\text{C}+^{12}\text{C}$, Bull. Am. Phys. Soc., 6, 470 (1961) (With A. R. Quinton)
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- Collective Excitations in the Even-Even Samarium Isotopes, Bull. Am. Phys. Soc., 9, 108 (1964) (With J. S. Greenberg, D. A. Bromley and F. K. McGowan)
- Fluctuations in the $^{19}\text{F}(\alpha, p)$ Cross Section, Bull. Am. Phys. Soc., 10, 156 (1965) (With G. Dearnaley, W. R. Gibbs, and R. B. Leachman)
- Fluctuations in the $^{23}\text{Na}(\alpha, p)^{26}\text{Mg}$ Cross Section, Bull. Am. Phys. Soc., 10, 463 (1965) (With R. B. Leachman and G. Dearnaley)

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- M1 Transition Probabilities in the Odd Ytterbium Isotopes ^{171}Yb and ^{173}Yb , Phys. Rev., 151, 3, 1004 (1966) (With J. M. Palms and E. M. Bernstein)
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- Further Evidence for Effective Nucleon Spin g-Factors, International Conference on Nuclear Physics, Gatlinburg, Tennessee, (1966) (With J. M. Palms and E. M. Bernstein)
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