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INTRODUCTION

The tandem Van de Graaff has been in increasingly heavy and productive usage for heavy-ion experiments during this year. Both the tandem accelerator and the on-line computer system have undergone modifications to increase their usefulness to experimenters.

PRINCIPAL INVESTIGATOR

R. B. Leachman, principal investigator since the accelerator installation, left Kansas State University in June, 1972, for a two-year leave of absence. James C. Legg was appointed Principal Investigator by Kansas State University to replace Dr. Leachman. The Principal Investigator devoted 40 percent of his time to the project during the academic year and will continue to devote 40 percent of his time to the project during the remainder of the current term. During the summer months of 1971, Dr. Legg devoted full time to the project.

APPLIED PHYSICS PROGRESS

Detection of Trace Elements in Flour Samples

G. G. Seaman and R. Martin

Initial studies of trace elements by observation of characteristic K X-rays with a 1.2-keV resolution thin Ge(Li) detector were limited to heavy elements in concentrations of about 1 part in 10^4 because of intense gamma ray backgrounds. Measurements were then made of the K and L X-rays by using

a Si(Li) detector with better than 200 eV resolution. This is sufficient to measure concentrations down to 1 part in 10^6 in the range of elements from Fe to I, and somewhat less than that for heavier elements. Individual elements are easily resolved. In collaboration with the Grain Science Department, measurements have been initiated on a set of samples from the milling process in order to correlate element composition of flour with the ash content.

ATOMIC PHYSICS PROGRESS

During the year 1972 to date, the Atomic Collision program under the direction of J. R. Macdonald has made significant progress on a large number of experimental programs. Contributions to the program have been made by S. M. Ferguson, M. D. Brown, L. D. Ellsworth, S. A. Savoy, Tang Chiao, L. Winters, and E. Pettus. The atomic physics program was strengthened by the collaborative work of W. W. Eidson and by the addition of C. L. Cocke and P. Richard to the list of faculty doing research in atomic physics using the tandem accelerator.

Measurements of Electron Transfer Cross Sections Along Isoelectronic Sequences for Heavy Ions with $Z < 10$.

At energies from 5 to 50 MeV in single collisions between noble gas atoms and ions with Z less than 10, a systematic study of the dependence of the electron capture and loss processes upon projectile velocity, isoelectronic sequence, and target shell structure is in progress. Results

have been published¹ for fluorine ions and analysis is under way for carbon and nitrogen ions to complement the previously published work with oxygen ions.² Experiments are planned to continue this work with lithium ions to expand the work by Nikolaev³ and to facilitate the understanding of trends along an isoelectronic system. Because of the importance of electron transfer cross sections to the applications of ionization in the atmosphere and heavy ion beam handling, trends determined in these fundamental collisions are being analyzed with theoretical models to develop formulation with general applicability.

Measurement of Charge Exchange Cross Sections for Energetic Heavy Ions with Many Electrons

For heavy ions with $Z > 10$, measurements of charge exchange processes have recently been reviewed⁴ and the collision systems that have been studied are restricted to rather few projectile-target combinations. Because of the importance of shell effects and the wide range of ionic charge state that occurs for these heavy ions, experiments have been planned and equipment development is underway to measure charge-exchange cross sections for a number of heavy ions from chlorine to bismuth in single collision

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1. J. R. Macdonald, S. M. Ferguson, T. Chiao, L. D. Ellsworth, and S. A. Savoy, Phys. Rev. A 5, 1188 (1972); T. Chiao, L. D. Ellsworth, S. M. Ferguson, L. M. Winters, and J. R. Macdonald, Bull. Am. Phys. Soc. 17 621 (1972).
  2. J. R. Macdonald and F. W. Martin, Phys. Rev. A 4, 1965 (1971).
F. W. Martin and J. R. Macdonald, Phys. Rev. A 4, 1971 (1971).
  3. V. S. Nikolaev, Soc. Phys. Usp. 8, 269 (1965).
  4. H. D. Betz, Rev. Mod. Phys. 44, 465 (1972).

conditions in noble gas and molecular targets. The importance of these results for the success of any beam handling system in heavy ion accelerators necessitates the accumulation of reliable charge-exchange data over a broad range of energy and atomic number.

Equilibrium Charge Distributions of Energetic Heavy Ions with $Z < 17$ Emerging from Solid Foils

In connection with the experimental program for the determination of charge-exchange cross sections, equilibrium distributions have been measured over a wide energy range for a number of ionic species emerging from thin carbon foils. This data is not of fundamental interest in understanding atomic collision processes but is necessary in technological applications related to accelerator and experiment design. With all new ion beams that are developed for the KSU tandem accelerator, these measurements will be made.

X-Ray Production Cross-Sections in Single Collisions Between Heavy Ions and Gaseous Atomic or Molecular Targets

The study of X-ray production cross sections for heavy ions in gases and solids has become a rapidly growing field of interest and research in physics. In general, the study of these cross-sections has been limited to dense targets where the initial state of the projectile is unknown because of the many collisions before the interaction which produces the characteristic X-ray. In addition, experiments in dense targets are subject to corrections from projectile energy loss prior to collision and significant absorption of the X-rays emerging from the target prior to detection. It is our belief that cross-section measurements under single collision conditions are

fundamental to understanding the physical phenomena which occur when a heavy ion collides with an atom or molecule. We have initiated a program to study the X-ray production cross-sections in thin gas targets using beams of fluorine, chlorine, and other heavy ions in the energy range from 10 to 60 MeV. In preliminary experiments now under analysis, large unexpected differences have been observed for atomic and molecular targets producing inner shell vacancies in energetic chlorine ions.

Dependence of X-Ray Yields upon the Heavy Ion Charge State in Single Collisions of Heavy Ions with Gas Targets

When a heavy ion collides with a target atom, one of the factors not previously investigated experimentally or theoretically is the charge state of the heavy ion entering the collision. We propose to study the dependence of the X-ray production on the charge state of various incident heavy ion projectiles in single collisions with target atoms or molecules. This study can be done only in gaseous targets. Preliminary measurements with fluorine ions at 36 MeV indicate that the X-ray production cross section in argon, krypton, and xenon increases by a factor of 4 or 5 as the fluorine ion charge state is varied from 5 to 9.¹ This preliminary work indicates the importance of the incident charge state in interpreting all heavy ion collisions. We propose to investigate the general trends of this phenomenon over a wide energy range and with a variety of projectiles.

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1. J. R. Macdonald, M. D. Brown, and L. M. Winters, to be submitted to Phys. Rev. Letters.

Production of Non-Characteristic X-Rays by the Interaction of Heavy Ions and Solid Targets

Recently an X-ray band which is not characteristic of either the target material or the incident heavy ion beam has been reported in collisions of argon ions with solid targets.¹ We have initiated a study of this X-ray band in several solid materials using various ion beams and have measured absolute yields of the X-rays.² By varying the target z , the projectile z , and the projectile energy we intend to investigate the systematics of the production of the non-characteristic X-ray band.

In our preliminary experiments, we have determined that the initial explanation of the X-ray band is at least somewhat in error. The energy threshold, the yield, and the peak shape of the X-ray band will be used to improve on the quantitative explanation of these X-ray bands. Because of the number of workers doing trace-element analysis with heavy ion induced X-rays it is imperative that this phenomenon be thoroughly understood.

Production of X-Rays from Solid Argon Targets

Recently we have produced solid argon targets by solidifying gaseous argon on a suitable material maintained at liquid nitrogen temperature. We propose to study the X-ray cross sections produced by these solid argon targets when bombarded by heavy ion beams. The purpose of this work is to understand the effect that target density has on characteristic X-ray

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1. F. W. Saris, W. F. Van der Weg, H. Tawara, and R. Laubert, Phys. Rev. Letters, 28, 717 (1972).
  2. J. R. Macdonald and M. D. Brown, Phys. Rev. Letters, 29, 4 (1972).

production. It is well known that as the time between collisions is shortened that the projectile is able to carry a considerable excitation of its electron cloud into successive collisions. This so called density effect is responsible for the difference in the equilibrium charge states from gases to solids. It is desirable to determine if this same effect plays a major role in heavy ion X-ray cross sections. Using solid argon targets one can determine the difference between solid and gaseous targets as related to X-ray production.

Spectra and lifetimes of Autoionization Electrons Emitted by Metastable Beams of Highly Stripped Chlorine Ions Following Single Collisions in Thin Gas Targets

Recently electrons emitted from metastable states in beam of fluorine,¹ oxygen,¹ chlorine,² and argon² have been energy analyzed. These beams were excited by passing them through a carbon foil and determining their lifetime by measuring their decay as the foil was moved upstream. We are designing a cylindrical mirror electron spectrometer and associated gas cell to study the lifetime and spectra of these autoionizing states in chlorine. Our desire is to excite these states in a single collision event and measure their cross section. The apparatus is designed to obtain high energy resolution spectra to compare with current theory. Our purpose is to determine

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1. I. A. Sellin, D. J. Pegg, Matt Brown, W. W. Smith and Bailey Donnally, Phys. Rev. Letters, 27, 1108 (1971).
  2. I. A. Sellin, D. J. Pegg, P. M. Griffin, and W. W. Smith, Phys. Rev. Letters, 28, 1229 (1972).

the collision mechanism which produces these metastable states and to determine the cross section as a function of target z and projectile energy.

X-Ray Production Cross Sections in Single Collisions between Protons and Gaseous Atomic Targets

X-ray production in thin noble gas targets by protons at energies from 0.5 to 4.5 MeV have been completed.¹ Comparisons with theoretical ionization cross sections are in very good agreement over most of the energy interval and this gives us confidence in the absolute calibration of the gas target thickness. This calibration will be used to permit normalization of heavy ion X-ray yields for which the X-ray production cross sections are expected to differ significantly from theory.

Inner Shell Vacancy Production in Heavy Ion Collisions at Definite Impact Parameter

Preliminary experiments have been performed to examine the production of inner shell vacancies in 10-25 MeV chlorine ions in fixed impact parameter collisions with carbon atoms. Coincidence techniques have been used between the ions scattered at a given impact parameter and X-ray photons emitted by the decay of the vacancy. Results of the preliminary experiments indicate that this technique will permit a mapping of the distance of approach in collisions for which inner shell vacancy production is important.

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1. Loren Winters, L. D. Ellsworth, Tang Chiao, and J. R. Macdonald, Proc. of Int. Conf. on Inner Shell Ioniz. Phenomena, Atlanta, Georgia, April, 1972 (to be published by North-Holland).

Radiative and Dielectronic Recombination of Electrons Merged with Energetic Heavy Ions

J. R. Macdonald and W. W. Eidson

Of fundamental importance in understanding various physical processes in stellar media and the terrestrial atmosphere is the rate for both radiative and dielectronic recombination of heavy ions and electrons. We have initiated direct measurements of these processes using merged beams of ions and monoenergetic electrons. The small recombination rates that have been theoretically predicted can be measured as a function of center-of-mass velocity in the experimental apparatus that we have designed especially for this experiment. To do this experiment has necessitated high vacuum conditions in the accelerator lower than 10^{-7} torr, and these improvements have been made.

Lifetimes and Charge States of Metastable X-ray Emitters Proceeded in Foil Excitation of High Velocity Heavy Ions

C. L. Cocke, J. R. Macdonald, and Basil Curnutte, Jr.

The observation of long-lived states that decay by X-ray emission have been made in several laboratories in recent months. We have observed these states in two, three, and four electron states of chlorine¹ that have been excited by passing chlorine beams at 40 - 60 MeV through carbon foils. To identify the lifetimes of individual states participating in these transitions, we intend to repeat these experiments with a crystal spectrometer with sufficient resolution to identify specific states. The observation of

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1. C. L. Cocke, J. R. Macdonald, and Basil Curnutte, Jr., Phys. Rev. Letters, 28, 1233 (1972); and in the Proceedings of the International Conference on Inner Shell Ionization, Atlanta, Ga., April 17-24, 1972.

the long-lived X-ray emitters in more than three electron systems was not expected and will be studied further in coincidence experiments between the emitted X-ray and the final charge state of the emitting ion.

Gas Fluorescence of Helium Lines by Protons at Energies from 1 to 5 MeV
C. L. Cocke and J. R. Macdonald

Experiments have been completed to determine the excitation cross sections of several of the optical lines of helium in collisions with protons of energies from 1.0 to 4.5 MeV. The excitation of these lines is highly dependent upon secondary collision processes, and this limits analysis of single collision cross sections to extremely thin targets. The results of this experiment have been compared at an energy of 1 MeV with the work of Thomas and Bent¹ and general agreement has been obtained. The analysis of the data from this experiment is continuing.

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1. E. W. Thomas and G. D. Bent, Phys. Rev. 164, 143 (1967).

NUCLEAR PHYSICS PROGRESS

Determination of Shapes of Deformed Nuclei, John S. Eck
(D. S. Gale)

Heavy-ion scattering just above the Coulomb barrier is dominated by surface interactions, which suggests a means of determining equilibrium shapes of nuclear surfaces. An axially-symmetric surface may be described by $R(\theta) = R_0(1 + \sum_L \beta_L Y_{L0}(\theta))$ where θ is the polar angle measured from the nuclear symmetry axis, and β_L is the L^{th} order deformation parameter. The spacing between successive maxima and minima of the surface distortions of L^{th} order has a mean value of about $\pi R_0/L$. The wavelength of the relative motion between target and projectile must, therefore, be about this value if the L^{th} order term is to influence the diffraction scattering, i.e. $kR_0/RL \geq 1$.

In particular, 30-40 MeV ^{16}O projectiles are especially suitable for measuring the surface deformations of the 2s-1d shell nuclei (i.e. $^{16}\text{O} - ^{40}\text{Ca}$) and have, so far, been used successfully in determining β_2 and β_4 for $^{24}\text{Mg}^{(1)}$ and $^{28}\text{Si}^{(2)}$ from elastic and inelastic scattering cross-sections. It is planned to use this heavy-ion scattering technique further to

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¹J.S. Eck and W. J. Thompson, Nuclear Reactions Induced by Heavy Ions, North Holland Publishing Co. 85 (1970).

²J. S. Eck and D. S. Gale (to be submitted to the Phys. Rev.)

study the surface deformations of ^{18}O .

Study of the Reaction Channels of the $^{16}\text{O} + ^{16}\text{O}$ Systems
J. S. Eck, G. Hinderer, H. H. Rassner, A. Weidinger, K. A.
Eberhard, and E. Mathias

The elastic scattering of $^{16}\text{O} + ^{16}\text{O}$ has been well studied by various groups and the data has been the impetus for many theoretical descriptions of nuclear heavy-ion interactions. In an effort to understand more fully the nuclear heavy-ion reaction channels for this system and the nuclear heavy-ion interaction in general, excitation functions for the $^{16}\text{O} + ^{16}\text{O} \rightarrow ^{19}\text{F}^* + ^{13}\text{N}$, $^{16}\text{O} + ^{16}\text{O} \rightarrow ^{28}\text{Si} + \alpha$, $^{16}\text{O} + ^{16}\text{O} \rightarrow ^{28}\text{Si} + \alpha$, $^{16}\text{O} + ^{16}\text{O} \rightarrow ^{12}\text{C} + ^{20}\text{Ne}$ plus many other reaction channels were measured at 30° and 40° in the ^{16}O bombarding energy range from 50 - 80 MeV using $E - dE/dX$ telescopes. These excitation functions show many prominent resonances and structures which are presently being studied and correlated with the structures in the $^{16}\text{O} + ^{16}\text{O}$ elastic scattering cross sections in an effort to better understand the interaction of two heavy nuclei.

"Better" Methods for Calculating Heavy Ion Scattering Cross-Sections, J. S. Eck, O. L. Weaver, and W. J. Thompson† (B. Doyle)

The present techniques used for calculating heavy-ion elastic scattering cross sections all involve the expansion of the incoming plane wave into partial waves identical to the

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†U. of N. Carolina and TUNL

procedure used for calculating proton and other light projectile nuclear scattering cross sections. In the case of heavy ions, this approach is useful but cumbersome due to the large number of partial waves involved for even modest energy (~ 30 MeV) heavy ion scattering. One approach which has so far proved successful, has been to consider the nuclear potential to be a perturbation on the Coulomb potential and to apply perturbation theory to the total wave function solution of the Coulomb field alone. This approach yields a closed form solution for the differential elastic cross section and yields reasonable results for bombarding energies near the Coulomb barrier, where the approximation, that the nuclear force can be considered as a perturbation on the Coulomb interaction, is expected to be valid.

Another approach presently being attempted is to use spheroidal coordinate systems, as opposed to spherical coordinates, to describe the elastic scattering of heavy-ions from deformed nuclei. In spheroidal coordinates, it is possible to separate the Schrödinger equation in some special cases and furthermore, it is easier to specify the correct boundary condition for scattering from a deformed nucleus.

Measurement of Nuclear Lifetimes of States Excited in Heavy-Ion Reactions, H. Launer and G. G. Seaman (K. C. Shane)

Several reactions will be studied which involve the use of heavy ion beams to populate excited nuclear states in order to measure the lifetimes by Doppler-shift attenuation techniques.

These heavy-ion reactions have two advantages over standard reaction with lighter ions. First, the recoiling nucleus has a much higher velocity, which then is at a higher stopping power. This allows shorter lifetimes to be measured. Second, nuclei not easily reached in other reactions can be studied in this way, or can be reached in various ways so that certain states may be more highly populated. As is generally known, heavy-ion reactions will populate high angular momentum states more readily.

As an example of these two advantages, consider ^{21}Ne , which is now being investigated. Ne targets must be gaseous, which makes measurements of short lifetimes difficult. The lifetimes have been studied in the $^{18}\text{O}(^3\text{He},n)$ reactions,¹ but only lower limits were set on many of the levels. The states in ^{21}Ne can be reached in the following reactions: $^{12}\text{C}(^{13}\text{C},\alpha)^{21}\text{Ne}$, $^6\text{Li}(^{19}\text{F},\alpha)^{21}\text{Ne}$ and $^{11}\text{B}(^{14}\text{N},\alpha)^{21}\text{Ne}$ as well as several others. Levels in ^{22}Ne will also be investigated in this way.

Neutron Transfer Reactions Induced by ^{13}C Beams, G. G. Seaman and H. Laumer (F. R. Keller

Measurements of the total reaction cross section for the reaction $^{19}\text{F}(^{13}\text{C}, ^{12}\text{C})^{20}\text{F}$ have been completed. These were made by observation of the 1.63 MeV gamma rays from the decay of ^{20}F

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¹J. G. Pronko et al, Phys. Rev. 186, 1174 (1969)

with an 11.4 second half-life. Measurements have been made at several bombarding energies for the total reaction cross sections of $^{23}\text{Na}(^{13}\text{C}, ^{12}\text{C}) ^{24}\text{Na}$ and $^{37}\text{Cl}(^{13}\text{C}, ^{12}\text{C}) ^{38}\text{Cl}$. Again, observation of the gamma rays from the decay of the final nucleus provides a measure of the total cross section. Analysis of the data to extract spectroscopic factors is being made by comparison with DWBA calculations.

Stopping Power of ^{20}Ne by Gamma Ray Doppler Shift Measurement, G. G. Seaman (K. C. Shane)

The technique of measuring the Doppler-shifted energy of gamma rays from a moving nucleus has been used to determine the velocity of ^{20}Ne ions before and after passing through an aluminum foil. The ^{20}Ne ions were produced in the $^{12}\text{C}(^{12}\text{C}, \alpha) ^{20}\text{Ne}^*$ reaction. The gamma rays from the first-excited state were measured in a Ge(Li) detector in coincidence with alpha particles scattered to about 170° , for a thin carbon target, and for a carbon target with aluminum backing. The lifetime of the first-excited state is long enough for most of the Ne ions to pass through the aluminum foil before decaying. The stopping power obtained at 19 MeV is in good agreement with extrapolations from other data. This technique is especially useful for measuring stopping powers of ions that cannot be accelerated to energies of about 1 MeV per nucleon.

Measurement of Gamma-Ray Correlations Resulting from the $^{12}\text{C}(^{13}\text{C},\alpha\gamma)^{21}\text{Ne}$ Reaction, J. C. Legg (S. Apostolescu, W. Hartwig, and J. W. Gray)

Angular correlations have been measured for gamma rays which are in coincidence with alpha particles resulting from the $^{12}\text{C}(^{13}\text{C},\alpha\gamma)^{21}\text{Ne}$ reaction at a lab energy of 26 MeV.¹ The information is gathered in the event-recording mode of the two-dimensional on-line computer analyzer. Over five million coincident events have been recorded. The correlations were measured by using Litherland-Ferguson Method II geometry.² Results are in good agreement with previous measurements³ for states below 5-MeV excitation and show the useful ability of heavy-ion reactions to strongly populate highly-excited high-spin or particle-hole states.

Measurement of Gamma-Ray Correlations Resulting from the $^{11}\text{B}(^{12}\text{C},\alpha\gamma)^{19}\text{F}$ Reactions and Other Planned Correlation Studies, J. C. Legg (W. Hartwig, J. W. Gray)

As a result of the evident success of the $^{12}\text{C}(^{13}\text{C},\alpha\gamma)^{21}\text{Ne}$ experiment, a full-scale program of heavy-ion reaction gamma-correlation studies is being undertaken. The second reaction

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¹J. C. Legg, S. Apostolescu, W. Hartwig, and J. W. Gray, Bull. Amer. Phys. Soc. 17, 529 (1972).

²A. E. Litherland and A. J. Ferguson, Can. J. Phys. 39, 778 (1961).

³A. J. Howard, J. P. Allen, D. A. Bromley, J. W. Olness, and E. K. Warburton, Phys. Rev. 157, 1022 (1957). J. G. Pronko, C. Rolfs, and H. J. Maier, Phys. Rev. 186, 1174 (1969).

for which preliminary data has been obtained is the $^{11}\text{B}(^{12}\text{C},\alpha\gamma)^{19}\text{F}$ reaction. Again, preliminary results are very encouraging. Particle detectors have been ordered so that future measurements can be made on gamma-ray correlations with reaction protons, deuterons, and alpha particles resulting from heavy-ion induced reactions with various target.

$^{76}\text{Se}(p,p)^{76}\text{Se}$ Analog Resonances, J. C. Legg (J. W. Gray)

Proton elastic scattering excitation curves have been obtained in the range of bombarding energies from 3.0 to 4.5 MeV. Several resonances were observed which could be identified as analogs of states in ^{77}Se . Six resonances were observed for which resonance parameters could be extracted. These lie in the bombarding energy range from 3.7 to 4.4 MeV and are identified as isobaric analogs of ^{77}Se states with excitations between 0.53 MeV and 1.27 MeV. Analysis of these results is underway to obtain spectroscopic factors for comparison with stripping experiment results.

Fission Modes from Proton-Induced Fission of Thorium and and Protoactinium, R. E. Leachman (C. W. Woods, C. Rudy)

Fission of bismuth and lighter elements is symmetric, while fission of uranium and heavier elements is asymmetric. Fission of radium provides a triply peaked mass yield resulting from a combination of symmetric and asymmetric fission. A search was made for evidence of symmetrical fission yields in fission of

isotopes of thorium and protoactinium.

Measurements have been made with 8- to 13-MeV protons inducing fission. Energies of the fragment pairs were detected by semiconductor detectors and recorded on the PDP-15 computer. Fission of ^{232}Th by the higher-energy protons resulted in a small peak of symmetric fission yield, especially for higher-energy proton bombardment and for those fission modes in which the total kinetic energy of fission is small. This confirms findings by Ferguson *et al.*¹ We have also found a pronounced symmetric fission yield of this nature for a ^{230}Th target and a much lesser effect for a ^{231}Pa target. Analysis of these results is in progress.

EXPERIMENTAL APPARATUS

ON-LINE COMPUTER, G. W. Hartnell, H. Irvin, G. G. Seaman, and F. R. Keller

The DEC writer units originally ordered with the PDP-15 computer instead of teletype units were finally received in June, 1972. (Teletype units had been used until then.) Hardware modifications were made to the interface to be able to use the 30-character-per-second speed of the DEC writers.

The foreground data acquisition program was made easier to use by installation of thumbwheels and switch options to manipulate display parameters without typewriter interaction.

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¹R.L. Ferguson, F. Plasil, and H.W. Schmidt, ORNL 4513, 79, (1969).

A second storage oscilloscope was added so that the "background" user in the time-showing system could get visual displays of data and could plot fitted functions.

An incremental, IBM-computable magnetic tape unit was also added. Coincidence data acquired as events (pairs of ADC addresses) have been stored on DEC tapes, which have a limited capacity. (Some experiments have filled as many as 25 DEC tapes in a day.) The incremental tape unit can contain many more events, and has the additional feature of allowing the extensive sorting required to be performed more quickly at the university computing center. A diagnostic routine has been written, and software interface programs are under development.

A hardware modification has been made to the line printer to allow software control of the number of lines printed per page. This has been useful in using the line printer for making fast graphs of data.

A multi-scaling provision has been built by simulating an ADC output address upon external command. The unit includes manual selection of channel range, and external channel advance.

Development of a High Temperature Hollow Cathode Positive Ion Source, J. R. Macdonald

To obtain stable operation of keV heavy ion accelerators and injectors with high intensity beams of metallic ions, the problem of electrical loading and beam contamination from carrier gases is difficult to overcome. To attain good high vacuum

operation, a high-temperature-hollow-cathode ion source of the Sidenius type¹ has been designed, constructed and put into operation on the KSU 150 keV heavy ion accelerator. In this source, operating temperatures up to 2800°C have been maintained permitting the extraction of most metallic ions from the vapor phase without a carrier gas. In preliminary tests with copper, more than 100 μ a of beam has been extracted with accelerator pressures less than 10^{-6} torr, and similar results are expected for many other elements when the application to use them arises. This source is now being used in a study of the production of non-characteristic X-rays in heavy ion collisions.

Development of an Alkali Charge-Exchange Cell for Negative Ion Formation, J. R. Macdonald

For the production of negative heavy ions for injection into tandem Van de Graaff accelerators, resonant charge exchange in alkali vapor has been used effectively in a number of laboratories, particularly for helium beams. With the heavy ion program at KSU, an exchange cell has been designed and is under construction incorporating precision temperature control of the lithium oven and a crossed beam technique to avoid beam tube contamination. To provide for velocity matching with the ion optics of the tandem accelerator, post acceleration of the negative ions from the exchange chamber to greater than 150 keV

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¹B. Sidenius, Nuc. Inst. and Meth., 38, 19 (1965).

has been included. A hollow cathode high temperature positive ion source will be used to develop beams of heavy ions useable with the tandem Van de Graaff.

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A Reaction Chamber for Isomeric Fission Measurements, E. J. Feldl and R. B. Leachman, Nucl. Instr. and Meth. 101, 563 (1972).

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Metastable X-Ray Emitters Produced in Beam-Foil Excitation of Fast Chlorine Beams, C. L. Cocke, B. Curnutte, and J. R. Macdonald, Phys. Rev. Lett. 28, 1233 (1972).

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Experimental Determination of Electron-Transfer Cross Sections for Fluorine Ions in Nitrogen at Energies from 4 to 54 MeV, J. R. Macdonald, S. M. Ferguson, T. Chiao, L. D. Ellsworth, and S. A. Savoy, Phys. Rev. A5, 1188 (1972).

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Lifetimes of Metastable X-ray Emitters in Helium-and Lithium-like Chlorine, C. L. Cocke, B. Curnutte, and J. R. Macdonald, Nucl. Instr. and Meth. (in press).

An Elementary Approach to Coupled Channel Equations, Douglas S. Gale, submitted to American Journal of Physics.

Nuclear Deformation of ^{28}Si from $^{16}\text{O} + ^{28}\text{Si}$ Elastic and Inelastic Scattering, D. S. Gale and J. S. Eck, submitted to Physical Review.

The Proton Optical-Model Potential Near the Coulomb Barrier, J. S. Eck and W. J. Thompson, submitted to Physical Review.

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