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Annual Progress Report

for the period

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Research in Heavy-ion Nuclear Physics

MASTER

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I. Introduction.

We have continued to focus our attention during this past year on the fission process in light nuclear systems. By studying this process we can probe the behavior of nuclei in very deformed configurations and learn about the interplay of nuclear structure and dynamics in these configurations. In our last annual report we discussed a model calculation, based on the transition-state model of nuclear fission, that was found to reproduce many of the experimentally observed fission systematics in systems with $40 \leq A_{cn} \leq 80$. This year we have confronted this model with additional measurements and have extended its application to even lighter mass systems.

At the time of our last annual report we had just completed a measurement of high-resolution excitation-energy spectra for fission fragments resulting from the $^{24}Mg+^{24}Mg$ reaction. This year we have completed the analysis of this measurement and have prepared a draft of a paper discussing the results. In an earlier analysis of fission from the $^{32}S+^{24}Mg$ reaction we observed surprising structure in the excitation-energy spectrum of the mass-symmetry breakup into two ^{28}Si fragments. We find even more pronounced structure in the symmetric and near-symmetric fission channels from the $^{24}Mg+^{24}Mg$ reaction. This behavior is particularly significant since the cross sections and mean excitation energies in these channels are well described by the transition-state calculations. The mechanism that leads to the focusing of the fission cross sections into only a few mutual excitations is not understood and is an area that we are actively investigating. Resolving this behavior is likely to have a significant impact on our understanding of the dynamical and structural aspects of fission in light systems.

The $^{24}Mg+^{24}Mg$ experiment is also significant as the first measurement where we have made use of our large Bragg-curve detector. This detector performed well and was an important component of the experimental arrangement. We have continued our detector development effort, however, along two lines of research.

To make the Bragg detector even more useful, we have modeled its response from the stage where the heavy-ion stops in the detector to the final voltage pulses out of the Bragg-peak amplifiers. This analysis has given us significant insight into the expected behavior of the Bragg, suggesting ways to optimize the detector response, and has also enabled us to determine, *a priori* , its useful dynamic range for all of the heavy-ions stopping in the detector. This latter ability enables us to set the proper voltages and gas pressures for a given measurement without having to loose valuable beam time trying to empirically determine these parameters.

Our second detector development effort, which was suggested during our last annual report, was to instrument the Bragg detector with an internal position-sensitive, multi-wire proportional counter (MWPC). In this configuration we can avoid the energy losses and multiple-scattering effects associated with using a separate MWPC to determine the particles

angle-of-incidence on the detector. This hybrid MWPC–Bragg-curve detector is now completed and has been tested with radioactive sources.

For the past two years we have been waiting to run a particle-γ coincidence measurement of the fission products from the $^{40}Ca+^{16}O$ reaction as a follow-up to our earlier $^{32}S+^{24}Mg$ particle-γ run reaching the same ^{56}Ni system. This experiment has been delayed because of the need to install an active radiation monitoring system at the ATLAS facility for safety reasons. Our wait finally ended last month. Instead of running the $^{40}Ca+^{16}O$ reaction, however, we obtained approval to change the measurement to use the $^{36}Ar+^{12}C$ reaction, reaching the ^{48}Cr compound system. This change was motivated by the results obtained in our $^{24}Mg+^{24}Mg$ experiment, also populating the ^{48}Cr compound nucleus, and the greater experimental simplicity associated with the $^{36}Ar+^{12}C$ reaction now that the positive-ion source is operational at ATLAS. Although we have only just begun the data reduction, from what we were able to see on-line it appears that this experiment was very successful.

We have also made progress on two on-going analyses during the year. We have developed the necessary software to allow a fully self-consistent analysis of our earlier $^{32}S+^{24}Mg$ particle-γ experiment using the measured absolute efficiencies of the γ-ray detectors. Our goal, which has now been achieved for the lower-lying mutual excitations, is to be able to determine the actual cross sections for specific mutual excitations comprising the fission yields. Although counting statistics limit how well we will be able to unfold the measured spectra, we believe this is an important analysis for determining the significance of the structures observed in the excitation-energy spectra. To our knowledge, this is the first time that such an analysis has been done for fully energy-damped reaction yields. The programs that have been developed can be used immediately for our more recent $^{36}Ar+^{12}C$ experiment where, because of better experimental Q-value resolution and a lower density of states in the fragments, the analysis should be considerably simpler.

We also completed last year the analysis of the singles data and started work on the particle-particle coincidence data for a measurement of the fission cross sections from the $^{29}Si+^{27}Al$ experiment at $E_{lab}(^{29}Si) = 120$ and 170 MeV. Our plan is to use these results as the principal experimental test of the Nilsson-Strutinski corrections to the saddle-point energies that we are currently working on. This is the most complete measurement of the overall fission cross sections and average energies yet accomplished in any system and should allow for a detailed test of the model calculations that we are developing.

For the past several years we have been investigating the limits to fusion in light nuclear systems. As one aspect of this work we have been collaborating with several groups on studying the limits to fusion for ^{28}Si induced reactions on a variety of targets. This project is nearing completion and the results are being prepared for publication. We have also been exploring the possibility of studying the temperature limitation to fusion in light systems, as opposed to the angular momentum limits typically studied using heavy-ion reactions. Unfortunately, after simulating a number of possible reactions, we have come to the conclusion that an unambiguous measurement of such a temperature limitation would be very difficult, and may not be currently feasible. The difficulties posed by these studies will be discussed later in this report.

With completion of data acquisition for the $^{24}Mg+^{24}Mg$ and $^{36}Ar+^{12}C$ experiments, our two senior student (A. Hasan and K. Farrar) are now in the final stages of their doctoral work and we expect both of these students to complete their dissertations this calendar year. The program was unfortunate to loose a more junior student (D. Zhou) who decided to leave Kansas after completing his masters degree, but we have been able to attract a new doctoral student (D. Desbien) who has played a major role in the design and construction of the MWPC for our hybrid detector.

At the end of this report we have incorporated the front page of a paper that appeared in print and complete copies of papers that were prepared during the year.

II. Research Program.

A. Global fusion-fission systematics in light nuclear systems.

Over the past several years we have been involved in developing the global systematics of the fission process in light systems. While this project was largely brought to completion last year with the publication of a consistent model calculation for the fission of light systems[1] that does an excellent job in reproducing the experimental behavior, we have been involved this past year with additional tests of the model predictions and we have also extended the scope of our investigation to lighter systems. The success of this model in describing the data from a wide range of reactions gives us confidence in its essential correctness, and allows us to use its predictions in discriminating among different reaction processes.

A.1) Study of ^{47}V fission as populated through multiple entrance channels.

Working with the Strasbourg group (C. Beck *et al.*) we have been studying the entrance-channel dependence of ^{47}V fission. Fusion-fission cross sections have now been measured for this systems using the $^{35}Cl+^{12}C$, $^{31}P+^{16}O$, and $^{23}Na+^{24}Mg$ reactions. In earlier measurements of damped reaction yields from the $^{28}S+^{12}C$ and $^{24}Mg+^{16}O$ reactions[2] no evidence was found for an entrance channel dependence of the ratio of $^{16}O/^{12}C$ yields, as had been observed earlier when comparing the large-angle yields from the $^{28}Si+^{12}C$ and $^{24}Mg+^{16}O$ reactions.[3]. In a more recent experiment the Strasbourg group has studied the more symmetric mass entrance channel $^{23}Na+^{24}Mg$ to test the compound nucleus hypothesis of the lack of entrance channel memory on the final fragment ratios. We have been working with the Strasbourg group on performing the transition-state model calculations for the various measured systems.

The ratio of oxygen to carbon yields for different channels leading to ^{40}Ca (top pane) and ^{47}V (bottom two panes) are shown in Figure 1. The predicted ratio for these various systems based on the transition-state calculations[1] are shown by the dashed lines. The ^{47}V systems are all found to be reasonably well described by the model calculations with little dependence of the oxygen/carbon ratio on the entrance channel. This is clearly in contrast with the results for the ^{40}Ca systems. These data suggest that an additional "orbiting" mechanism is present in the ^{40}Ca systems.

A paper discussing these results in greater detail is bound at the end of this report.

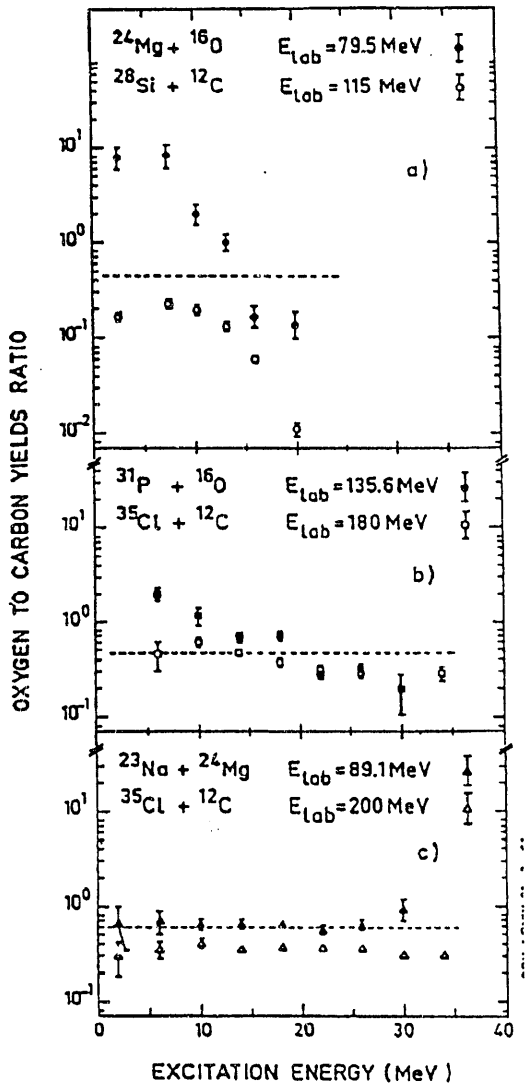


Figure 1. Ratio of oxygen to carbon yields for different entrance channels reaching the ^{40}Ca (a) and ^{47}V (b,c) compound systems. The dashed lines are the calculated ratios based on the transistion-state model.

A.2) Extension of the fission systematics to A ≈ 28 systems.

In our earlier work to develop the fission systematics of light nuclear systems we restricted our considerations to compound nuclei of mass A≥40. This lower limit was based on the concern that for even lighter systems the spin and mass-asymmetry dependent saddle-point energy calculations that are essential components of the transition-state calculations may not be valid.[4]. For these very light systems the potential energy surface becomes very "soft" to non-physical deformations and it becomes difficult for the calculations to converge on appropriate saddle-point configurations.

Experimental studies done by the São Paulo group (A. Szanto de Toledo *et al.*) of the binary reaction products for different reactions reaching compound nuclei with A≈28, however, find behavior very similar to that seen for the fusion-fission process in somewhat heavier systems. Encouraged by the success of the transition-state calculations in the mass

$40 \leq A_{cn} \leq 80$ range we have been working with the São Paulo group to extend these calculations into their mass range.

To determine the fission barrier energies in the lighter systems we are using the double-spheroid approximation that was developed as a parameterization of the full macroscopic energy calculation.[1]. Although the calculations of mass-asymmetric fission barriers is difficult in the lighter systems, we have been able to check the double-spheroid parameterization against the full energy calculations for the mass symmetric saddle points of ^{28}Al and find good agreement. Since for lighter systems the saddle-point configuration approaches the shape of two touching spheroids, the double-spheroid approximation may be expected to reproduce the main features of the barrier dependence on spin and mass asymmetry.

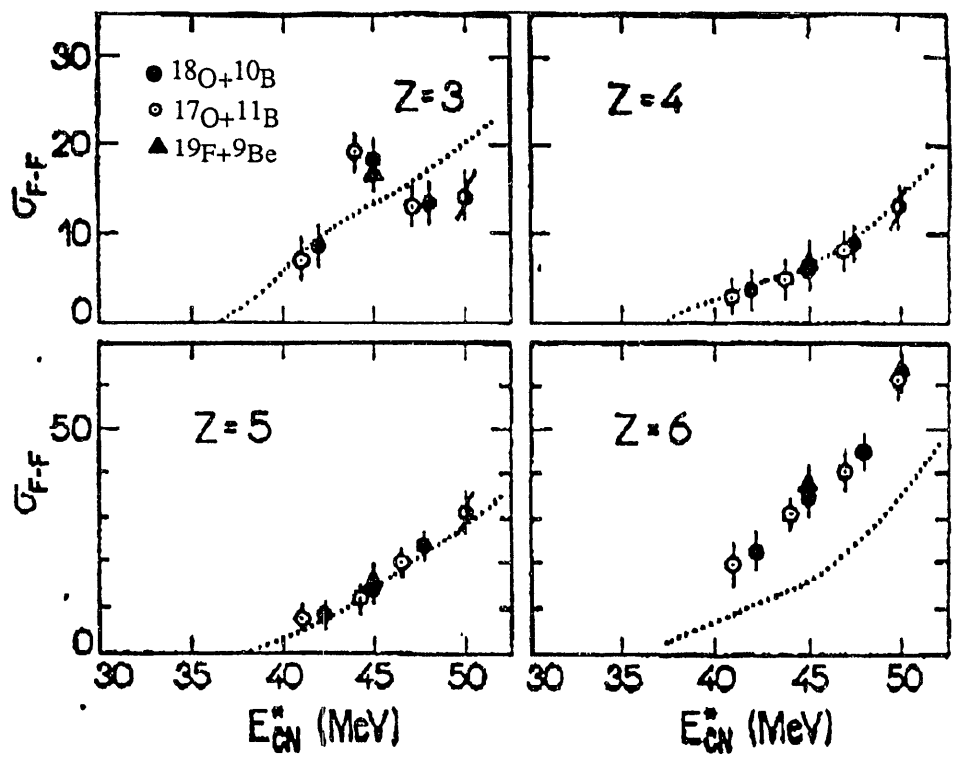


Figure 2. Fusion-fission cross sections for three systems reaching the ^{28}Al compound nucleus as a function of the compound-nucleus excitation energy. The dotted curves are the results of the transition-state calculations.

In Figure 2 we show the strongly energy damped yields (Z=3,4,5, and 6) for three different reactions reaching ^{28}Al as a function of the compound-nucleus excitation energy. The dotted curves represent the transition-state model calculations. Remarkably good agreement is found between the calculated and experimental results. It might be noted that even with the low number of nucleons comprising the compound system, the statistical requirement of large level densities is satisfied with these reactions. Two papers have been prepared on this work and are bound at the end of this report.

A.3) Fusion-fission in the $^{29}Si+^{27}Al$ system

Several years ago we performed a complete measurement of the fission cross sections from ^{56}Co as populated with the $^{29}Si+^{27}Al$ reaction at E_{lab} = 125 and 160 MeV. The original stimulus for the measurement was to compare the fission mass distribution from ^{56}Co to that measured earlier for the ^{56}Ni compound nucleus.[5]. With the development of the transition-state model calculation[1] (which does a very good job in describing both the ^{56}Ni and ^{56}Co results) and the measurements of Beck *et al.*[6, 7] developing the entrance channel dependence of ^{47}V fission, our principal interest with the ^{56}Co data has now shifted to one of developing the detailed isotopic mass dependence of the primary (before secondary light-particle evaporation) fission cross sections for a system. We would like to have such a precise measurement to test the next generation of light-nucleus fission calculations where we hope to include realistic shell corrections to the saddle-point energies.

The $^{29}Si+^{27}Al$ experiment consisted of a series of 400 mm^2 Si(Surface Barrier) fission detectors on one side of the beam path with two large-area MWPC located so as to measure the binary fragments in coincidence with these detectors. In addition a Bragg-curve detector was located behind the forward MWPC (which was configured in a transmission geometry). With this detector arrangement we can obtain mass (using time-of-flight) and charge (from the Bragg-curve detector) identification of the reaction fragment and are also able to deduce the primary mass distributions based on the particle-particle coincidence data from the Si detectors and MWPC's.[8] We had largely completed the analysis of the singles data last year and have now started on the analysis of the coincidence data. In Figure 3 we show examples of the angular distribution ($d\sigma/d\theta$) for a number of different mass channels based on the Si(SB) detectors.

Although we had hoped to be further advanced on the analysis of the coincidence data, we have suffered a delay on this project with the departure of the graduate student who was doing the analysis. Fortunately, most of the necessary calibrations of the coincidence detectors has been completed and we expect to be able to finish the analysis during the upcoming year.

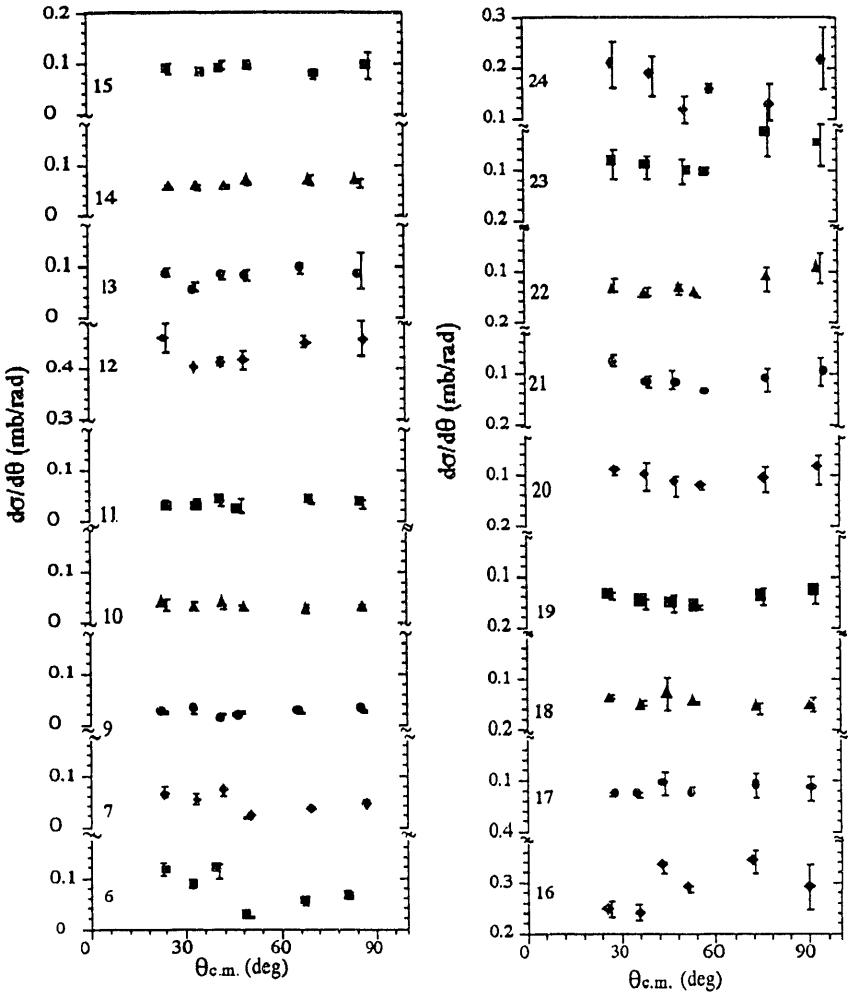


Figure 3. Angular distributions for different mass channels of the $^{29}Si+^{27}Al$ reaction at E_{lab} = 125 MeV.

B. Structural aspects of light nucleus fission

The next major challenge in studying the fission of light nuclear systems is to determine the role of nuclear shell structure on this process. We are exploring this aspect of the problem with both theoretical and experimental programs and have made progress during the year along both of these avenues of investigation.

B.1) Nilsson-Strutinski calculations

In calculating the general trends of the mass and energy distributions from the light-nucleus fission process we have used a transition-state model based on the macroscopic saddle-point energy. The microscopic shell structure of the nucleus is only introduced in the calculation through a Wigner energy correction to the saddle-point energy. Although this correction does lead to overall good agreement between the calculations and the reported experimental mass distributions, it is clearly too crude of a shell correction to be able to reproduce the details of these distributions.

We are now planning to introduce shell corrections based on the Strutinski method[9] into the calculation of the saddle-point energies in light systems. Our intent is to use either an averaged or summed correction for the two nascent fission fragments in our minimization procedure that searches for the spin- and mass-asymmetry dependent saddle-point energies based on the finite-range model.[4] During the past year we developed and tested the routines necessary for the Nilsson-Strutinski calculations. We hope to start with the full calculations within the next month.

B.2) High-resolution Q-value measurement for the $^{24}Mg+^{24}Mg$ reaction.

One of our major efforts during the past year has been to complete the data reduction and analysis of an experiment measuring high-resolution Q-value spectra for the $^{24}Mg+^{24}Mg$ reaction. This experiment, which was run shortly before the submission of our last annual report, was motivated by the structure observed in the excitation-energy spectra for the symmetric fission of ^{56}Ni, as populated with the $^{32}S+^{24}Mg$ reaction. For our earlier measurement we had not expected significant structure in the excitation-energy spectra and therefore had not optimized the experimental arrangement to observe such structure. Since the observation of structure in the Q-value spectra suggests the influence of the nuclear shell structure at scission, we are very interested in understanding this behavior.

The $^{24}Mg+^{24}Mg$ experiment was designed to obtain high-resolution Q-value spectra for the symmetric and near-symmetric ^{48}Cr fission channels as well as establish the overall fusion and mass-dependent fission cross sections for this reaction. The experimental arrangement for the experiment is shown in Figure 4. Two MWPC's were operated in a coincidence geometry to obtain the Q-value spectra. From the angles and relative time-of-flight of the fission fragments it is possible to deduce the exit channel masses. The observed mass spectrum is shown in Figure 5. Once the mass is determined, the reaction Q-value can be deduced from the angle measurements, alone. The experimental Q-value resolution is then determined primarily by the angular resolution of the detector and multiple-scattering effects in the target.

The experimental arrangement also included a number of Si(surface barrier) detectors at more forward angles which were used to establish the total evaporation-residue cross section. This is important to determine the partial-wave idstribution that is to be used in the fission-model calculation. The summed experimental cross sections for evaporation-residue production and fission, giving the total fusion cross section, allows us to normalize the area under this distribution.

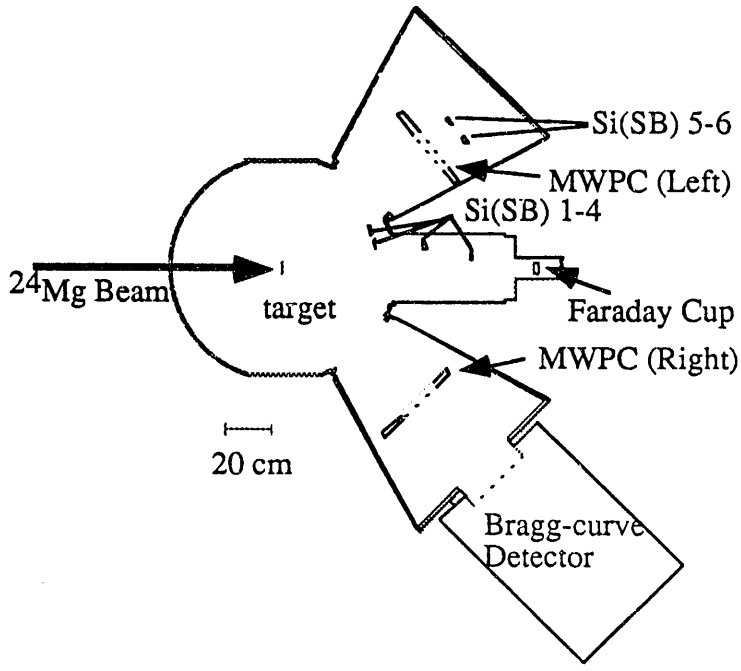
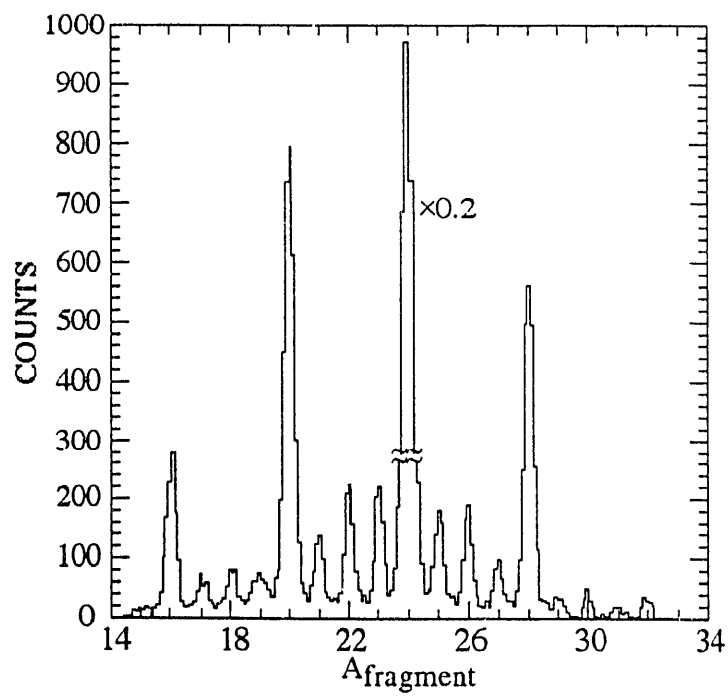


Figure 4- Experimental arrangement for the 24Mg+24Mg measurement. The Kansas Bragg-curve detector is behind the right multi-wire proportional counter. A second MWPC is located on the opposite side of the beam to detect the recoiling fragments. Also shown are six Si (surface barrier) detectors used for normalization purposes and to measure the evaporation-residue cross sections. The dashed lines indicate pressure windows. (Drawing is to scale except for target.)

Figure 5. Mass spectrum for the $^{24}Mg+^{24}Mg$ reaction at E_{lab}=90 MeV.



The final results from this measurement are discussed in a draft paper prepared on this work and bound at the end of this report. To summarize, we find that the excitation-energy spectra for the symmetric and near-symmetric fission channels, shown in Figure 6, are dominated by only a few mutual excitation. Even so, the total cross sections and average kinetic energies in these channels are well described by the transition-state calculations. It is not yet clear how to reconcile the evident selectivity seen in the excitation function and the statistical basis of the transition-state model. It is possible that this selectivity reflects the special significance of certain final states because of their strong overlap with the nuclear scission configuration. Alternatively, these structures may result from angular momentum matching conditions which are made more pronounced because of the identical particle nature of the entrance channel. We are now investigating both of these possibilities.

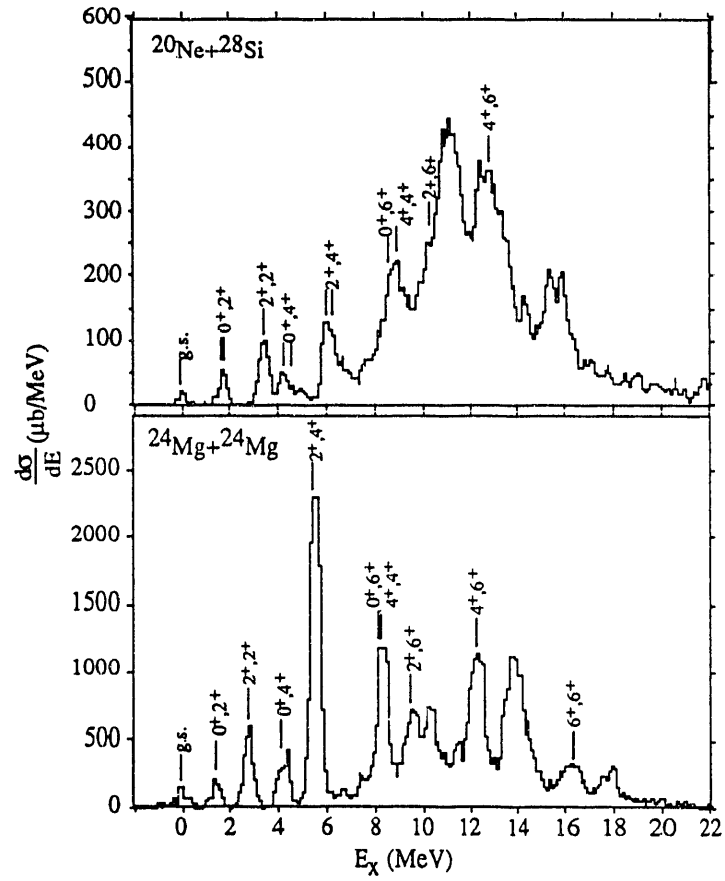


Figure 6. Excitation functions for binary fragment emitted in the $^{24}Mg+^{24}Mg$ reaction at E_{lab}=90 MeV. The locations of mutual excitations consisting of particle-bound members of the respective ground-state bands are indicated.

B.3) $^{32}S + ^{24}Mg$ Particle-γ coincidence measurement

The analysis of the $^{32}S+^{24}Mg$ particle-γ coincidence experiment is continuing. Last year we developed the necessary software to perform self-consistent fits of the particle and

coincident γ-ray data using the known γ-decay branching ratios for the symmetric ^{28}Si fission fragments and the measured absolute efficiency calibrations of the Ge detectors. This is a difficult analysis because of the limited counting statistics and the need to unfold the background under the Doppler-broadened γ-ray lines. We believe we have most of the analysis problems solved, however, and expect to finish this analysis by summer.

The programs and techniques used in this analysis should be directly applicable to our recent $^{36}Ar+^{12}C$ particle–γ coincidence measurement. We expect the analysis of this newer experiment will go much faster since we should have better counting statistics together with improved excitation-energy resolution of the fission fragments.

B.4) $^{36}Ar + ^{12}C$ Particle-γ coincidence measurement

As indicated, we have recently completed a particle-γ coincidence measurement of fission fragments from the $^{36}Ar+^{12}C$ reaction at E_{lab}=180 MeV. This reaction populates the ^{48}Cr compound nucleus at the same excitation energy as our earlier $^{24}Mg+^{24}Mg$ experiment. Once analyzed, this measurement should clarify many of the unresolved questions concerning the influence of nuclear structure on the fission of light nuclei.

The experimental arrangement for the particle detectors in this measurement was very similar to that shown in Figure 5 for our previous $^{24}Mg+^{24}Mg$ experiment. The $^{36}Ar+^{12}C$ measurement was located, however, at the Argonne-Notre Dame γ-ray facility to allow for the detection of the coincident γ-rays. This should allow us to determine the specific mutual excitations that dominate the excitation-energy spectra.

The complexity of this measurement required considerable preparation and setting up and, consequently, was the principal activity of our group for the past two months. Its analysis will be one of our major activities during the coming year. We have started this analysis, but are at too preliminary a stage to report any results.

C. Heavy-ion reactions and limits to fusion.

C.1) ^{28}Si induced fusion reaction

For several years we have been involved in studies of fusion-evaporation reactions and the competition between complete and incomplete fusion reactions. As part of this program a number of measurements were made at the ATLAS facility with beams of ^{28}Si at energies of 309, 397, and 452 MeV. These exclusive measurements, with M. F. Vineyard as spokesperson, will probably be the last of this kind done at ATLAS. The first paper on this work, with a target of ^{28}Si, was published in 1990 and has been reported in previous progress reports. The second, with a target of ^{40}Ca, was published in April, 1992, and is included in the reprint and preprint portion of this report. The third, with a target of ^{12}C, has been

submitted for publication and is also included in this report as a preprint. The results in all three are in reasonable agreement with Morgenstern systematics and, therefore, present no surprises. However, the results from the ^{12}C target are in disagreement with earlier measurement in this system by Harmon *et al.*[10] The source of this disagreement is not understood, but was checked by a further experiment at Florida State University at lower energies. The results from this experiment, included in the preprint, matched well with the ATLAS results and remained in disagreement with the Harmon results.

C.2) Feasibility study for a measurement of temperature-limited fusion

In our previous two progress reports we have discussed the possibility of exploring possible limitations on heavy-ion fusion imposed by excitation energy (or temperature) rather than by angular momentum. A number of years ago, Moretto reported experiments that appeared to indicate the persistence of compound nucleus formation at relatively high bombarding energies with beams of ^{3}He;[11] however, these results have not been substantiated. He chose to use ^{3}He so that production of medium mass residues could not be ascribed to projectile fragmentation.

We have chosen to consider very mass-asymmetric target-projectile systems for a different reason, as indicated by the table below. In the three mass 56 systems that have been studied extensively at ATLAS, the systematics at the highest bombarding energies are shown. With a limiting angular momentum for a vanishing fission barrier of about 44 $\hbar$ for mass 56,[4] all three systems have been observed to reach saturation of the fusion cross section, and the $^{16}O + ^{40}Ca$ and $^{28}Si + ^{28}Si$ systems have clearly shown the onset of incomplete fusion. On the other hand, they are still well below the Morgenstern limitation[12] on $v_L/c \approx 0.21$-0.23 and the predicted limits on excitation energy and temperature.

As the table shows, it is necessary to go to much more mass-asymmetric systems in order to reach excitation energies of more than $E^*/A \geq 4$ MeV before far surpassing this critical angular momentum. For comparison, several such systems are shown for equal values of E^*/A spanning this range. The excitation energy limit predicted for fusion differs slightly with different formulations,[13, 14] but should be in the range from about 4 MeV to 8 MeV, where the latter is the typical nucleon separation energy. The temperatures shown in the table have been calculated with a constant value of "little a" = 8 MeV, which may not be appropriate at the higher excitation energies, but the comparison between systems should remain valid.

It is clear that the more asymmetric systems have the better chance to probe energy limitations. However, the ^{6}Li and ^{7}Li examples are of little use because of the large probability of breakup, a process that will exhaust a large fraction of the reaction cross section and produce a large background of light fragments. The ^{11}B and ^{12}C examples do not present this problem to the same degree, but are clearly still too close to symmetry to test energy limits before angular momentum limits. Thus only the use of ^{4}He appears to offer a reasonable possibility, but other problems remain.

Table: Comparisons of the reaction dynamics for different channels reaching compound systems with $A \approx 56$. The interaction radius, R, was calculated with $r_0 = 1.4$ fm; μ is the reduced mass; v_{rel} is the relative velocity at the top of the Coulomb barrier, V_C; v_L is the velocity of the lighter reaction partner at this point; l_g is the grazing angular momentum; and l_c is the limiting angular momentum with the sharp cutoff approximation for the cross section.

	μ	R	V_C	Q	E*/A	T	E_{cm}	E_{lab}	v_{rel}/c	v_L/c	l_g	l_c
$^4He + ^{52}Cr$	3.71	7.45	9.3	7.6	2.00	4.0	104	112	0.23	0.22	31	
					4.00	5.7	216	233	0.35	0.32	45	
					8.00	8.0	440	474	0.50	0.46	65	
$^6Li + ^{51}V$	5.37	7.73	12.8	22.1	2.00	4.0	92	103	0.18	0.16	35	
					4.00	5.7	206	230	0.28	0.25	55	
					8.00	8.0	434	485	0.41	0.37	81	
$^7Li + ^{48}Tl$	6.11	7.77	12.2	24.1	2.00	4.0	86	98	0.16	0.14	36	
					4.00	5.7	196	224	0.25	0.22	57	
					8.00	8.0	416	477	0.38	0.33	84	
$^{11}B + ^{45}Sc$	8.84	8.09	18.7	28.2	2.00	4.0	84	104	0.13	0.10	43	
					4.00	5.7	196	244	0.21	0.17	70	
					8.00	8.0	420	522	0.31	0.25	106	
$^{12}C + ^{48}Ti$	9.60	8.29	22.9	16.0	2.00	4.0	104	130	0.13	0.11	51	
					4.00	5.7	224	280	0.21	0.17	80	
					8.00	8.0	464	580	0.31	0.25	118	
$^{16}O + ^{40}Ca$	11.43	8.31	27.7	14.3	2.99	4.9	153	214	0.15	0.11	69	35
$^{32}S + ^{24}Mg$	13.71	8.48	32.6	14.0	2.38	4.4	119	278	0.12	0.05	64	44
$^{28}Si + ^{28}Si$	14.00	8.50	33.2	10.9	4.23	5.8	226	452	0.17	0.09	97	33

The first is that already at the lowest energy shown the $^4He + ^{52}Cr$ system is at the Morgenstern limit on v_L/c for the existence of complete fusion. However, this limit has not been tested in such an asymmetric system and it would be of interest to see if this limit still applies. The more important difficulties remain experimental. These have been indicated by a number of PACE simulations.[15] If ^4He is used as the projectile, the recoil velocity of the residues is too low to identify the Z values using ΔE-E techniques. Separation by mass will require either good beam timing and/or long flight paths. The first is not available at either Indiana or Michigan State where suitable beams are available; the second poses difficulties with

solid angle. Also, with the small recoil velocity, significant residue yield extends to 40°; so a large angular range must be covered. These requirements are antithetical and make even a test experiment probably prohibitive.

Beams in the mass range of ^{52}Cr have become available at Michigan State to allow the reaction to be run in inverse kinematics at equivalent center-of-mass energies. The need for a ^{4}He target would pose some problems, but is possible. Obviously, in this case, all reaction products would be strongly forward-focused in the lab; almost all residues are within 6° of the beam. However, if incomplete fusion results from the loss of nucleons from the lighter partner, as is usual, the recoil velocity remains determined by the heavier beam partner. Thus, if a nucleon is lost in pre-equilibrium emission from the ^{4}He and is followed by fusion between the resulting ^{3}He or ^{3}H with the projectile, the resulting mass and energy distributions of the residues is virtually indistinguishable from that predicted for complete fusion. Only a very complete inclusive experiment, which looked for the signature of the pre-equilibrium nucleon, would be useful.

Until a simpler and suitable experiment can be determined, we plan to postpone further consideration of this interesting, but difficult problem in favor of other experiments now approved at ATLAS.

D. Hybrid MWPC-Bragg curve detector development .

Our large-acceptance, segmented-anode Bragg curve detector has been an important component in our recent $^{24}Mg+^{24}Mg$ and $^{36}Ar+^{12}C$ experiments. In this latter measurement the detector was essential for obtaining high-statistics γ-rays spectra in coincidence with charge-identified fission fragments.

During the past year we have developed a program to simulate the Bragg-detector response. This calculation starts with a calculation of the differential stopping of heavy-ions in the detector, using standard stopping-power tables, and follows the charge collection and subsequent amplification stages of the electronics to determine the signal at the ADC input. Figure 7 shows how well this calculation is able to simulate our observed detector response. It should be noted that the low-energy threshold for Bragg-peak identification is a consequence of amplifier time constants rather than being at too low an energy to produce a Bragg peak. We are now able to calculate the appropriate voltages and pressures for the Bragg detector to optimize its dynamic range for any specified reaction.

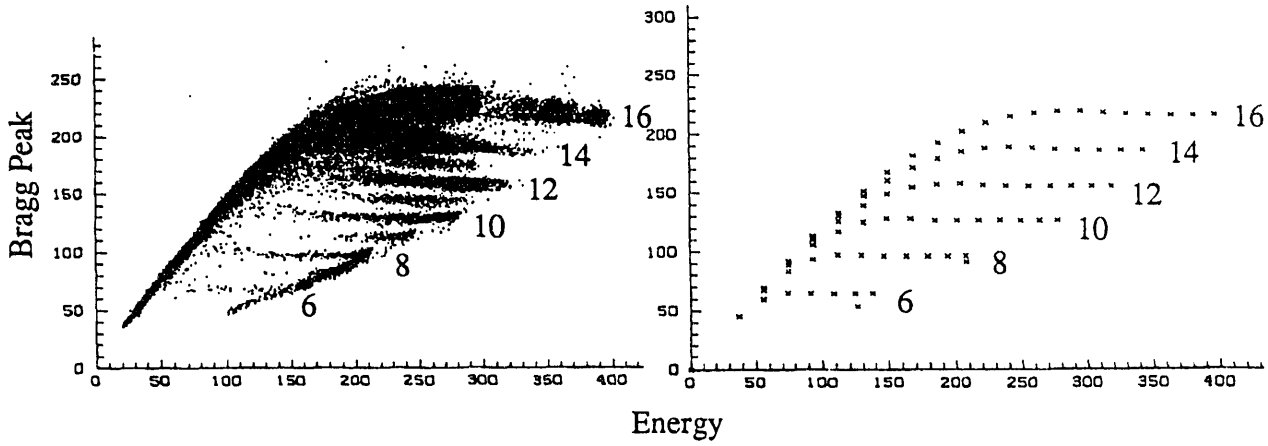


Figure 7. Comparison of calculated and experimental Bragg-peak identification spectra for the $^{32}S+^{24}Mg$ reaction at E_{lab}=140 MeV. The calculated spectrum only shows the even charge channels, as indicated.

As suggested in our last report, during the past year we have instrumented this detector with an internal position-sensitive, multi-wire proportional counter. This detector will allow us to forgo the separate MWPC that we have been using to obtain the reaction angle information, thus resulting in a simpler experimental arrangement, with the elimination of two pressure windows. We also expect to achieve improved resolution in the Bragg because of reduced energy losses before reaching the Bragg volume.

During the past year we have built two separate position counters for the Bragg. For our first detector we attempted a three plane configuration consisting of a grided-anode plane sandwiched between two position-sensitive cathode planes. By having only three planes, rather than using the more common four-plane configuration,[16] we hoped to be able to save on the transmission losses associated with the fourth plane. Unfortunately, even though we achieve high gains at the pressures used in the Bragg configuration, these increases in gain were not found to be sufficient to compensate for the gain loss in going to the three-plane configuration. We have since reconfigured our internal MWPC using a five-plane configuration, with the position planes sandwiched between the anode and two cathode planes. This new MWPC has been tested with radioactive sources and found to work very well. Our decision to use five planes rather than four was based on source tests with a prototype detector where we found somewhat greater gain and cleaner looking signals from the five plane configuration as compared to the four. Our design is such, however, that we can easily reconfigure the counter with only four planes should this prove desirable.

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Sao Paulo, Brazil: A. Szanto de Toledo

Strasbourg, France: C. Beck

IV. Meetings and Research Trips.

April 20-24 – Washington APS meeting. (Prosser)

June 16-27 – ATLAS: Beam test of the Hybrid MWPC-Bragg detector. (Desbien, Farrar, Hasan, Prosser, and Sanders)

Sept 25-26 – Berkeley: Workshop on Auxillary Detectors for GAMMASPHERE (Sanders)

Oct. 14-17 – Sante Fe: Fall APS Nuclear Divisional Meeting. (Farrar, Hasan, Sanders, Prosser)

Nov 12-14 – ATLAS: FMA workshop and PAC meeting (Sanders)

Nov 23-Dec 22 – ATLAS Run: $^{36}Ar+^{12}C$ particle-γ coincidence experiment. (Hasan, Farrar, Prosser, Sanders).

(Note: For the ATLAS runs the entire group would, in general, not be present for the full time indicated.)

V. Personnel.

Senior personnel:

Francis W. Prosser Professor of Physics

Stephen J. Sanders Associate Professor of Physics

Graduate Students:

Kelly Farrar

Asad Hasan

Zhou Dac' ıg (through Spring, 1992)

Dwain Desbien (from Summer, 1992)

END

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5/11/93