MASTER

Deexcitation Processes in Nuclear Reactions

Norbert T. Porile, Principal Investigator

Progress Report for the period August 1, 1978 to July 31, 1979

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Abstract

The following studies, currently in progress, are discussed: 1). Angular distributions and differential ranges of Sc and Ba fragments emitted in the interaction of 0.8-400 GeV protons with ^{238}U ; 2). comparative study of the emission of light (^{24}Na - ^{52}Mn) fragments in the interaction of Cu - U with relativistic ^{12}C ions and protons; 3). comparative study of the recoil properties of products of the spallation of silver by relativistic ^{12}C ions and protons; 4). measurement of the excitation functions of the $^{127}\text{I}(\pi^{\pm}, \pi^{\pm} \text{xn})$ reactions; 5). energy spectra of isotopically resolved fragments emitted in the interaction of high-energy protons with complex nuclei.

I. Research Activities

During the past year our research program has involved a continuation of studies of fragmentation and deep spallation reactions of ^{238}U with high-energy protons. In addition, a number of new studies were initiated. These include a comparative study of fragment emission in the reactions of Cu - U with relativistic ^{12}C ions and protons, a comparison of the recoil properties of products from the interaction of silver with relativistic ^{12}C ions and protons, and the measurement of the excitation functions of the $^{127}\text{I}(\pi^+, \pi^+ \text{xn})$ reactions. In addition, we have been involved in the design and construction of the apparatus for a counter physics experiment on fragment emission from nuclei at Fermilab energies in collaboration with members of the Purdue Physics Department.

We have completed the experimental measurements of the emission of ^{44}Sc , ^{46}Sc , ^{47}Sc , and ^{48}Sc fragments in the interaction of ^{238}U with 0.8-400 GeV protons. We have measured the angular distributions and differential ranges (at 90°) of these fragments at 0.8, 3.0, 11.5, and 400 GeV. In addition, differential ranges were measured at forward (17°) and backward (163°) angles for 400 GeV protons. This study was motivated by an earlier thick-target recoil study performed in our laboratory,¹ which showed that the forward-to-backward emission ratios (F/B) of Sc nuclides peaked at 3 GeV and decreased to values as low as unity at 300 GeV. These data suggested that, in addition to a transition at 3 GeV, something peculiar might be happening at the highest energies since an F/B value of unity for a fragmentation product is highly unusual.

Figure 1 shows the angular distributions of ^{47}Sc measured at 0.8, 3.0, 11.5, and 400 GeV. The curves represent least-squares fits to the data of the function

$$d\sigma/d\Omega = 1 + A_1 \cos\theta_L + A_2 \cos^2\theta_L \quad (1)$$

which fits the data quite well. It is seen that the angular distribution is forward-peaked up to 3 GeV. This result is consistent with the two-step model of high-energy reactions in which an intra-nuclear cascade imparts a forward component of momentum to the struck nucleus. The latter subsequently decays to the observed fragments presumably by two-body breakup accompanied by extensive evaporation. Between 3 and 11.5 GeV the angular distribution changes from forward- to sideward-peaked.² This change may be indicative of a transition from a cascade to a collective interaction mechanism, exemplified by the tube model³ or the effective target model.⁴ There is not much additional change in the angular distribution between 11.5 and 400 GeV except for an accentuation of a novel effect barely noticeable in the 11.5 GeV data, namely, the emission of more fragments at backward than at forward angles.

The differential ranges were measured by stopping the fragments in a stack of thin Mylar foils. The range-energy relation of Northcliffe and Schilling⁵ was used to convert the ranges to energy spectra. The spectra obtained for ^{47}Sc , which are typical of all the data, are displayed in Fig. 2. It is seen that, with increasing proton energy, the spectra broaden and shift to lower energies. At 0.8 GeV the spectrum is, in fact, consistent with liquid drop model predictions⁶ for binary fission of a

nucleus in the $A \sim 200$ mass region. At higher energies the spectra are too broad to be consistent with such a process. The exponential tails of the spectra are consistent with a nuclear temperature of ~ 8 MeV at 0.8 GeV and of 16-17 MeV at the higher energies.⁷

In order to obtain some more detailed information about the unusual angular distributions obtained at 400 GeV, differential ranges were measured at 17° and 163° as well as at 90° . If the preferential backward emission of the fragments were to be the result of backward motion of the emitting nucleus, the spectra obtained at backward angles should peak at higher energies than those at forward angles. The spectra obtained for ^{47}Sc are shown in Fig. 3. The spectra, in fact, vary in the normal way with angle, peaking at the highest energies at forward angles. The results are consistent with an emitting nucleus moving slowly along the beam direction ($\beta_{||} \approx 0.003$). If it is assumed that a nucleus having such a positive β breaks up to yield Sc fragments, the angular distributions can be transformed to this moving system. The resulting curve for ^{47}Sc is shown in Fig. 4 and it is apparent that emission at forward angles is inhibited. This may conceivably be related to the ejection of hadronic flux at forward angles.⁸

We have also been engaged in a similar study of the formation of Ba nuclides in the interaction of ^{238}U with 0.8, 3.0, 11.5, and 400 GeV protons. We have completed measurements of the angular distributions and 90° differential ranges of ^{128}Ba , ^{131}Ba , and ^{140}Ba . The first two of these nuclides are deep spallation products whereas ^{140}Ba is a fission product. The results of this study will provide information of comparable detail to that

obtained for Sc fragments for these higher Z products.

In our recently published comparison of the interaction of silver with 25.2 GeV ^{12}C ions and 300 GeV protons⁹ it was found that the factorization hypothesis was obeyed for all but the lightest fragments. The formation of fragments having $A \leq 40$ in the ^{12}C induced reaction was enhanced by as much as a factor of two relative to the ratio of total reaction cross sections. Since the enhanced emission of light fragments appeared to be the one distinctive feature of reactions induced by relativistic heavy ions, we began a series of experiments focusing on the emission of these fragments. We are in the process of measuring the cross sections and thick-target recoil properties of a number of light fragments ranging from ^{24}Na to ^{52}Mn emitted in the interaction of Cu, Ag, Gd, Ta, Au, and U with relativistic ^{12}C ions and high-energy protons. This experiment will indicate whether the enhanced emission of light fragments depends on the mass number of the target or not and whether the momentum transfer and fragment energies depend on the identity of the projectile. In a related experiment, the recoil properties of a broad range of products from the interaction of Ag with relativistic ^{12}C ions and protons are being measured in order to complete our comparative study of the interaction of these projectiles with a medium-A target.

In the course of the past year we began a study of the excitation functions of the $^{127}\text{I}(\pi^{\pm}, \pi^{\pm} \text{xn})$ reactions. These reactions are analogous to the (p, pxn) reactions, which have proved to be of value in the determination of the relative importance of direct knockout and inelastic scattering-evaporation processes as a function of the number of emitted neutrons. The $(\pi, \pi \text{xn})$ reactions can, in addition, permit an examination of the role

of the (3,3) resonance in a series of progressively more complicated reactions which are, nonetheless, all of the same type. ^{127}I is a particularly good choice of target since activation techniques may be used to determine a uniquely large number of products of this type.

We have devoted a good deal of attention to the preparation of suitable I targets and have found that 100-200 mg/cm^2 thick KI pellets have satisfactory mechanical and thermal properties. However, for assay of very short-lived activities, LiI, which is highly deliquescent on a time scale of days, has a simpler γ -ray spectrum and may be more suitable. In a series of exploratory experiments performed with 360 MeV π^+ at LAMPF we were able to determine the activity of ^{118}I , ^{119}I , ^{120}I , ^{121}I , ^{123}I , ^{124}I , ^{125}I , and ^{126}I without radiochemical separation. The cross sections of shorter-lived ^{115}I , ^{116}I , ^{117}I , and ^{122}I should also be measurable, but will require in situ assay.

We have devoted a great deal of effort this past year to the design, fabrication, and testing of the equipment needed to measure the energy spectra of isotopically resolved fragments emitted in the interaction of 10-400 GeV protons with complex nuclei. The fragments will be detected electronically by a combination of time-of-flight, energy loss, and energy measurements. The TOF measurements will be performed with microchannel plate detectors, using a flight path that is variable between ~ 20 -200 cm. The ΔE -E measurements will be performed in two distinct ways, one for the determination of Li-Na fragments, and the other for the assay of $\sim \text{F-Cu}$ fragments. In the first case, a three element solid state detector system will be employed while in the second case, a gas ΔE detector will be used in conjunction with a solid state E detector. Both types of detectors will

be in use simultaneously in different detector arms.

The various detector systems have been built and separately tested. The first arm, comprising the interface to the gas jet target box, collimating systems, channel plate boxes, $\Delta E-E$ telescope, alignment elements, and vacuum and mechanical support systems has been built. A schematic diagram of the arm is shown in Fig. 5. This system is presently being installed at the Internal Target Laboratory at Fermilab and testing is to commence in the very near future.

The research performed this past year is in compliance with the contract requirements and closely follows the outline submitted in the last renewal proposal. The principal investigator has devoted approximately 50% of his time and effort to this project during the present contract year. It is expected that this figure will be maintained at the same level for the remainder of the year.

References

1. Ø. Scheidemann and N. T. Porile, Phys. Rev. C14, 1534 (1976).
2. D. R. Fortney and N. T. Porile, Phys. Lett. 76B, 553 (1978).
3. G. Berlad, A. Dar, and G. Eilam, Phys. Rev. D13, 161 (1976).
4. Meng Ta-chung and E. Moeller, Phys. Rev. Lett. 41, 1352 (1978).
5. L. C. Northcliffe and R. F. Schilling, Nucl. Data A7, 233 (1970).
6. J. R. Nix and W. J. Swiatecki, Nucl. Phys. 71, 1 (1965).
7. G. D. Westfall, R. G. Sextro, A. M. Poskanzer, A. M. Zebelman,
G. W. Butler, and E. K. Hyde, Phys. Rev. C17, 1368 (1978).
8. K. Gottfried, Phys. Rev. Lett. 32, 957 (1974).
9. N. T. Porile, G. D. Cole, and C. R. Rudy, Phys. Rev. C19, 2288 (1979).

Fig. 1. Angular distribution of ^{47}Sc emitted in the interaction of ^{238}U with high-energy protons. The points represent the data and the curve is a fit of Eq. (1).

Fig. 2. Energy spectra of ^{47}Sc fragments emitted at 90° to the beam.

Fig. 3. Energy spectra of ^{47}Sc emitted at 17° , 90° , and 163° in the interaction of 400 GeV protons.

Fig. 4. Angular distributions of ^{47}Sc at $T_p = 400$ GeV in the lab system (top panel) and in the moving system symmetrizing the velocity spectra.

Fig. 5. Schematic diagram of fragment detector arm.

same, $\frac{1}{2}^2 = 1''$

II. Technical Reports, Preprints, and Articles

Compound and precompound emission of α -particles in reactions of even Zn isotopes with low-energy protons and ^4He ions. C. R. Lux and N. T. Porile, Phys. Rev. C18, 148 (1978).

Emission of ^{24}Na fragments in the interaction of ^{197}Au with intermediate-energy pions and protons. N. T. Porile, B. J. Dropesky, and R. A. Williams, Phys. Rev. C18, 2231 (1978).

Differential ranges and angular distributions of Ba fragments from the interaction of ^{238}U with 11.5 GeV protons. N. T. Porile, S. Pandian, H. Klonk, C. R. Rudy, and E. P. Steinberg, Phys. Rev. C19, 1832 (1979).

Nuclear reactions of silver with 25.2 GeV ^{12}C ions and 300 GeV protons. N. T. Porile, G. D. Cole, and C. R. Rudy, Phys. Rev. C19, 2288 (1979).

Unusual backward enhancement in the angular distribution of products from the interaction of ^{238}U with 400 GeV protons. N. T. Porile, D. R. Fortney, S. Pandian, R. A. Johns, T. Kaiser, K. Wielgoz, T. S. K. Chang, N. Sugarman, J. A. Urbon, D. J. Henderson, S. B. Kaufman, and E. P. Steinberg, submitted to Phys. Rev. Lett.

Formation of isobaric nuclides with $A=131$ in the interaction of ^{238}U with 0.8 - 11.5 GeV protons. S. Biswas and N. T. Porile, Phys. Rev. C (in press).

Emission of ^{24}Na fragments in the interaction of gold with intermediate energy pions and protons. N. T. Porile, B. J. Dropesky, and R. A. Williams, Abstracts of the Division of Nuclear Chemistry and Technology, American Chemical Society, September 1978.

Recoil properties of Ba, La, and Ce fragments emitted in the interaction of ^{238}U with 0.8 - 11.5 GeV protons. S. Pandian, S. Biswas, H. Klonk, N. T. Porile, C. R. Rudy, and E. P. Steinberg, Abstracts of the Division of Nuclear Chemistry and Technology, American Chemical Society, September 1978.

Differential ranges and angular distributions of scandium fragments from the interaction of ^{238}U with 0.8 - 400 GeV protons. D. R. Fortney and N. T. Porile, Abstracts of the Division of Nuclear Chemistry and Technology, American Chemical Society, September 1978.

Changes in the spectra and angular distributions of Sc fragments from the interaction of ^{238}U with 1 - 400 GeV protons. N. T. Porile and D. R. Fortney, Abstracts of the Division of Nuclear Physics, American Physical Society, November 1978.

Emission of Sc fragments in the interaction of ^{238}U with 0.8 - 400 GeV protons. D. R. Fortney and N. T. Porile, 8th International Conference on High Energy Physics and Nuclear Structure, Vancouver, B.C. Canada, August 13, 1979.

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