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NUCLEAR PHYSICS EXPERIMENTS WITH THE ORNL-HHIRF
SUPERSONIC GAS JET TARGET

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ABSTRACT

A study of target-like fragments produced by bombarding a ^{14}N target with 150 MeV ^{28}Si shows that mass and charge distribution of products from orbiting processes is determined by partitioning of an equilibrated dinuclear system. The experiment was performed with the HHIRF supersonic gas jet target which is also described briefly.

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1. Introduction

The new 25 MV folded tandem electrostatic accelerator at Oak Ridge National Laboratory (HHIRF facility) can produce intense, high quality ion beams of species spanning the periodic table. The ions can be accelerated to kinetic energies that are high enough to surmount the repulsive electrostatic and centrifugal barriers for a variety of target ions and initiate nuclear collisions.

The study of nuclear reactions which have typical cross sections in the millibarn range, or lower, requires both intense beams and high density targets. The majority of available solid target materials, however, cannot sustain high intensity heavy particle bombardment. A supersonic jet of gas streaming at right angles to the beams' path is in effect a dense (many $\mu\text{g}/\text{cm}^2$ for submillimeter thickness) and indestructible target. Such a target has many other virtues such as controllable uniformity, purity and thickness.

In this presentation I shall briefly describe a supersonic gas jet target built at HHIRF [1] and show results from a recent experiment performed with this device. The final section will discuss plans for future experiments with the HHIRF gas jet target.

2. The supersonic gas jet target

The essential features of our design appear in Figs. 1 and 2 which show two schematic views of the apparatus (the mechanical details have been omitted for the sake of clarity). At the center and the heart of this device is a convergent-divergent laval nozzle [2] which allows for rapid supersonic expansion of gas at high pressures into the target

region. In this device the gas moves upward, and close above the nozzle is an intake tube through which more than 90% of the gas flowing out of the laval nozzle is pumped away (stage I). Surrounding this central region are three additional stages of differential pumping, the last of which (stage IV) is the chamber into which the gas jet has been mounted. The parts of the gas jet drawn in heavy lines in Fig. 2 can be removed as an unit and mounted at other sites.

A schematic drawing of the gas handling system used to control gas flow through the jet is shown in Fig. 3. For normal operation only one control stage is needed (by-pass valve B2 can be left open); the pressure P_0 is then controlled by C1. Both controls are needed when operating the gas jet in a recycling mode. This permits us to run at inlet pressures P_0 that may not be compatible with the pressure that is optimal for the recycling line (near one atmosphere).

The predicted shape of the gas jet [2] is shown in Fig. 4 where we also list several of the gas jet parameters. The beam traverses the target in a direction perpendicular to the jet flow and close to the nozzle exit edge. Tight beam collimation is needed in order to have precise control of the beam and jet's intersection region. A composite plan of the beam handling and collimation system, the target chamber and the magnetic spectrograph and detection apparatus is shown in Fig. 5. Further details about the jet target itself or the detection system appear in references 1 and 3.

3. Mass and charge flow during orbiting of light heavy nuclei

In a series of experiments performed at ORNL and elsewhere it has been demonstrated that colliding light heavy nuclei are likely to form a long lived rotating dinuclear system which does not fuse [4]. The cross section for this process is tens of millibarns, a substantial magnitude for nuclear processes. The fact that such a process requires a precarious balance between attractive and repulsive forces in a nucleus-nucleus collision make the existence and our understanding of this process important.

We focused on the study of backscattering of ^{12}C from ^{28}Si . Very large cross sections for emission of B, C, N and O isotopes to backward angles were measured. These particles emitted to the backward hemisphere were concentrated mostly at large negative Q value (corresponding to high excitation of the end fragments). The most probable kinetic energy (the peak of the Q value distribution) does not vary with angle of emission (completely relaxed), it does vary linearly, however, as a function of bombarding energy. It was also found that this particle yield at backward angle has a $1/\sin\theta$ dependence in the center of mass systems. These results indicate that the two colliding nuclei (^{12}C and ^{28}Si) have formed a rotating dinuclear system. This complex subsequently decays with isotropic probability $d\sigma/d\theta = \sin\theta * d\sigma/d\Omega = \text{const}$) and the kinetic energy of the emitted fragments equals the energy stored in the rotating complex and does not depend on the angle of emission in agreement with the observed behavior.

A question that comes immediately to mind is how long is long lived? This question cannot be answered directly but it can be answered

relative to certain processes. For example the isotropic angular distribution requires rotation of at least 180° (that makes "long" about 10^{-21} sec!). We know that the dinuclear complex lives long enough for some mass and charge transfer to occur as well as complete equilibration of the energy degree of freedom, i.e. complete damping of the kinetic energy in the entrance channel has occurred and most of the excitation for a given exit channel is in the heavy fragment [5] (equal temperature). One could next ask the question: "Since we do have mass and charge flow was there enough time for this degree of freedom to equilibrate?" Figure 6, however, already points out the inadequacy of the $^{12}\text{C} + ^{28}\text{Si}$ system for studying this question. The $^{12}\text{C} + ^{28}\text{Si}$ channel is bound to dominate under any assumption — since this is the entrance channel as well as the favored exit channel. The $^{28}\text{Si} + ^{14}\text{N}$ system shown on the left side of Fig. 6 is much better suited for answering this question. While the $^{28}\text{Si} + ^{14}\text{N}$ exit channel would be favored with a fast process, the $^{12}\text{C} + ^{30}\text{P}$ channel would dominate if equilibrium emission took place. In order to bypass some of the difficulties encountered in backscattering experiments all the measurements discussed here were done at forward angles, reversing the role of target and projectile. ^{12}C (or ^{14}N in the present experiment) were bombarded with energetic ^{28}Si beams and a study of the target-like nuclei, recoiling forward, was carried out. Natural nitrogen gas (99% ^{14}N) was used in the gas jet to produce a $15 \mu\text{g cm}^2$ thick ^{14}N target. This target was bombarded with highly collimated ($1/4 \text{ mm}^2$) 5 pnA 150 MeV ^{28}Si beam. The products were momentum analyzed in the spectrograph and

identified ($\Delta E, E$) in an ionization chamber. A two-dimensional energy vs. energy loss map showing all the detected target-like products appear in Fig. 7. The three other maps display focal plane position (momentum) vs. energy and show the mass and charge state distribution of the products. The projected energy spectra for products with $Z = 6, 7$ and 8 are shown in Fig. 8. These spectra are clearly dominated by ^{12}C , ^{14}N and ^{16}O (parts b, c and d of Fig. 7). Measurements at other angles have shown that the centroids of these energy spectra are unaltered and as Fig. 9 shows the emission probability for these products ($d\sigma/d\theta$) remains constant with angle. Therefore these products come, in all likelihood, from the same orbiting process previously observed in $^{28}\text{Si} + ^{12}\text{C}$ and other systems [6]. The new information from these data is also obvious; A brief examination of the data in Fig. 7, 8 and 9 shows that the dominant yield is in the $^{12}\text{C} + ^{30}\text{P}$ channel and not in the $^{14}\text{N} + ^{28}\text{Si}$ entrance-like channel. The process therefore lasts long enough for energy, mass and charge flow to reach equilibrium. This still does not put an absolute time limit on the process but it is likely that more than the time needed for one rotation is involved. We are now actively engaged in calculations that assume equilibrium partitioning of the products and shall find out how such model predictions compare with the observed data.

4. Future plans

Clearly there is a wide variety of experiments such as studies of continuum and high resolution spectra of products from heavy ion induced reactions where a dense windowless gas target would be most useful. A

special class of experiments, however, would utilize the gas jet as a carrier for atoms of any substance seeded in the gas. A group of scientists at HHIRF [6] is presently working on the production of a polarized target of Europium nuclei using the apparatus shown in Fig. 10. Europium atoms seeded in hot argon gas and flowing through the nozzle will have their nuclei linearly polarized, in the reaction plane, by depopulation pumping with a polarized laser. A series of experiments is planned with a variety of beams and the target atoms linearly polarized along different axes in the reaction plane.

References

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ORNL SUPERSONIC GAS JET TARGET
SCHEMATIC TOP VIEW

SUPERSONIC GAS JET FLOW PARAMETERS

GAS	MACH NO. M	θ (deg)	μ (deg)	TARGET HEIGHT e (mm)	MASS FLOW RATE M (g/s)	TARGET THICKNESS t ($\mu\text{g}/\text{cm}^2$)
N ₂	3.17	77.43	18.36	2.25	0.214	14.19
Ar	3.8	41.76	15.26	2.83	0.262	21.27

GENERAL LAYOUT FOR EXPERIMENTS WITH GAS JET TARGET

Fig. 6

150 MeV $^{28}\text{Si} + ^{14}\text{N}$
 $\theta = 5^\circ$

FOCAL PLANE POSITION

ENERGY LOSS

FOCAL PLANE POSITION

FOCAL PLANE POSITION

150 MeV $^{28}\text{Si} + ^{14}\text{N}$
 $\theta = 5^\circ$

fig 3

POLARIZED TARGET APPARATUS