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RECENT PROGRESS IN APPLICATIONS OF HIGH ENERGY HEAVY ION BEAMS TO NUCLEAR STRUCTURE AND ATOMIC PHYSICS

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We discuss some recent experiments at the Bevalac which demonstrate the usefulness of relativistic heavy ion beams for study of the nuclear structure of radioactive isotopes.

In the three years that have passed since the first conference in this series, the study of relativistic heavy ion collisions has come of age. The most striking manifestation of this has been the steady stream of new data obtained using 4π detectors such as the GSI-LBL Plastic Ball, the streamer chambers at Berkeley and Dubna, and the new spectrometer DIOGENE at Saclay. The consequence of this effort is that we are at last beginning to see experimental results that can be related directly to parameters of the nuclear equation of state. These results are discussed in several contributions to this conference and are summarized in the talk by H. Stöcker.[1] In parallel with these developments, another trend can be found. This is the application of relativistic heavy ion beams to other fields of physics that only a short time ago would have been unexpected. In this contribution, we shall briefly review the progress that has been made during the last year in the study of nuclear structure and atomic physics using the unique properties of relativistic heavy ion beams.

Projectile fragmentation is a process that was studied in some detail in the first years of Bevalac operation.[2] It was realized early on that the relatively small momentum spread of the fragments produced, and the ease of separation of different isotopes by magnetic rigidity has two important consequences. Firstly, isotopes far from stability can be produced with yields that are competitive with low energy isotope separators and without dependance on the chemical properties of the isotope. This comes about because of the very high detection efficiency that is possible. Several new isotopes were discovered at the Bevalac[3] and these studies have been extended using the intense beams that are now available at GANIL.[4] The

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second important aspect of the fragmentation process is the copious production of isotopes that are unstable but not necessarily at the limits of stability. Because of their small momentum spread ($\Delta p/p \sim 1\%$ at 1 GeV/nucleon) these fragments can be transported through a conventional beam line and used as secondary beams. Experiments along these lines have now begun at the Bevalac.

In the past year Tanihata and co-workers,[5,6] have carried out a series of elegant measurements of the reaction cross sections of the particle-stable He and Li isotopes. In discussing this experiment, we shall concentrate less on the final results than on the question of whether these measurements can be used to extract reliable nuclear structure information. The experiments were performed using 800 MeV/nucleon ^{11}B and ^{20}Ne beams incident on a Be target to produce secondary beams which were transported to the HISS spectrometer. Interaction cross-sections were found for each isotope using Be, K and Al targets. Further details of the experimental technique can be found in references 5 and 6.

To relate the measured cross-sections to theoretically calculable quantities such as the nuclear radius, the authors developed the following procedure. They first defined an interaction nuclear radius (R_I) using the geometrical relation

$$\sigma_I\,(p,t) = \pi\,[R_I\,(p) + R_I\,(t)]^2 \qquad (1)$$

where $R_I(p)$ and $R_I(t)$ are the interaction nuclear radii of the projectile and target respectively. Using this relation, the authors have deduced R_I for all the particle stable isotopes of He and Li relative to ^{4}He. The results are illustrated in figure 1. Significant nuclear structure effects are clearly visible. For example, the interaction radius of ^{11}Li is very much larger than that of ^{12}C. It can also be seen that for two nuclei of the same mass number, the more neutron rich isotope invariably has the larger interaction cross-section. These effects may be related to the increased diffuseness of the neutron skin as neutrons are added.

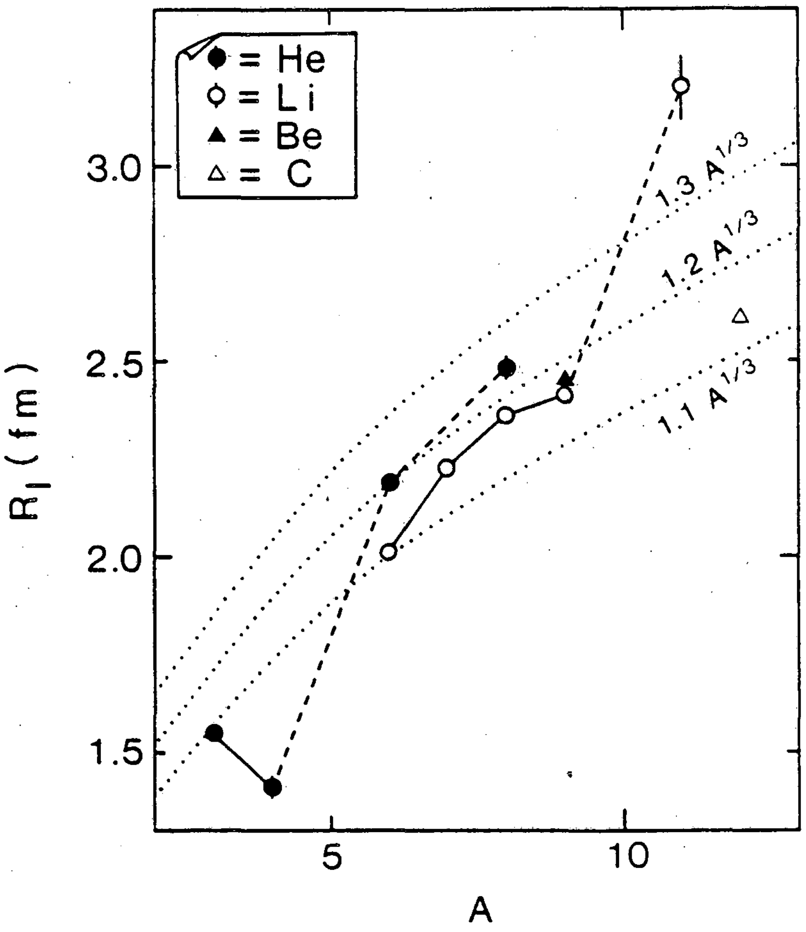

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FIGURE 1

Interaction nuclear radii R_I are plotted for all the He and Li isotopes as well as for ^{9}Be and ^{12}C. The dotted lines in the figure indicate an $A^{1/3}$ dependence on radius. (Taken from reference 6.)

When the results of this experiment were first presented, some criticism was expressed suggesting that it was unclear whether R_I could in fact be compared in a reliable way to a nuclear structure calculation. Tanihata and collaborators have since gone a long way towards proving that the technique is indeed a powerful one. First, they have demonstrated that the separability of projectile and target R_I values that is assumed in equation 1 holds very well except for the very lightest nuclei such as ^{4}He. The stability of the R_I value is typically better than 0.1 fm when the target is varied. Secondly, they have made a detailed study of the measured R_I values in comparison to the rms radii of the stable isotopes ^{4}He, ^{5}Li, ^{7}Li, ^{9}Be and ^{12}C measured by electron scattering. The results are shown in figure 2.

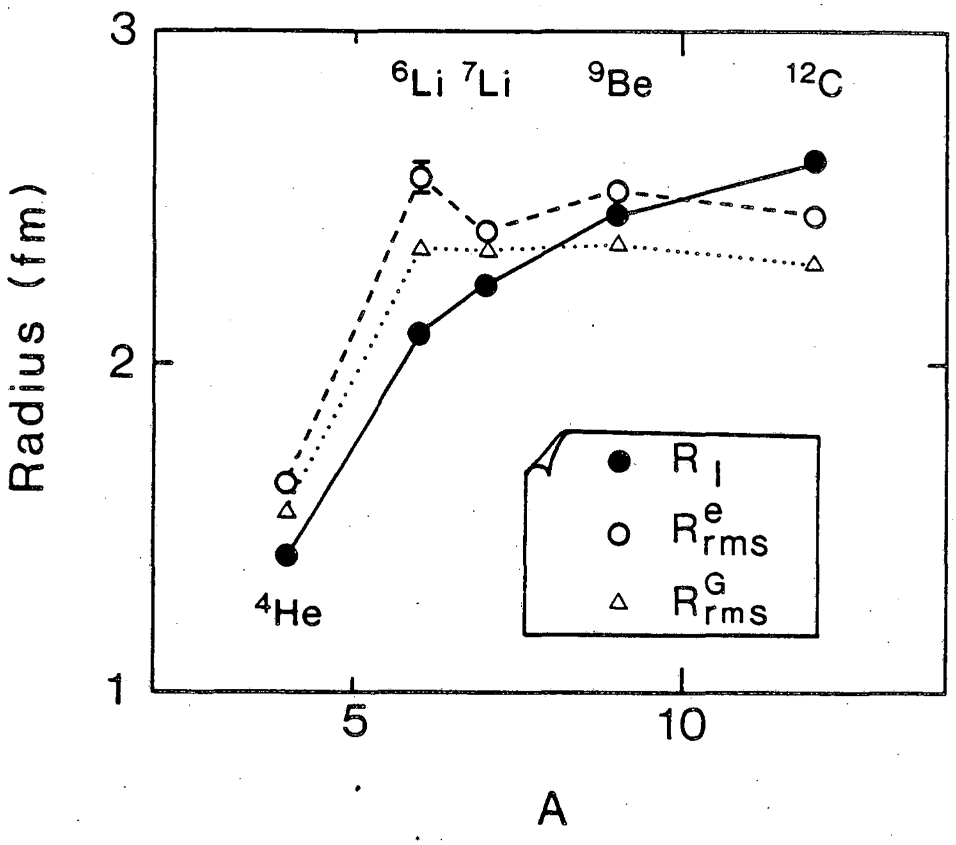

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FIGURE 2

The interaction radius, R_I, and the rms radius, R^e_{rms}, (measured by electron scattering) are plotted for ^{4}He, ^{6}Li, ^{7}Li, ^{9}Be and ^{12}C. Triangles in the figure show the rms radii, R^G_{rms} of Gaussian matter distributions which reproduce the present R_I values as discussed in the text. (Taken from reference 6.)

The first point to note is that the absolute values of R_I and R^e_{rms} are not in agreement. This is not particularly surprising. What is much more disturbing is that the variation with mass number is also quite different. This difference has now been explained by the authors in a quantitative way. Using gaussian wave functions, they calculated the interaction cross-section using a semi-classical optical model.[7] The only adjustable parameters in this calculation are the nucleon-nucleon cross-section and the width parameter of the gaussian distributions which can be related directly to R_{rms}. Fixing the nucleon-nucleon cross-section at the free nucleon value and adjusting the radius to fit the interaction cross-section, they obtain the results in the figure. As can be seen, this calculation reproduces nicely the variation in radius deduced from electron scattering! This is a striking result that greatly increases ones confidence in the technique as a quantitative probe of nuclear structure. The next step will be to perform similar calculations using shell model wavefunctions.

These pioneering experiments are just the beginning of studies using secondary beams and many other possibilities are open. In particular, Minamisono, et al. plan to measure ground state magnetic moments of nuclei in the fp shell using NMR techniques. Looking farther into the future, the SIS18/ESR project at GSI will provide outstanding opportunities for secondary beam studies. These are discussed by Kienle in these proceedings.[8]

Another quite different application of relativistic heavy ion beams is to atomic physics. High energy heavy ion beams offer the unique possibility of producing few electron systems of very high Z atoms in the laboratory, For example, a beam of $^{90+}$U can be prepared by stripping the electrons from the Uranium atom in a foil. However, energies in excess of 100 MeV/nucleon are needed to do this efficiently. As a first step in these studies, Gould et al. studied the stripping and pick-up of electrons from high Z atoms accelerated by the Bevalac.[9] With this knowledge in hand, a measurement of the Lamb shift in He-like Uranium is now being attempted. The first test run for this experiment has recently taken place and results can be expected within the next year. The measurement will allow high order QED effects to be tested that are inaccessible by studies of lighter atoms event though the precision of these measurements may be very much higher. As with the secondary beams, these measurements are without doubt the beginning of a new generation of experimental studies that will be made at our present accelerators and at those that are just now being constructed.[10]

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