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Editorial: Modern advances in direct reactions for nuclear structure

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Editorial on the Research Topic
Modern advances in direct reactions for nuclear structure

1 Introduction

The study of nuclei far away from stability, with large imbalances between the number of protons and neutrons, is a central Research Topic in modern nuclear physics today. New experimental facilities now provide access to nuclei that were previously inaccessible, revealing new and unexpected behaviors. Older models of nuclear structure fail to explain the properties of such nuclei, spurring major new theoretical developments. Key to testing these new theories are new data. Direct reactions have, for decades supplied the underpinnings of nuclear structure models. The necessity to use radioactive beams from the new facilities introduces a host of technical difficulties, including experiment count rates, and complicated kinematics that adversely affect experimental resolutions.

In this Research Topic, we draw together works from experimentalists and theorists that show just some of the many new developments in detector and spectrometer technology, experimental approaches, and structure and reaction theory to confront the challenges that will drive studies in the field into the next decade and beyond. These collected papers illustrate how modern experimental techniques can yield data on nuclei far from stability, and how modern theory can help understand those data.

New instrumentation is key to addressing the physics of exotic isotopes, and modern methods can access data that were previously inaccessible. Ayyad et al. describe advances using the Active-Target Time-Projection Chamber (ATTPC), a highly sensitive device that is both a thick gaseous target and a detector capable of untangling complex multi-particle final states with good resolution. The ATTPC permits sensitive measurements with beams of very low intensity, extending the reach of direct-reaction studies. Silicon detectors have long been a workhorse for direct-reaction measurements, and new, complex multi-segmented arrays play an important role. In his paper, Pain describes the ORRUBA, GODDESS and associated instruments used for a wide variety of measurements, for both nuclear structure and nuclear astrophysics. The coupling of the silicon-detector array with large, modern arrays of germanium gamma-ray detectors adds to the capabilities. Many direct-reaction studies involve nucleon transfer between a light ion, typically ^{1,2}H or ^{3,4}He, and a heavier nucleus; with unstable nuclei, the heavy nucleus is the beam, and the light species is often in the form of a solid plastic or metal foil. Such targets have impurities that can complicate the measurements, but a high-purity gas-jet target that can alleviate such problems. Chipps describes a powerful alternative to solid targets, the JENSA device, which has facilitated a number of high-resolution studies of hydrogen- and helium-induced reactions.

With new instruments come exciting new measurement techniques. Sobotka and Charity have pioneered a groundbreaking approach to studying a wide range of nuclear phenomena using Invariant-Mass Spectroscopy. They apply this powerful method to light proton-rich nuclei to study the nature of the proton dripline, and exotic unbound systems beyond that dripline. The data characterize unbound states that can help understand the shell structure of exotic nuclei. Another aspect key to the evolution of shell structure in neutron-rich systems is the nature of the spin-orbit interaction. In her contribution, Chen examines the trends in spin-orbit splitting for neutron-rich silicon and tin nuclei. Her analysis can distinguish between effects of the spin-orbit potential itself, and from the wave functions of weakly bound nucleons. The data she describes for the ^{32}Si(d,p)^{33}Si reaction were obtained using the SOLARIS spectrometer, one of three spectrometers that exist worldwide with a novel design based on a solenoidal magnetic field. The helical motion of the light ions emitted in two-body reactions within the magnetic field provide an innovative way to avoid kinematical factors that degrade the Q-value resolution obtained when making such measurements with radioactive beams in inverse kinematics with more conventional techniques.

The data from direct-reaction measurements do not immediately yield information about nuclear structure; they must be understood in the context of theoretical analyses of the reactions. Reaction theory has made significant advances in recent years, and our Research Topic includes two examples highlighting these developments. Any experimental result needs a measure of the uncertainty, and in the case of direct reactions, uncertainties associated with theoretical analyses are often neglected. The contribution by Hebborn and Nunes seeks to address the problem by describing sources of uncertainty from optical-model analyses of reaction data and their propagation in the determination of direct-reaction observables. A key ingredient in the analysis of direct reaction data involves predicting the reaction cross section from Distorted-Wave Born or Distorted-Wave Impulse Approximation (DWBA or DWIA) calculations. Central to those calculations are the optical-model parameters used to understand the scattering states. Typically, those parameters are the product of empirical fits to scattering data, but Atkinson and Dickhoff present a different approach, the Dispersive Optical Model (DOM) that uses dispersion relations to connect continuum and bound states, developing data driven predictions for nucleon knockout reactions.

New structure data inspire new theoretical interpretations. Correlations in nuclei are the focus of many current investigations. Macchiavelli et al. address the connection between correlations and the well-known quenching of spectroscopic factors. They consider the case of electron-induced proton knockout from ^{48}Ca, one also addressed by Atkinson and Dickhoff, and discuss the implications of correlations on other features of nuclear structure.

Finally, no experiments are possible without facilities able to provide the necessary beams. While FRIB, CERN/ISOLDE, and FAIR are well known, smaller facilities also play a crucial role in modern nuclear experimental science. The J. D. Fox Superconducting Linear Accelerator Laboratory at Florida State University, described by Spieker and Almaraz-Calderon, is an excellent example of what can be done on a scale smaller than the major national laboratories. They provide a tour of the laboratory, presenting examples of high-resolution spectrometer results, as well as data from sophisticated particle, gamma-ray and neutron detector arrays.

We hope that this Research Topic provides a glimpse into just a few of the many diverse efforts marking current progress in the field of direct nuclear reactions.

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