Studies in Low Energy Nuclear Science

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Located in the hilly, southeastern corner of the state, Athens is host to Ohio University, Ohio's oldest institute for higher education. Here, the Department of Physics and Astronomy has run the Edwards Accelerator Laboratory for the last 40 years. The laboratory has specialized in nuclear astrophysics measurements, level density measurements, and other studies with neutrons.

Boiling Nuclei

Atomic nuclei share many similarities with liquid drops. Heating a nucleus will lead to protons and neutrons boiling off, just like steam from a boiling kettle. And just as higher temperatures will make steam production more prolific, heating nuclei more boils off more energetic nucleons.

Heating nuclei is not easy. It requires the nucleus to be struck by an energetic microparticle such as a proton. In our laboratory, an electric terminal that can be charged to +4 MV, attracts negatively charged particles which gain kinetic energy in the process. Once they reach the terminal, they traverse a thin carbon foil or gas under reduced pressure. Contact with carbon or gas atoms will make the particles lose electrons, thus reversing their charge. The already energetic particles will now be repelled from the +4 MV terminal. They leave the accelerator and gain more kinetic energy along the way. The terminal voltage of +4 MV is utilized twice to transfer energy to beam particles; this acceleration concept is known as a tandem accelerator. The charging system of the terminal will soon be upgraded from a belt-driven Van de Graaff system to a Pelletron system.

The beam is directed to target nuclei, which are heated by reactions. We measure the number and energies of emitted nucleons to determine the temperature of the target nuclei. However, we also need to know the energy to heat nuclei to the measured temperatures in the first place. This is calculated from the beam energy, which is set by adjusting the terminal voltage, and the reaction Q-value which is tabulated. When both the energy and temperature of a nucleus are known, a third quantity, the entropy, can be determined.

Entropy is an important concept throughout physics. Colloquially speaking, it measures disorder. More specifically, it measures the number of ways a given energy can be distributed across the degrees of freedom of a system. In a quantum system, entropy is connected to the level density. Level density is the result of our investigation of heatednuclei. Analysis of the angular distribution of the emitted particles yields the average spin of the excited levels. Theoreticians require knowledge of the nuclear level density of many nuclei to model diverse systems such as nucleosynthesis in stars, transmutation of elements in a reactor, and behavior of tracers in a National Ignition Facility shot.

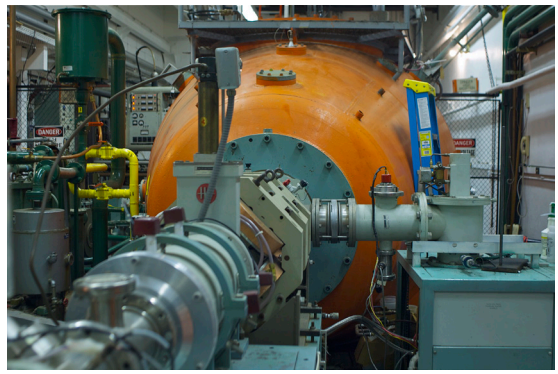

Figure 1. The orange tank (seen from high-energy end) contains the +4 MV terminal and electron stripping system of the tandem accelerator.

Detecting Neutrons

Neutrons are neutral and hardly interact with electrons. This makes it difficult to develop a good neutron detection device.

To get detected, neutrons first transfer their energy to protons, which then knock electrons out of their orbits to produce a charge pulse, or a flash of light, which is electronically processed and analyzed. This process causes several problems. Neutrons rarely transfer all their energy to protons in the detection material. Therefore, unlike charged particles, which produce a signal in proportion to their energy, this connection gets lost for neutrons. Instead, the velocity of a neutron on its path between emission and detection is measured.

Also, the transfer of energy from a neutron to a proton requires the two particles to get close together (1 fm). Since such encounters are rare, large detection volumes are employed. This makes neutron detectors sensitive to background radiation, in particular gamma radiation. The problem with neutrons now turns into an advantage. Since neutrons transfer their energies to protons and not electrons as gamma rays do and since protons and electrons produce light flashes with different time structure, analysis of this time structure allows for differentiation between neutrons and gamma rays.

Figure 2. Three neutron detectors sitting in the 30 m time-of-flight tunnel of the Edwards Accelerator Laboratory.

We have focused on characterizing neutron detectors as precisely as possible. The techniques we have developed are fast and allow calibration with energy steps and resolution typical for time-of-flight spectrometers. Our detector located in a 30 m long tunnel, might be the best-calibrated neutron detector found anywhere. Groups from other institutions visit to calibrate their detectors against ours. We welcome researchers to make use of our facilities and interacting with our students. For more information, please visit our website http://edwards1.phy.ohiou.edu/~oual/