Development of Quasi-monoenergetic Neutron Beams using the 88-Inch Cyclotron

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The Coulombic breakup of the deuteron is being studied as a mechanism for production of high-flux quasi-monoenergetic neutron beams in the range $E_{neutron}$ = 10-32 MeV for neutron cross section measurements on unstable targets and other applications.

Coulombic breakup has been studied for many years, but very little data exists in this energy range, almost no data exists using the thin targets necessary to produce a quasi-monoenergetic beam and most theoretical studies are limited to higher energies. Because of these limitations, we have embarked on three experimental studies to determine the viability of this mechanism:

1. a TOF measurement of the neutrons at forward angles to measure the energy spectrum,
2. an activation foil measurement to get absolute neutron production cross sections, and
3. a study of the breakup cross section on various targets using the LLNL STARS (Silicon Telescope Array for Reaction Studies) detector array to detect the proton.

These three studies are in various stages of completion and are described below.

TOF measurements

For Phase 1 of the neutron project, the neutron production target will be located in the Vault at the entrance to the main switching magnet and the deuterons will be swept into Cave 2. A new beamline has been built into Cave 2 with larger diameter beampipe and good pumping in order to minimize scattered neutrons. This line is presently being commissioned. A Stilbene detector, borrowed from Svedberg Lab in Sweden, was used to measure the neutron energy at 0° by measuring the flight time of the neutrons relative to the Cyclotron RF pulse. Pulse-shape discrimination was used to separate gammas from neutrons. The neutron threshold was 5 MeV. The gamma signal was used to measure the time width of the beam and to determine various locations – in addition to the target – which were contributing to the gamma and neutron spectra. Most of the thermal neutrons could be attributed to neutrons scattering from various locations in the Vault, including downstream of the production target due to beam scattering in the target and from the exit of the Cyclotron itself. The background-subtracted neutron TOF spectra is shown in Figure 1. The contribution from scattering downstream is expected to decrease when Cave 2 is operational since there is an extra set of focusing quadrupoles in the Vault beamline. The contribution from the exit of the Cyclotron can never be totally eliminated in this beamline configuration, but may be decreased by using slits inside the Cyclotron to cut down on the extraction of multiple orbits. These studies are ongoing.

Activation Foil Measurements

Using the same beamline configuration, a set of foils - for which the cross section and energy thresholds of neutron reactions are well-known – were placed in the beam for one short high-intensity run. Measuring the gamma rays from these activated foils using a Ge-detector with a well-calibrated efficiency curve, the flux of neutrons which might be downstream of the switching magnet could be calculated. For this run, 29 MeV deuterons impinged on a thin carbon target, chosen such that approximately 1 MeV was lost in the target, similar conditions to the TOF studies.

The results of this measurement showed that on average, a total of <2-3> x 10^8 neutrons/sec/cm^2 impinged on the foils placed just downstream of the switching magnet at 0°. This number was obtained for the (n,gamma) products, which have a very low energy threshold. For the (n,charged particle) cross sections, which have threshold energies >2.5 MeV, the cross section was varied but averaged around <2-3> x 10^6 neutrons/sec/cm^2. This was significantly lower than expected and the measurement needs to be repeated.

STARS cross section measurements

Another set of ongoing measurements uses the STARS array to detect the proton product of the breakup reaction. Using this we can obtain the relative cross section (compared to elastic scattering) of the breakup peak for various targets. With the target moved into the beam line, an angular range of 2-12° can be covered. This data will be compared to theoretical calculations made by Ian Thompson in order to extract neutron yields from the proton data.

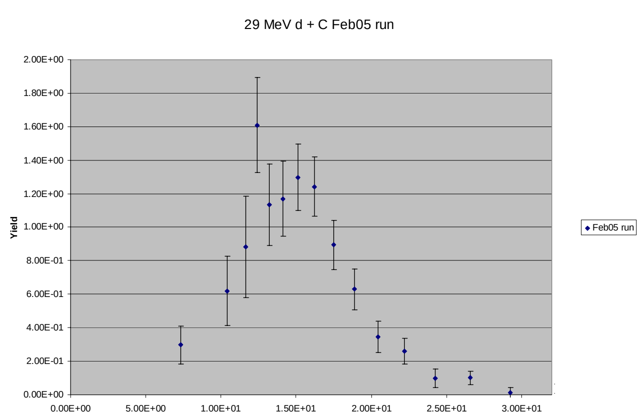

FIG. 1: Measured neutron time-of-flight spectrum