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A HYBRID CHARGED-PARTICLE GUIDE FOR STUDYING
(n, CHARGED PARTICLE) REACTIONS*

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Charged-particle transport systems consisting of magnetic quadrupole lenses have been employed in recent years in the study of (n, charged particle) reactions. We have completed a new transport system that is based both on magnetic lenses as well as electrostatic fields. The magnetic focusing of this charged-particle guide is provided by six magnetic quadrupole lenses arranged in a COCCOC sequence (in the vertical plane). The electrostatic field is produced by a wire at high voltage which stretches the length of the guide and is physically at the center of the magnetic axis. The magnetic lenses are used for charged particles above 5 MeV; the electrostatic guide is used for lower energies. This hybrid system possesses the excellent focusing and background rejection properties of other magnetic systems. For low energy charged-particles, the electrostatic transport avoids the narrow band-passes in charged-particle energy which are a problem with purely magnetic transport systems. This system is installed at the LLNL Cyclograff facility for the study of (n, charged particle) reactions at neutron energies up to 35 MeV.

[Charged-particle spectrometer, magnetic quadrupoles, electrostatic guide, neutron-induced reactions.]

Introduction

In recent years, magnetic quadrupole spectrometers have been used extensively in the study of neutron-induced reactions that produce charged particles.¹⁻³ These spectrometers consist of a magnetic quadrupole lens multiplet that focuses the charged-particle reaction products onto detectors that are a few meters from the neutron source and the target foil. The detectors subtend a small solid angle for background events due to neutrons and secondary gamma rays and thus these backgrounds can be reduced significantly. The magnetic quadrupole lenses restore a large solid angle (several msr) for detecting the charged particles. The net result is a large increase in the signal-to-background ratio.

One disadvantage of the magnetic quadrupole spectrometer is that the magnetic lens acts as a band-pass filter; that is, it accepts only a finite range of energies for a given magnetic field gradient setting. Typical band-widths are in the range of 25 to 35% in $\Delta E/E$. To measure continuum spectra of protons produced by 14-MeV neutron bombardment of target nuclides below A=100, we have found that about 10 magnet settings are required for reliable data, and about half of these are for charged particles below 4 MeV. For targets of light nuclides even more magnet settings are required to investigate the charged particles below 1 MeV. Thus the measurement of the lower energy charged particles can consume a major fraction of the experimental effort.

To measure low energy charged particles more efficiently we have developed a hybrid charged-particle guide that retains the advantages of the magnetic quadrupole spectrometer at the higher energies. For a good signal-to-noise ratio at all energies, the charged particles are transported from the target to the detectors that are a few meters away. The essence of this hybrid spectrometer then is the transportation of the low energy charged particles by a method different from that of using magnetic lenses. Previous work on electrostatic guiding fields⁴ led us to the current design.

Spectrometer Design

Design Considerations

The spectrometer consists of the hybrid charged-particle guide and a particle detector. It is designed for use at the LLNL Cyclograff facility which can be used as a neutron source by accelera-

ting protons or deuterons and directing them to suitable neutron production targets. The source reactions of most interest are the $^2\text{H}(d,n)$ and $^3\text{H}(d,n)$ reactions. The Cyclograff can accelerate deuterons to energies from low energies (around 1 MeV) to 20 MeV and thereby produce neutrons up to 35 MeV. The neutron flux on target is much less than that available in previous experiments at the LLNL Rotating Target Neutron Source--1 (RTNS-1), however, so that a new magnetic lens configuration has been constructed for a larger solid angle of acceptance. The electrostatic transport of low energy particles is all the more necessary to achieve reasonable experimental running times with the reduced flux. Since the angular distribution of the charged particles is to be studied, the spectrometer must in addition be rotatable around an axis passing through the target.

Quadrupole Lens Multiplet

A symmetric magnetic quadrupole lens sextuplet (see Fig. 1) was chosen for the magnetic transport. The two outer lenses have 10 cm diameter apertures and the inner four lenses have 15 cm diameter apertures. The first lens is placed as close as possible to the target for maximum solid angle of acceptance. The order of the lenses is COCCOC (C = converging, O = diverging) in the vertical plane. This symmetric configuration was chosen so that the lens system could be lengthened by separating the first three lenses from the last three. This option will reduce further the background of neutron-induced events in the detectors.

To achieve rotation of the system about an axis passing through the target, the entire spectrometer is placed on a gun mount that allows rotation from 0 to 160 degrees with respect to the incident neutron direction.

Electrostatic Particle Guide

Electrostatic fields have been used previously to guide charged particles produced by the bombardment of materials with neutrons from a reactor.⁴ These studies quantified the efficiency of such a system and furthermore showed that it could be used in a high radiation environment. This latter result is important to the implementation of the present charged-particle guide in the neutron flux from the Cyclograff and especially so if the concept is to be used in the more intense, 34-MeV neutron flux from the RTNS-1.

Fig. 1. Hybrid charged-particle guide for studying (n, α) charged particle reactions. For low charged-particle energies the central high voltage wire acts as a guide for the charged particles which follow trajectories typified by the dotted curve around the wire. For particles of higher energy, the magnetic quadrupole lenses focus the particles which follow trajectories such as shown by the dashed lines for the horizontal (H) and vertical (V) planes.

The electrostatic guide chosen here is similar in principle, but differs in detail from that of Ref. 4. The wire is 1.5 mm diameter nichrome supported by 3 mm glass stalks that are drawn to approximately 1 mm near the wire. The junction between the wire and the stalks is provided by a corona ball, 4.8 mm diameter, through which the wire passes. The diameter of this ball was chosen to improve the voltage-holding properties of the system by reducing the electrical field where the glass stalk meets the wire. The vacuum in the spectrometer is maintained by a cryopump to be better than 1.3×10^{-4} Pa. Voltages of -45 kV can be maintained reliably in this manner.

Test Results

The hybrid charge-particle guide has been tested with a 6 mm diameter ^{244}Cm alpha-particle source (5.7 MeV) in both the magnetic and electrostatic modes. The detector was a silicon surface barrier diode collimated to 7 mm diameter, which is approximately the size of the alpha-particle source. The high-voltage wire was approximately 14 cm from the source on one end and from the detector on the other.

In the magnetic mode the solid angle accepted by the spectrometer for a source of this size was measured to be 6.9 msr or somewhat larger than the 3.1 msr of the magnetic quadrupole triplet used previously at this laboratory. (These solid angles depend on the size of the source of charged particles and hence are larger than the values given in Refs. 1 and 2 for sources of larger size.) The present system places the detector 2.5 m from the neutron source, more than the 2.65 m of the triplet system of Refs. 1 and 2, so that the ratio of solid angle accepted to the square of the distance to the source is better by a factor of 2.7. This value is a measure of the improved signal-to-background ratio.

In the electrostatic mode the acceptance of the

spectrometer for 5.7 MeV alpha particles is 0.22 msr or considerably less than that in the magnetic mode of operation. One reason is that the particles diverge after leaving the guide field and therefore many will miss the detector. This effect can be compensated for by moving the detector closer to the end of the wire or by using a larger detector. At lower charged-particle energies, the efficiency is expected to be larger as shown in Ref. 4. If collisions with the wire or its supports are neglected, the efficiency should vary as $1/E$ for $E \propto qV$ where E and q are the particle energy and charge, and V is the voltage on the wire.

A prototype of the electrostatic guide was tested in the neutron flux of RTNS-1 to see if the voltage-holding characteristics deteriorated under bombardment by 14-MeV neutrons. In this case the voltage on the wire was 50 kV and the neutron flux was 6×10^{10} neutrons/cm² sec⁻¹. No deterioration was seen after bombardment for several hours. Thus we are confident that the system will perform well in the less intense radiation environment at the Cyclotron facility.

Conclusion

We have built and tested a hybrid charged-particle spectrometer for investigating neutron-induced reactions that produce charged particles. This spectrometer uses magnetic focusing for charged particles above a few MeV and an electrostatic guide field for particles of lower energy. The efficiency of the spectrometer in the magnetic mode is larger than that of its predecessor at this laboratory and the background is expected to be lower. In the electrostatic mode, the new spectrometer is used to measure charged particles of low energy without changing the field. The reduction in the number of runs is approximately a factor of 5 for these low energies.

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