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AUG 12 1997

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CONF-970564--

Proton Propagation Through Nuclei and The Quasi-Free Reaction Mechanism Studied with (e, e'p) Reactions.

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QUASI-FREE ($e, e'p$) SCATTERING

Quasi-free ($e, e'p$) scattering is the process in which the incident electron directly knocks out a proton from the target nucleus, with the scattered electron and the knocked out proton detected in coincidence. Important kinematic quantities which can be measured in these processes are missing energy, E_m and missing momentum, P_m . These can be interpreted as measures of the separation energy and initial momentum of the proton in the nucleus. The definitions of these quantities are given below;

$$E_m = \omega - E_{p'} + M_p - T_{A-1} \quad (1)$$

$$\vec{P}_m = \vec{q} - \vec{p}' \quad (2)$$

Here ω is the energy transfer, $\vec{q}$ is the 3 momentum transfer from the electron to the nuclear system, $\vec{p}'$ is the momentum of the outgoing proton, M_p is the proton mass and T_{A-1} is the kinetic energy of the recoiling A-1 nucleons. The coincidence scattering cross-section for such a process in the plane wave impulse approximation (PWIA) can be written as,

$$\frac{d^6\sigma}{d\omega d\Omega_e' dE_{p'} d\Omega_{p'}} = P_{p'} E_{p'} \sigma_{ep} S(E_m, P_m) \quad (3)$$

where $E_{p'}$ and $P_{p'}$ are the energy and momentum of the scattered proton, σ_{ep} is the cross-section of the electron scattering off an off-shell proton [3] and $S(E_m, P_m)$ is the spectral function which gives the probability of finding a proton with separation energy and momentum (E_m, P_m) in the nucleus. If we compare the experimental cross-section with the cross-section calculated using the expression above, we get a measure of the proton attenuation. Under the PWIA it is assumed that there are no final state interactions and that the kinematics of the knocked out proton remains unchanged. Thus the ratio of the measured to the calculated cross-section tells us the fraction of the knocked out protons which emerge from the nucleus without any interaction with the residual nucleons which we define as the transparency T.

$$T = \frac{\int_V d^3P_m dE_m N_{\text{expt}}(E_m, P_m)}{\int_V d^3P_m dE_m N_{\text{PWIA}}(E_m, P_m)} \quad (4)$$

Here V is the finite experimental phase space volume of integration.

RESULTS

The PWIA calculations are done by using a realistic Monte Carlo [2,4,5] simulation of the apparatus, which uses model spectral functions based on the

Abstract. Jefferson Lab experiment E91-013 measured the energy dependence of proton propagation in nuclei, using the quasi-free ($e, e'p$) reaction. The ratios of the experimental ($e, e'p$) cross-sections integrated over the quasi-free region to PWIA calculations are presented as a function of momentum transfer, ($0.6 < Q^2 < 3.3 \text{ GeV}^2$) and target nucleus (C, Fe and Au). As a first step towards a longitudinal and transverse separation of the quasi-free cross-section, a super ratio of the measured to the calculated cross-sections at forward and backward angles is presented.

INTRODUCTION

The propagation of nucleons through nuclei is one of the basic nuclear many body problems. Since electrons can probe the entire nuclear volume and knock protons from deep in the nuclear interior, quasi-free electron-proton scattering is an excellent tool to study proton propagation, if single nucleon currents dominate the reaction mechanism. This assumption can be directly tested by comparing the longitudinal and transverse nuclear response. The longitudinal response is expected to be predominantly single particle in nature while the transverse response can have significant contributions from two-body and n-body currents. Previous experiments at Bates at lower momentum transfer, Q , observed significantly more transverse quasi-free strength than longitudinal strength above the two-body threshold and concluded that multi-nucleon absorption mechanisms were important [1]. Quasi-free experiments at higher Q , seemed to support the single nucleon picture, but did not perform a longitudinal-transverse separation. Experiment NE18 at SLAC found that the measured spectral functions agreed very well with PWIA calculations [2] at Q^2 ranging from 1 to 6.8 GeV^2 . Our experiment was designed to study the reaction mechanism with a longitudinal-transverse separation at two momentum transfers and use this understanding of the reaction mechanism to interpret the ($e, e'p$) results in terms of nucleon propagation through the nucleus.

With these goals in mind, the experiment was carried out at the Thomas Jefferson National Accelerator Facility (Jefferson Lab), in experimental Hall C. The accelerator at Jefferson Lab provided a continuous electron beam with currents of about $20 \mu\text{A}$ and energies ranging from 0.8 to 4.0 GeV. The experiment was performed using the two magnetic spectrometers (The High Momentum Spectrometer, HMS and the Short Orbit Spectrometer, SOS) in the hall. For each momentum transfer, data were taken at several proton angles over the range of quasi-free scattering. The two spectrometers had similar detector packages which consisted of two drift chambers for tracking, two planes of hodoscopes for trigger and time-of-flight, a threshold Čerenkov counter and a Lead-Glass calorimeter for particle identification.

QUASI-FREE ($e, e'p$) SCATTERING

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$$T = \frac{\int_V d^3P_m dE_m N_{expt}(E_m, P_m)}{\int_V d^3P_m dE_m N_{PWIA}(E_m, P_m)} \quad (4)$$

Here V is the finite experimental phase space volume of integration.

RESULTS

The PWIA calculations are done by using a realistic Monte Carlo [2,4,5] simulation of the apparatus, which uses model spectral functions based on the

FIGURE 1. Transparency vs momentum transfer for C, Fe and Au. The present experiment has systematic uncertainty of $\pm 5\%$. NE18 results are from reference [6] and Bates results on C, Ni and Ta targets are from reference [7]

independent particle shell model. Radiative corrections are included in the Monte Carlo and the de Forest prescription ccl1 is used for the off-shell e-p cross-section. Both the data and the simulation were integrated over a finite volume defined by cuts $E_m < 80$ MeV and $|P_m| < 300$ MeV. Fig.1 shows the transparency as a function of momentum transfer Q and target nucleus. The transparency at a particular Q is determined by taking a weighted average of the transparency obtained at different proton angles around the momentum transfer direction. In addition, the transparency was multiplied by a factor (C 1.11, Fe 1.22 and Au 1.28) to correct for correlations, following the procedure of reference [6]. In Fig.1 our results are shown along with the results from the two previous experiments, the Bates [7] and the NE18 [6] experiments. The results from our experiment have less than 1% statistical uncertainty and systematic uncertainty of $\pm 5\%$, which we expect to reduce significantly. Our results are in agreement with the previous experiments and have better accuracy. One can also notice that the transparency is relatively flat beyond Q of 1 GeV. The pair of points at Q of both 0.8 GeV and 1.4 GeV correspond to the forward and backward angle data, with the backward angle data being higher in all cases.

These data, taken with a range in virtual photon polarization, $\Delta\epsilon$, of around 0.5, will enable us to perform a Rosenbluth separation at these kinematics.

At this stage we do not have separated cross-sections, but as a first step we have calculated a super-ratio defined as:

$$R = \frac{\text{data(backward)}/\text{MonteCarlo(backward)}}{\text{data(forward)}/\text{MonteCarlo(forward)}} \quad (5)$$

The top panels of Fig.2 show the super-ratio as a function of missing energy for carbon at the two different Q^2 . Each plot is for proton angles along the momentum transfer directions. The lower panels are plots of missing energy distributions which show the location of the p and s-shell peaks. The super-ratio is unity for the p-shell in both cases. At the lower Q^2 , we see some excess transverse strength beyond 50 MeV in missing energy, while at the higher Q^2 , we do not see any excess transverse strength over the full missing energy region. We are currently in the process of reducing our systematic uncertainties and doing a L/T separation of the data.

FIGURE 2. Top: super-ratio (ratio of the backward angle data to Monte Carlo over forward angle data to Monte Carlo) as a function of missing energy at Q^2 of 0.6 and 1.8 GeV^2 . Bottom: missing energy distribution for the two Q^2 values.

ACKNOWLEDGMENTS

This work was supported in part by the U.S. Department of Energy and by the National Science Foundation.

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