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A. TITLE: Medium Effects of the ($e, e' p$) Nucleon Knockout Reaction

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C. THIS PROPOSAL IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

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Medium Effects of the ($e, e' p$) Nucleon Knockout Reaction

D. ATTACH A SEPARATE PAGE LISTING ALL COLLABORATION MEMBERS AND THEIR INSTITUTIONS

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RESEARCH PROPOSAL TO CEBAF

30 October 1989

MEDIUM EFFECTS ON THE ($e, e' p$) NUCLEON KNOCKOUT REACTION

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ABSTRACT

We propose to measure the quasielastic proton knockout reaction on two target nuclei over a large range of 4-momentum transfer (Q^2). The measurement would be performed in Hall A. The main objective of this experiment is to investigate the medium modification on the nucleon properties in nuclei.

INTRODUCTION AND PHYSICS BACKGROUND

The medium modification on the properties of nucleon in nuclei has been the subject of great interest recently. Probably the most striking phenomenon is the so-called EMC effect.¹ In medium energy nuclear physics, most of the works concentrate on the quasielastic ($e, e' p$) reaction.² However, the results obtained so far are not conclusive due mainly to the final state interactions of the "low" energy outgoing protons.

We propose to measure the proton knockout reaction for two nuclear targets over a range of Q^2 . We plan to use a special kinematics arrangement which we used at MIT-Bates, i.e., we will keep the energy transfer ω , the magnitude of the outgoing proton momentum, and the magnitude of the recoil momentum fixed, while varying the 3-momentum (or 4-momentum) transfer. Furthermore, because of the higher incident electron energy at CEBAF we can choose to keep the outgoing proton energy fixed at a value between 250 and 400 MeV. The combination of higher outgoing proton energy and this new kinematic arrangement is attractive because the variation and the magnitude of the distortion and the uncertainty in the proton bound state wave function can all be kept to a minimum. This would make the situation simpler to investigate the medium effects on electromagnetic current operators of proton in nuclei.

The Q^2 and density dependence of the nucleon form factors G_F^p and G_M^p have been calculated by Shakin.³ Since the variation of G_F^p and G_M^p on Q^2 and density is different, it is important to separate the longitudinal and the transverse response functions for the ($e, e' p$) reactions.

In the one-photon-exchange approximation, the unpolarized differential cross section for the ($e, e' p$) reaction can be written as

$$\left(\frac{d^3\sigma}{d\Omega_e d\Omega_{e'} dE_p} \right) = \frac{m|\vec{p}'|}{2(2\pi)^3} \cdot \left(\frac{d\sigma}{d\Omega_{e'}} \right)_{\text{Mott}} \cdot \left(V_L R_L + V_T R_T + V_{TT} R_{TT} \cos(2\beta) + V_{LT} R_{LT} \cos\beta \right) \quad (1)$$

where the Vs' are the kinematic factors.

MEASURING PLAN AND THE COUNT RATE ESTIMATES

As mentioned in the previous section, we propose to measure only the longitudinal and the transverse response functions in parallel kinematics. In fact, the parallel kinematics are special cases of a more general kinematic arrangement. In this kinematics, we propose to keep the energy transfer ω , the magnitude of the outgoing proton momentum, and the magnitude of the recoil momentum fixed, while varying the 3-momentum (or 4-momentum) transfer by varying the scattered electron angle and the opening angle between the recoil momentum and the momentum transfer vectors. The parallel kinematics would then correspond to the opening angle being either 0° or 180° .

Under the parallel kinematic arrangement, there are two 3-momentum (or 4-momentum) transfers for a given fixed scattered proton momentum (or energy). These two momenta correspond to the situation where the recoil momentum vector is either parallel or anti-parallel to the momentum transfer vector. We propose to take data at three fixed scattered proton energies, i.e., at 250, 325, and 400 MeV, which will enable us to measure R_L and R_T at six values of Q^2 ranging from about 9 f^{-2} to 23 f^{-2} . Tables I and II shows some of the useful kinematics variables for the ground state p -shell knockout on ^{12}C and ^{63}Cu .

We estimate the $^{12}\text{C}(e, e' p)^{11}\text{B}$ (g.s.) and $^{63}\text{Cu}(e, e' p)^{62}\text{Ni}$ (g.s.) reactions coincidence count rates. The differential cross sections for these two targets listed in Tables III and IV were calculated in factorized DWIA using a code which was developed by one of our collaborators (N. S. Chant). Under the parallel kinematic condition, the interference response functions, R_{LT} and R_{TT} , vanish, and the differential cross section for the $(e, e' p)$ reaction becomes

$$\left(\frac{d^3\sigma}{d\Omega_e d\Omega_p dE_{e'}} \right) = \frac{m|\vec{p}'|}{2(2\pi)^3} \cdot \left(\frac{d\sigma}{d\Omega_{e'}} \right)_{\text{Mott}} \cdot \left(V_L R_L + V_T R_T \right) \quad (2)$$

or, after substituting the expressions for the kinematic factors V_L and V_T , Eq. (2) can be rewritten as

$$\left(\frac{d^3\sigma}{d\Omega_e d\Omega_p dE_{e'}} \right) = \frac{m|\vec{p}'|}{2(2\pi)^3} \cdot \left(\frac{d\sigma}{d\Omega_{e'}} \right)_{\text{Mott}} \cdot \frac{Q^2}{2q^2 c} \cdot \left(R_T + c \cdot (2Q^2/q^2) R_L \right) \quad (3)$$

where $c = \left(1 + \frac{2q^2}{Q^2} \cdot \tan^2(\theta_e/2) \right)$. In principle, only two measurements at two

different incident electron energies are needed for the super-Rosenbluth separation for extracting the longitudinal and the transverse response functions. Since we are interested in investigating the possible medium modification of the nucleon properties inside a nucleus, it is our intention to be able to measure both R_L and R_T to an accuracy of a few percents. Therefore, we propose to perform the super-Rosenbluth separation for a given Q^2 (or a given fixed scattered proton energy) at four incident electron energies. These energies are also listed in Tables I and II.

The following parameters are used for the coincidence count rate estimates:

$$\Delta\Omega_e = 7.8 \text{ msr}$$

$$\Delta p_e/p_e = \pm 5\% \text{ (see below)}$$

$$\Delta\Omega_p = 7.8 \text{ msr}$$

$$\Delta p_p/p_p = \pm 5\%$$

$$\begin{aligned} \text{Luminosity} &= {}^{12}\text{C } 1.6-6.2 \times 10^{36}/\text{cm}^2 \text{ sec} \\ &\quad {}^{63}\text{Cu } 0.3-1.1 \times 10^{36}/\text{cm}^2 \text{ sec} \end{aligned}$$

In order to perform a separation of R_L and R_T , we plan to match the acceptances in the physical variables: $|q|$, ω , and $|\vec{P}_B|$. Therefore, the full spectrometer acceptances are not available at all energies. A Monte Carlo calculation was performed to determine the available acceptances for the spectrometers, and an acceptance factor determined from the Monte Carlo was entered into the coincidence count rate estimates. We plan to measure the cross sections in 20 MeV/c $|\vec{P}_B|$ bins between 50 and 110 MeV/c. Part of the acceptance factor is due to this binning. Tables III and IV show the cross sections and beam time needed for at least 5000 counts for ${}^{12}\text{C}$ and 1000 counts for ${}^{63}\text{Cu}$. This requires a total of about 100 hours of beam time.

Also, Table V and VI contain the singles count rates for the two spectrometers, estimated from single arm cross sections developed by Lightbody and O'Connell.⁴ The electron arm includes count rates for e^- and π^- , while the hadron arm count rates are for $p+\pi^+$. For these relatively low single arm rates, the real to accidental ratio is ≥ 50 to 1 for all kinematics.

Most of the collaborators in this proposal have had considerable experiences in carrying out the $(e,e'p)$ experiment. We plan to participate actively in the implementation of both high resolution spectrometers planned in Hall A.

REFERENCES

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TABLE I. Kinematic Variables for ^{12}C

Case	T_p MeV	E_0 MeV	E' MeV	θ_e Deg	θ_p Deg	q (Mev/c)	Q^2 f^{-2}	c	Parallel/ Antiparallel
1	400	775	341.65	127.51	15.99	1034.27	23.0	0.092	$\rightarrow \rightarrow$
2			341.65	93.49	24.21	874.27	15.2	0.255	$\rightarrow \leftarrow$
3		775	376.67	127.51	15.99	1034.27	23.0	0.092	$\rightarrow \rightarrow$
4			376.67	93.49	24.21	874.27	15.2	0.255	$\rightarrow \leftarrow$
5		1550	1133.73	41.83	47.00	1034.27	23.0	0.741	$\rightarrow \rightarrow$
6			1133.73	33.70	46.04	874.27	15.2	0.808	$\rightarrow \leftarrow$
7		2325	1908.73	25.97	53.93	1034.27	23.0	0.887	$\rightarrow \rightarrow$
8			1908.73	21.02	51.58	874.27	15.2	0.918	$\rightarrow \leftarrow$
9		3100	2683.73	18.88	57.16	1034.27	23.0	0.938	$\rightarrow \rightarrow$
10			2683.73	15.31	54.19	874.27	15.2	0.955	$\rightarrow \leftarrow$
11	325	700	341.65	118.15	20.00	925.88	19.0	0.134	$\rightarrow \rightarrow$
12			341.65	86.22	27.91	765.88	12.1	0.313	$\rightarrow \leftarrow$
13		700	376.67	118.15	20.00	925.88	19.0	0.134	$\rightarrow \rightarrow$
14			376.67	86.22	27.91	765.88	12.1	0.313	$\rightarrow \leftarrow$
15		1400	1058.73	41.38	49.14	925.88	19.0	0.752	$\rightarrow \rightarrow$
16			1058.73	32.70	48.34	765.88	12.1	0.823	$\rightarrow \leftarrow$
17		2100	1758.73	25.87	56.01	925.88	19.0	0.891	$\rightarrow \rightarrow$
18			1758.73	20.55	53.72	765.88	12.1	0.924	$\rightarrow \leftarrow$
19		2800	2458.73	18.88	53.24	925.88	19.0	0.943	$\rightarrow \rightarrow$
20			2458.73	15.01	56.28	765.88	12.1	0.958	$\rightarrow \leftarrow$
21	750	600	317.84	117.02	21.59	809.14	15.0	0.143	$\rightarrow \rightarrow$
22			317.84	82.71	30.71	649.14	9.0	0.349	$\rightarrow \leftarrow$
23		600	350.42	117.02	21.59	809.14	15.0	0.143	$\rightarrow \rightarrow$
24			350.42	82.71	30.71	649.14	9.0	0.349	$\rightarrow \leftarrow$
25		1200	933.73	42.29	50.98	809.14	15.0	0.748	$\rightarrow \rightarrow$
26			933.73	32.46	50.58	649.14	9.0	0.831	$\rightarrow \leftarrow$
27		1800	1533.73	26.58	58.03	809.14	15.0	0.889	$\rightarrow \rightarrow$
28			1533.73	20.52	55.94	649.14	9.0	0.927	$\rightarrow \leftarrow$
29		2400	2133.73	19.43	61.36	809.14	15.0	0.938	$\rightarrow \rightarrow$
30			2133.73	15.03	58.49	649.14	9.0	0.960	$\rightarrow \leftarrow$

TABLE II. Kinematic Variables for ^{63}Cu

Case	T_p MeV	E_0 MeV	E' MeV	θ_e Deg	θ_p Deg	q (Mev/c)	Q^2 f^{-2}	ϵ	Parallel/ Antiparallel
1	396	775	355.05	123.23	17.67	1028.65	23.0	0.110	$\rightarrow \rightarrow$
2			355.05	91.36	25.45	868.65	15.2	0.272	$\rightarrow \leftarrow$
3		775	391.44	123.23	17.67	1028.65	23.0	0.110	$\rightarrow \rightarrow$
4			391.44	91.36	25.45	868.65	15.2	0.272	$\rightarrow \leftarrow$
5		1550	1147.82	41.56	47.78	1028.65	23.0	0.746	$\rightarrow \rightarrow$
6			1147.82	33.54	46.92	868.65	15.2	0.812	$\rightarrow \leftarrow$
7		2325	1922.82	25.87	54.67	1028.65	23.0	0.889	$\rightarrow \rightarrow$
8			1922.82	20.98	52.43	868.65	15.2	0.920	$\rightarrow \leftarrow$
9		3100	2697.82	18.84	57.89	1028.65	23.0	0.939	$\rightarrow \rightarrow$
10			2697.82	15.30	55.04	868.65	15.2	0.956	$\rightarrow \leftarrow$
11	322	700	354.55	114.65	21.60	920.64	19.0	0.152	$\rightarrow \rightarrow$
12			354.55	84.38	29.20	760.64	12.1	0.331	$\rightarrow \leftarrow$
13		700	390.94	114.65	21.60	920.64	19.0	0.152	$\rightarrow \rightarrow$
14			390.94	84.38	29.20	760.64	12.1	0.331	$\rightarrow \leftarrow$
15		1400	1072.32	41.09	49.99	920.64	19.0	0.756	$\rightarrow \rightarrow$
16			1072.32	32.52	49.31	760.64	12.1	0.827	$\rightarrow \leftarrow$
17		2100	1772.32	25.76	56.82	920.64	19.0	0.893	$\rightarrow \rightarrow$
18			1772.32	20.49	54.67	760.64	12.1	0.926	$\rightarrow \leftarrow$
19		2800	2472.32	18.82	60.04	920.64	19.0	0.941	$\rightarrow \rightarrow$
20			2472.32	14.99	57.22	760.64	12.1	0.959	$\rightarrow \leftarrow$
21	247	600	333.30	113.38	23.35	804.24	15.0	0.163	$\rightarrow \rightarrow$
22			333.30	80.87	32.16	644.24	9.0	0.368	$\rightarrow \leftarrow$
23		600	364.16	113.38	23.35	804.24	15.0	0.163	$\rightarrow \rightarrow$
24			364.16	80.87	32.16	644.24	9.0	0.368	$\rightarrow \leftarrow$
25		1200	946.82	41.94	51.93	804.24	15.0	0.754	$\rightarrow \rightarrow$
26			946.82	32.25	51.69	644.24	9.0	0.835	$\rightarrow \leftarrow$
27		1800	1546.82	26.44	58.94	804.24	15.0	0.891	$\rightarrow \rightarrow$
28			1546.82	20.44	57.03	644.24	9.0	0.928	$\rightarrow \leftarrow$
29		2400	2146.82	19.36	62.24	804.24	15.0	0.939	$\rightarrow \rightarrow$
30			2146.82	14.99	59.57	644.24	9.0	0.961	$\rightarrow \leftarrow$

TABLE III. Coincidence Count Rate Estimates for ^{12}C

Case	$d^3\sigma/(d\Omega_e d\Omega_p dE')$ (nb/sr 2 -MeV)	Luminosity (10 $^{37}/\text{cm}^2$ sec)	Counts/hr	Running Time (Hours)
1	2.270×10^{-2}	0.6266	9.38×10^2	5.5
2	1.431×10^{-1}	0.6266	7.52×10^3	1.0
3	3.563×10^{-2}	0.6266	1.77×10^3	3.0
4	5.368×10^{-2}	0.6266	3.67×10^3	1.5
5	3.038×10^{-1}	0.6266	1.65×10^4	0.5
6	1.073×10^0	0.3133	6.01×10^4	0.5
7	8.645×10^{-1}	0.6266	2.72×10^4	0.5
8	3.193×10^0	0.1567	9.70×10^4	0.5
9	1.710×10^0	0.6266	3.02×10^4	0.5
10	6.339×10^0	0.1567	1.03×10^5	0.5
11	3.287×10^{-2}	0.6266	1.42×10^3	3.0
12	2.399×10^{-1}	0.6266	1.22×10^4	0.5
13	5.543×10^{-2}	0.6266	2.87×10^3	2.0
14	9.535×10^{-2}	0.6266	6.12×10^3	1.0
15	4.299×10^{-1}	0.6266	2.00×10^4	0.5
16	1.710×10^0	0.3133	6.86×10^4	0.5
17	1.200×10^0	0.6266	3.13×10^4	0.5
18	4.980×10^0	0.1567	1.11×10^5	0.5
19	2.377×10^0	0.6266	5.46×10^4	0.5
20	9.985×10^0	0.1567	1.89×10^5	0.5
21	4.459×10^{-2}	0.6266	1.93×10^3	3.0
22	3.911×10^{-1}	0.6266	1.78×10^4	0.5
23	8.206×10^{-2}	0.6266	4.11×10^3	1.5
24	1.704×10^{-1}	0.6266	7.55×10^3	1.0
25	5.820×10^{-1}	0.6266	2.03×10^4	0.5
26	2.757×10^0	0.3133	7.63×10^4	0.5
27	1.597×10^0	0.6266	3.23×10^4	0.5
28	7.887×10^0	0.1567	1.39×10^5	0.5
29	3.159×10^0	0.6266	3.52×10^4	0.5
30	1.582×10^1	0.1567	1.46×10^5	0.5
			Total	32.5

TABLE IV. Coincidence Count Rate Estimates for ^{63}Cu

Case	$d^3\sigma/(d\Omega_e, d\Omega_p dE')$ (nb/sr ² -MeV)	Luminosity ($10^{37}/\text{cm}^2 \text{ sec}$)	Counts/hr	Running Time (Hours)
1	9.839×10^{-2}	0.1194	2.38×10^2	4.0
2	2.132×10^{-1}	0.1194	1.86×10^2	5.0
3	1.073×10^{-2}	0.1194	2.52×10^1	5.0
4	1.443×10^{-1}	0.1194	1.43×10^2	7.0
5	1.149×10^0	0.1194	3.78×10^2	3.0
6	5.830×10^0	0.1194	1.89×10^3	1.0
7	4.066×10^{-1}	0.1194	6.35×10^2	1.5
8	2.167×10^0	0.0597	1.47×10^3	1.0
9	4.057×10^{-2}	0.1194	7.14×10^2	1.5
10	2.762×10^{-1}	0.0597	1.40×10^3	1.0
11	1.536×10^{-1}	0.1194	3.71×10^2	3.0
12	3.231×10^{-1}	0.1194	8.40×10^2	1.5
13	2.120×10^{-2}	0.1194	5.20×10^1	2.0
14	2.598×10^{-1}	0.1194	6.38×10^2	1.5
15	1.774×10^0	0.1194	4.68×10^2	2.0
16	9.015×10^0	0.0597	1.00×10^3	1.0
17	6.416×10^{-1}	0.1194	7.65×10^2	1.5
18	3.411×10^0	0.0597	1.61×10^3	1.0
19	7.102×10^{-2}	0.1194	8.37×10^2	1.5
20	4.635×10^{-1}	0.0597	1.37×10^3	1.0
21	2.266×10^{-1}	0.1194	5.51×10^2	2.0
22	4.898×10^{-1}	0.1194	1.10×10^3	1.0
23	4.470×10^{-2}	0.1194	8.95×10^1	2.0
24	4.545×10^{-1}	0.1194	1.04×10^3	1.0
25	2.700×10^0	0.1194	5.91×10^2	2.0
26	1.382×10^1	0.0597	1.18×10^3	1.0
27	9.944×10^{-1}	0.1194	8.41×10^2	1.5
28	5.301×10^0	0.0597	1.76×10^3	1.0
29	1.178×10^{-1}	0.1194	9.73×10^2	1.0
30	7.574×10^{-1}	0.0298	8.79×10^2	1.5
			Total	60.0

Table V. Singles Rates for ^{12}C

Case	$e^- + \pi^-/\text{sec}$	$p + \pi^+/\text{sec}$
1	33	16558
2	2431	14459
3	23	16558
4	2109	14459
5	709	12183
6	3083	6508
7	3313	13577
8	6469	4144
9	9144	14753
10	17456	4893
11	71	18522
12	2754	16785
13	51	18522
14	2290	16785
15	1330	16648
16	5723	8708
17	5993	19426
18	11984	5756
19	16226	21622
20	31958	6893
21	145	25978
22	3217	24445
23	106	25978
24	2754	24445
25	2447	26494
26	11009	13475
27	10648	31109
28	22891	8828
29	28685	35028
30	60403	10574

Table VI. Singles Rates for ^{63}Cu

Case	$e^- + \pi^-/\text{sec}$	$p+\pi^+/\text{sec}$
1	30	10862
2	2595	9007
3	21	10862
4	1977	9007
5	592	7208
6	5712	7584
7	2704	8821
8	12078	5430
9	7360	10102
10	32782	6794
11	65	13460
12	2908	11582
13	46	13460
14	2168	11582
15	1099	10822
16	5340	5584
17	4836	13537
18	22682	8004
19	12915	15682
20	60610	10038
21	132	21709
22	3372	19619
23	95	21709
24	2448	19619
25	2002	49729
26	10384	9934
27	8513	23994
28	43362	13482
29	22379	27642
30	57583	8275