## A-DEPENDENCE OF HIGH-ENERGY INELASTIC ELECTRON-NUCLEUS SCATTERING

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## \_ ABSTRACT

Differential cross sections for the inelastic scattering of electrons from hydrogen, deuterium, beryllium, aluminum, copper and gold have been measured at incident electron energies of up to 19.5 GeV at a laboratory scattering angle of six degrees. In the final state only the electron was detected. Within the stated errors, the cross sections were found to be directly proportional to the sum of the constituent nucleon cross sections.

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As part of an experiment at the Stanford Linear Accelerator Center (SLAC) primarily studying deep inelastic electron-proton (e-p) and electron-deuteron (e-d) scattering<sup>1</sup>, we have also investigated electron scattering from beryllium, aluminum, copper and gold.<sup>2</sup> The cross sections for electron scattering from protons and neutrons, as extracted from the e-p and e-d cross sections, have been used in the analysis of the electron-nucleus (e-A) data to examine nuclear shadowing for virtual, space-like photons, as has been done by others for real photons.<sup>3</sup> As observed in this experiment, the equality of the e-A cross sections to the sum of the constituent nucleon cross-sections differs from the predictions of vector dominance theories.<sup>4,5</sup>

We measured the doubly differential cross section  $d^2\sigma$  (E,E', $\theta$ )/d $\Omega d$ for scattering an electron from an incident energy E to a final energy E' centered in an energy interval dE' and into a solid angle d $\Omega$  centered on a laboratory scattering angle  $\theta$ . Measurements were made with all targets for a  $\theta$  of  $6^{\circ}$  and for six values of E from 4.5 to 19.5 GeV. Values of E' at each E ranged from slightly above that corresponding to elastic e-p scattering down to about 2.5 GeV. The data taken spanned ranges in squared four momentum transfer  $Q^2 = -q^2 = 4EE' \sin^2\theta/2$  of  $3.7 \gtrsim Q^2 \gtrsim 0.1 \text{ GeV}^2$ , in electron energy loss  $\nu = E-E$ of  $17.0 \gtrsim \nu \gtrsim 0.1 \text{ GeV}$ , and in the mass of the unobserved final hadronic state (defined as if the scattering occurred from a free proton of mass  $W = (M^2 + 2M\nu - Q^2)^{\frac{15}{2}}$  of  $5.7 \gtrsim W \gtrsim M$  GeV. Uncertainties, due to radiative corrections at low E' and arising from the presence of

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resonance enhancements at small W, cause us to present data here only from the restricted kinematic range E' $\gtrsim$  5 GeV and W $\gtrsim$ 2 GeV, thus limiting 13.6  $\gtrsim$  V  $\gtrsim$  2.0 GeV and 3.3  $\gtrsim$  Q<sup>2</sup>  $\gtrsim$  0.4 GeV<sup>2</sup>.

Acquisition and analysis of all the data were essentially the same as that reported previously for hydrogen and deuterium.<sup>1</sup> The primary electron beam of SLAC was energy analyzed to a width  $\Delta E/E=\pm 0.25\%$ . Its intensity was measured just before the targets using two independent toroid charge monitors which were calibrated against a Faraday cup at every E. The targets were all about 0.01 radiation lengths thick (except for A1, the dummy cell for the liquid targets, about 0.002 rl thick, and for Au about 0.006 rl thick), ranging from about 7 cm for H and D to about 0.002 cm for Au.

Scattered particles were analyzed with a double focussing magnetic spectrometer capable of momentum analysis up to 20 GeV/c. Slits limited the vertical angular acceptance to  $\pm$  4.2 mrad. Two scintillation counter hodoscopes were used to limit the horizontal (scattering plane) angular acceptance to  $\pm$  3.7 mrad and the momentum acceptance to  $\frac{+1.55\%}{-1.70\%}$ . Electrons were distinguished from other particles, primarily pions, by using information from a threshold Cerenkov counter and a shower detector composed of alternating layers of lead and lucite.

The measured electron yields were converted to differential cross sections after corrections were made for fast electronics dead time, computer sampling dead time, and electron detection and identification inefficiencies. These corrections had quasi-random

errors ( $\leq 1\%$ ) which were folded in quadrature with the counting errors. Electron yields from  $\pi^{\circ}$  decays and pair production processes, obtained by reversing the spectrometer polarity and measuring positron yields, were subtracted. Checks were made periodically with empty solid target holders to verify that backgrounds due to particles from the beam halo were negligible.

Also folded into the errors in quadrature were the estimated errors in the target thicknesses due to variations in density or thickness over the area of the beam spot, including the effects of beam heating. These were  $\pm 0.5\%$  (Be),  $\pm 1.0\%$  (H, D, Cu), and  $\pm 3.0\%$  (A1, Au). We estimate further normalization uncertainties due to target thicknesses of  $\pm 2\%$  (Cu) or  $\pm 5\%$  (A1, Au), which are not folded into the errors of the cross sections. Other systematic uncertainties, which cancel in ratios of the cross sections, and which are not folded with the other errors, arise from spectrometer solid angle and momentum acceptance ( $\pm 2\%$ ); scattering angle ( $\pm 0.1 \text{ mrad}$ , or  $\pm 1\%$  in the cross sections); energy calibration of the incident and scattered electron beams ( $\pm 0.2\%$  or  $\pm 1\%$  in the cross sections); calibration of the charge monitors ( $\pm 0.5\%$ ) and counter efficiencies ( $\pm 1\%$ ).

Radiative corrections to the measured cross sections were performed in two steps: (a) radiative tails from elastic and quasi-elastic e-A scattering were subtracted; and (b) inelastic radiative corrections were made yielding final cross sections. The elastic tails were calculated using cross sections derived from a Woods-Saxon model<sup>6</sup> for the

nuclear charge distribution and constituted less than 10% of the measured cross sections, within our restricted kinematic range. The quasi-elastic tails were calculated using cross sections derived from a Fermi-gas nuclear model<sup>7</sup> and similarly were less than 10% of the measured results. The inelastic radiative corrections formulae were the same for all targets<sup>2</sup>. We estimate the total systematic uncertainty from the radiative corrections to be about 5% over this kinematic range and refative uncertainties for the several targets to be no-more than about 3%.

We discuss the results in terms of the shadowing factors

 $F(A) = \sigma_A / (N \sigma_d - (N-Z) \sigma_{pd})$ where  $\sigma_A = d^2 \sigma_A / d \Omega dE'$  is the differential cross section for e-A scattering where the nucleus of atomic number A contains Z protons and N neutrons,  $\sigma_d$  is the e-d scattering cross section and  $\sigma_{pd} = \sigma_p / S_{pd}$  is the effective e-p cross section for scattering from a proton bound in a deuteron. We calculate the correction factor  $S_{pd}$  for proton motion in the deuteron according to the theory of West<sup>8</sup> as modified by Bodek<sup>9</sup>, and find 1.009  $\leq S_{pd} \leq 1.028$ . Any significant deviation of F(A) from unity could be interpreted in terms of shadowing of one nucleon by another inside the nucleus.

In Figures 1(a)-1(d) we show F(A) versus  $\nu$  for our four nuclear targets, with corresponding points from real photoproduction, where available<sup>3</sup>. The curves shown for comparison are calculated from a generalized vector dominance theory<sup>4</sup>, including  $\rho$ ,  $\omega$ ,  $\phi$  and continuum contributions. In Figure 1(e) we show the A-dependence

exponent X, found at each  $\gamma$  by fitting a function  $A^{X-1}$  to four corresponding F(A). The average value of X is  $\overline{X} = 1.0003\pm0.0009$ . In Figures 1(f)-1(j) we show F(A) for our four targets, and X, versus  $Q^2$  with curves calculated from GVD<sup>4</sup>.

We have fitted functions a + by to the results shown in Figures 1(a)-1(e), and functions  $c + dQ^2$  to those in Figures 1(f)-1(j) Table 1 gives the parameters of these fits. These fits are acceptab statistically, and adding additional terms did not yield significant improvement. We checked that our results are insensitive to the radiative correction procedure by repeating the above analysis and fits using the measured cross sections instead of the final cross sections. Typically a and d decreased, and b and c increased by one standard deviation compared with the values in Table 1.

We also made an estimate of the differences between the effects of nucleon motion in the deuteron and in the heavier nuclei by calculating  $F = \sigma_A / (Z \sigma_{pA} + N \sigma_{nA})$  where  $\sigma_{pA}$  and  $\sigma_{nA}$  are the effective e-nucleon cross sections for scattering from nucleons bound in a nucleus using the same technique as for the deuteron<sup>8,9</sup> but with a cru nuclear model for the nucleon momentum distribution.<sup>10</sup> The new value of F and X were fitted as above with the result that, compared with Table 1, the values of a and c decreased by about one-half standard deviation, and the values of b and d remained nearly the same.

In conclusion, we have found that within the errors the cross sections for electron scattering from nuclear targets in the spacelike  $Q^2$  region, for 0.4 GeV<sup>2</sup>  $\leq Q^2 \leq 3.7$  GeV<sup>2</sup>, are

equal to the sum of the cross sections for scattering from their constituent nucleons. Early versions of vector meson dominance<sup>5</sup> did not accurately predict the shadowing observed in photoproduction, and disagree even more strongly with the data presented in this paper. More recent versions of vector dominance<sup>4</sup> are in reasonable agreement with the results of photoproduction but still predict shadowing effects in electroproduction which do not appear to be supported by our data.

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## Figure Caption

Figure 1

Shadowing factors F(A) for Be, Al, Cu, and Au, and A-dependence exponents X from fitting the four F(A) at each  $\nu$  and Q<sup>2</sup> with the function F(A) = A<sup>X-1</sup>. In (a)-(e) these are shown versus energy loss  $\nu$ , and in (f)-(j) versus Q<sup>2</sup>. Note that the zeros on all vertical scales are suppressed. The cross sections used are final radiatively corrected and the errors include statistical and quasi-random components, as discussed in the text. The five curves shown are calculated from the gencralized vector dominance theory of Schildkneckt (Ref. 4). On (a) - (d), the lowest curve is for  $Q^2 = 0$ , the next for  $Q^2 = 0.25$ , then 0.75, 1.5 and 4.0  $\text{GeV}^2$ . On (f) - (i), the lowest curve is for  $\mathbf{Y}$  = 14, the next for  $\mathbf{Y}$  = 10, then 7, 4, and 2 GeV. No curves are shown on (e) or (j) because the GVD predictions are not well represented by the parametrization  $F(A) = A^{X-1}$ . The photoproduction results for  $\bigvee \langle 4 \rangle$  GeV are from Brookes et al.; the rest are from Caldwell et al. The photoproduction results in (a) are for carbon and in (d) are for lead.

Table 1

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Parameters from fitting the shadowing factors F(A) and the A-dependence exponent X with the functions  $a + b\nu$  or  $c + dQ^2$ . The cross sections are final radiatively corrected and the errors include statistical and quasi-random components, as defined in the text.

Fitted	1000 b		1000 d	
Quantity-	a	(GeV <sup>-1</sup> )	c (GeV <sup>-2</sup> )	
F(Be)	0.9841±0.0107	0.5+1.6	0.9872±0.0114 -0.4±6.1	
F(A1)	0.9898±0.0250	-0.4+3.8	1.0339±0.0248 -25.3±11.9	
F(Cu)	1.0277 <u>+</u> 0.0145	-4.5+2.1	0.9968 <u>+</u> 0.0148 2.0 <u>+</u> 8.0	
F(Au)	1.0758 <u>+</u> 0.0238	-7.3 <u>+</u> 3.5	1.0505 <u>+</u> 0.0241 -12.7 <u>+</u> 12.8	
х	1.0047 <u>+</u> 0.0023	-0.7 <u>+</u> 0.3	1.0026 <u>+</u> 0.0023 -1.4 <u>+</u> 1.2	

Best Fit Parameters and Their Errors



k.