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THE A-DEPENDENCE OF DEEP-INELASTIC ELECTRON SCATTERING FROM NUCLEI*

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ABSTRACT

The deep inelastic electron scattering cross sections per nucleon σ_A for d, He, Be, C, Al, Ca, Fe, Ag, and Au were measured in the kinematic range $0.09 \leq x \leq 0.9$ and $2 \leq Q^2 \leq 15$ $(\text{GeV/c})^2$ using electrons with energies ranging from 8 to 24.5 GeV. The ratio σ_A/σ_d is consistent with unity in the range $0.1 < x < 0.3$. For $0.3 < x < 0.8$, the ratio decreases logarithmically with atomic weight A, or linearly with average nuclear density. No Q^2 dependence in the ratio was observed over the kinematic range of the data.

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Significant differences in the inelastic structure functions of Fe, Al, and deuterium nuclei have recently been observed in muon[1] and electron[2] scattering experiments. This has been interpreted as a distortion of the quark momentum distributions in bound nucleons. To study the A-dependence of this effect, we have measured differential cross sections for the inelastic scattering of electrons from deuterium, He, Be, C, Al, Ca, Fe, Ag, and Au over a large kinematic range (x values between 0.09 and 0.9 and Q^2 values of 2, 5, 10, and 15 $(\mathrm{GeV/c})^2$). The experiment was performed in May and June, 1983. The results have been published in Physical Review Letters and in a SLAC-PUB.[3]. The SLAC-PUB differs from the journal article in that it contains all the measured cross section ratios in tabular form, making it easier to compare with theoretical predictions.

The Stanford Linear Accelerator Center (SLAC) provided electrons with incident energies (E) ranging from 8 to 24.5 GeV. The SLAC 8 GeV/c spectrometer was used at 20 kinematic settings to detect electrons with energies (E') from 3.1 to 8.4 GeV scattered at angles (θ) between 11° and 23°. A nitrogen-filled threshold Čerenkov counter and a 20 radiation length (r.l.) segmented lead glass shower counter were used to identify electrons whose trajectories were defined by ten planes of proportional wire chambers. The target assembly consisted of a 15 cm long cylindrical target of recirculating liquid deuterium, a 25 cm long cylindrical target of recirculating pressurized helium, empty target cells, and >99.9% pure solid targets with natural isotopic abundances. To monitor the d and He target densities, the SLAC 1.6 GeV/c spectrometer was used as a relative luminosity monitor for all data taking. The measured cross sections were radiatively corrected using the method of Mo and Tsai[4] in a manner similar to that described in Stein *et al.*[5] The Z-dependent correction for the nuclear Coulomb field was not applied, but has been calculated[6] to be less than 1.5% for Au over our kinematic range. The cross sections were adjusted to compensate for neutron excess, such that σ_A represents the cross section per nucleon of a hypothetical nucleus with an equal number (A/2) of protons and neutrons. Using the approximation $\sigma_n = \sigma_p(1 - 0.8x)$, corrections as large as 10% for Au were obtained at $x = 0.8$. A small correction was also made for the 1.5% contamination of HD in the deuterium target.

The deuterium cross sections extracted from the data are in excellent agreement (see Fig. 1) with a fit to previous data[7] in the same kinematic region. Systematic uncertainties (Δ) in the ratios σ_A/σ_d due to radiative corrections (±0.6%), spectrometer acceptance (±0.3%), electronics dead time (±0.3%), beam intensity monitoring (±0.1%), pion backgrounds (±0.5%), neutron excess (up to ±0.7%), and pair-symmetric electron backgrounds (up to ±0.5% except ±2% at $x = 0.09$) were, when added in quadrature, comparable to the uncertainties in the target thicknesses, estimated to be ±0.8% for deuterium and ±0.5% to ±1.5% for the other targets.

Within the quark-parton model, the variable $x = Q^2/2M_p\nu$ is related to the momenta of the quarks in a nucleon, where $Q^2 = 4EE'\sin^2(\theta/2)$, $\nu = E - E'$, and M_p is the proton mass. The structure functions W_1^A and W_2^A per nucleon are related to the differential cross section per nucleon by

$$\sigma_A = \sigma_M \left[W_2^A(x, Q^2) + 2W_1^A(x, Q^2)\tan^2(\theta/2) \right]$$

where $\sigma_M = 4\alpha^2 E'^2 \cos^2(\theta/2)/Q^4$. The ratio $W_2^A/W_1^A = (1+R)/(1+Q^2/4M_p^2x^2)$ is determined by $R = \sigma_L/\sigma_T$, the ratio of the cross sections for absorption of longitudinal and transverse virtual photons. To study the possible A-dependence of R, measurements were made at $Q^2 = 5$ (GeV/c)^2 and $x = 0.3$, 0.5, and 0.7 using two different angles θ for each x value. The results are shown in Fig. 2. The errors are statistical only. The results are consistent with the average value for deuterium ($R = 0.24 \pm 0.1$) from previous measurements[8] in our kinematic region, but do not exclude an increase with A that would change the extracted structure function ratios by as much as 8% . The effect would be biggest at low x. Therefore we do not make the assumption that $W_2^A/W_2^d = \sigma_A/\sigma_d$ in this paper.

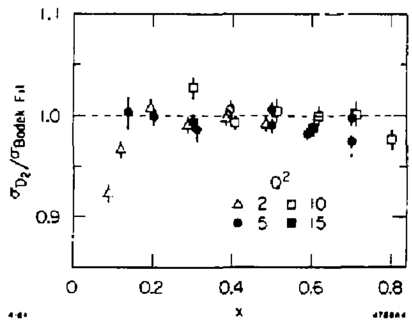

Fig. 1. Comparison of present deuterium cross sections with a fit to previous data. The fit is not valid for $x < 0.13$.

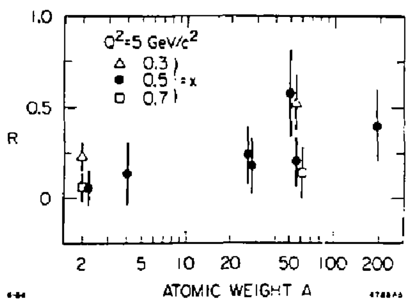

Fig. 2. Values of $R = \sigma_L/\sigma_T$ obtained at $Q^2 = 5$ (GeV/c)^2 for deuterium, He, Al, Fe, and Au.

Figure 3(a) shows our data for the ratio σ_{Fe}/σ_d (taken at Q^2 values of 2, 5, 10 and 15 (GeV/c)^2), along with data from higher energy muon experiments[1,9]. Our data show no statistically significant Q^2 dependence,even at low x, where nuclear shadowing is expected to be important. Comparison with the muon data[1] ($\Delta \approx \pm 6\%$) shows good agreement except in this same low x region.

Because we see no significant Q^2 dependence in our data, Figs. 3(b-i) show Q^2-averaged ratios for each target in finer x bins than in Fig. 3(a). Also shown are data from Stein *et al.*[5] for Be ($\Delta = \pm 3.2\%$), Al ($\Delta = \pm 3.2\%$), Cu ($\Delta = \pm 4.2\%$), and Au ($\Delta = \pm 10\%$) and from Bodek *et al.*[2] for Al ($\Delta = \pm 2.3\%$) and Fe ($\Delta = \pm 1.1\%$). Systematic differences between our results and the earlier data are within quoted systematic errors. The data for all the targets display a similar trend. The deviation from unity is largest for x near 0.6 and is larger for the heavier elements. Except for $x > 0.8$, the trend of the data is opposite to that expected from Fermi motion effects[10,2].

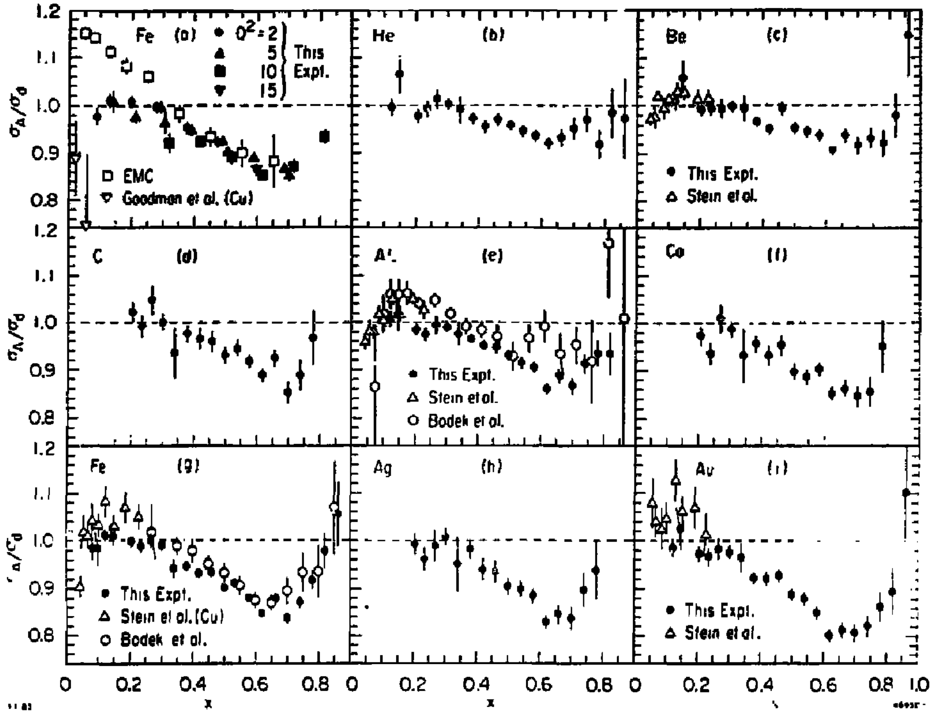

Fig. 3. (a) σ_{Fe}/σ_d as a function of x for various values of Q^2, as well as higher energy muon data from Refs. 1 and 9. (b)-(i) σ_A/σ_d averaged over Q^2 as a function of x for various nuclei, as well as electron data from Refs. 2 and 5. The errors shown are statistical only.

Figure 4 shows Q^2-averaged ratios σ_A/σ_d as a function of atomic weight A for two selected values of x. The data may be equally well described by two-parameter fits of the form $\sigma_A/\sigma_d = cA^{\alpha}$ or $\sigma_A/\sigma_d = a[1 + b\rho(A)]$, where $\rho(A)$ is the average nuclear density[11]. Values of α and b from fits to our data are shown in Fig. 5. The systematic uncertainties in the target thicknesses were included in the fits, resulting in χ^2 per degree of freedom of ≈ 1.2 for either type of fit.

The data do not directly correlate with binding energy per nucleon, which peaks around Fe, since the observed ratios continue to decrease for A above Fe. The anomalous binding energies and nuclear densities for d and He make them of particular interest. For $x > 0.4$, where $|\alpha|$ and $|b|$ are large, the x-averaged ratio σ_A/σ_d for d (He) differs from the power fit by $1.3 \pm 0.3\%$ ($-1.9 \pm 0.4\%$), and from the nuclear density fit by $0.3 \pm 0.3\%$ ($2.0 \pm 0.4\%$).

These differences are only slightly greater than the systematic uncertainties in the d and He normalizations.

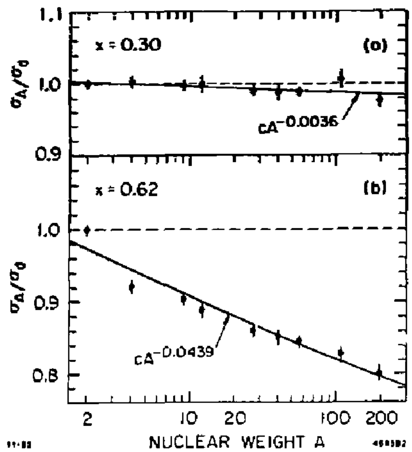

Fig. 4. Q^2-averaged ratios σ_A/σ_d versus A at fixed x. (a) $x = 0.3$, (b) $x = 0.62$. The solid line is a fit of the form $\sigma_A/\sigma_d = cA^{\alpha}$. The errors shown are statistical only.

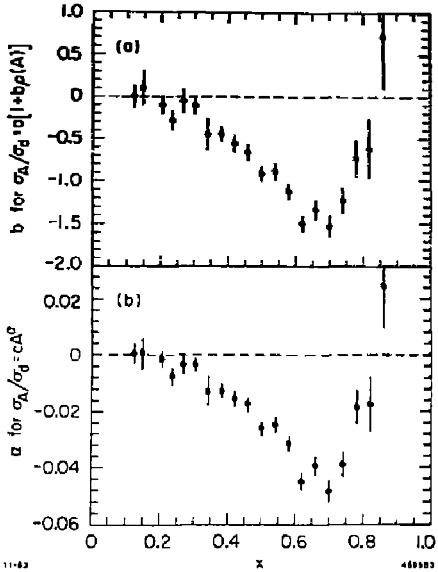

Fig. 5. Values as a function of x of parameters in fits to Q^2-averaged ratios σ_A/σ_d. (a) nuclear density fit and (b) power law fit.

Theoretical mechanisms[12] for the distortions of structure functions of bound nucleons include ideas such as multi-quark bags, a larger confining radius for bound nucleon bags, delta resonances in nuclei, and an enhancement of the abundance of pions or quark-antiquark pairs in large nuclei. Our data on the atomic weight dependence of nuclear cross sections have already provided a test for such models (see other contributions to this conference).

We are presently studying the possibility of extracting the ratio of neutron and proton structure functions by comparing deep inelastic scattering from ^{3}He and tritium targets. Since the nuclear wave functions for these two isotopes are similar, this way of looking at the neutron should provide a good check of the results previously obtained using hydrogen and deuterium targets, where fermi motion and other nuclear effects complicate the interpretation.

We are also interested in investigating the region $x > 1$ for a variety of nuclei. Some 'archeological' data for σ_{Al}/σ_d and σ_{Al}/σ_{He} are presently being analyzed. It is possible that more data may be obtained in the future using the new Nuclear Physics Injector being built at SLAC. It will provide an 80 ma peak current beam at 180 pps, with energies from 0.5 to 3.0 GeV.

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