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MEASUREMENT OF THE A-DEPENDENCE OF THE EMC EFFECT AND R IN DEEP-INELASTIC ELECTRON SCATTERING FROM NUCLEI*†

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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 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 23 settings to detect electrons with energies (E') from 3.1 to 8.4 GeV scattered at angles (θ) between 11° and 23°.

The measured cross sections were radiatively corrected using the method of Mo and Tsai[3] in a manner similar to that described in Stein et al.[4] The Z-dependent correction for the nuclear Coulomb field was not applied, but has been calculated[5] 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 $x = 0.8$.

The deuterium cross sections extracted from the data are in excellent agreement (±2%) with a fit to previous data[6] in the same kinematic region. Systematic uncertainties (Δ) in the ratios σ_A/σ_d due to radiative corrections (±0.6%), sepctrometer 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 ±1.2% 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

$$\begin{aligned}\sigma_A &= \sigma_M\left(W_2^A(x,Q^2) + 2W_1^A(x,Q^2)\tan^2(\theta/2)\right)\\ &= \sigma_M/\varepsilon\cdot W_2^A(x,Q^2)(1+\varepsilon R^A(x,Q^2))/(1+R^A(x,Q^2))\end{aligned} \qquad (1)$$

where $\sigma_M = 4\alpha^2E'^2\cos^2(\theta/2)/Q^4$ and ε is the photon polarization. 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. Results[7] for σ_A/σ_d have been recently published so this talk will concentrate on the measurement of R. To extract $W_2^A/W_2^d = F_2^A/F_2^d$ from the cross section it necessary to measure the A dependence of R. To study this measurements were made at $Q^2 = 5\,(\mathrm{GeV}/c)^2$ and $x = 0.3$, 0.5, and 0.7 using two different angles θ for each x value. The resulting x-averaged values for R are 0.112±0.048 for d, 0.127±0.174 for He, 0.195±0.112 for Al, 0.299±0.079 for Fe, and 0.382±0.197 for Au. 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. However, as described below, in the best fit to our data R has an A dependence that would give a large difference between σ^A/σ^d and F_2^A/F_2^d. Therefore, one must be careful to distinguish between the experimentally measured cross sections which depend on x, Q^2 and ε and the derived structure functions which depend on x and Q^2.

Figure 1 (a) shows our data for the ratio σ_{Fe}/σ_d (taken at Q^2 values of 2, 5, 10 and 15 $(\mathrm{GeV}/c)^2$), along with data from higher energy muon experiments[1,9]. While our data alone show no significant Q^2 dependence, ($\chi^2/\mathrm{df} = 1.2$ to this hypothesis) comparison with the higher Q^2 and ε muon data[1] ($\Delta \simeq \pm 6\%$) indicate a Q^2 or R dependence for $x < 0.3$.

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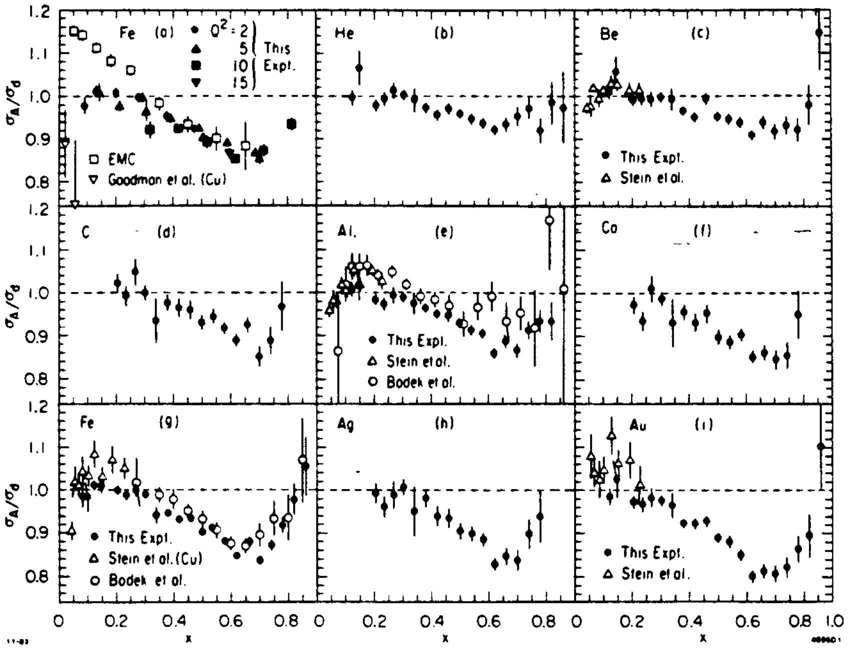

Fig. 1. (a) σ_{Fe}/σ_d as a function of x for various values of Q^2, as well as higher energy muon data from Refs. 1 and 9. (b)-(i) σ_A/σ_d averaged over Q^2 as a function of x for various nuclei, as well as electron data from Refs. 2 and 4. The errors shown are statistical only.

Because we see no significant Q^2 dependence in our data, Figs. 1(b-i) show Q^2-averaged ratios for each target in finer x bins than in Fig. 1(a). Also shown are data from Stein et al.[4] for Be (Δ = ±3.2%), Al (Δ = ±3.2%), Cu (Δ = ±4.2%), and Au (Δ = ±10%) and from Bodek et al.[2] for Al (Δ = ±2.3%) and Fe (Δ = ±1.1%). Systematic difference 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]

In order to make a better comparison with the results of other experiments taken at different kinematic conditions we have plotted in Fig. 2 the ratio σ_{Fe}/σ_d vs ϵ with the statistical errors. From eq. 1 $\sigma_{Fe}/\sigma_d \sim (1+\epsilon(R_{Fe}-R_d))W_2^A/W_2^d$ for R small. The best linear fits to our $Q^2 = 5$ data at $x = 0.3$, 0.5 and 0.7 have slopes $d(\sigma_{Fe}/\sigma_d)d\epsilon = 0.15\pm0.12$, 0.19 ± 0.11 and 0.11 ± 0.11.

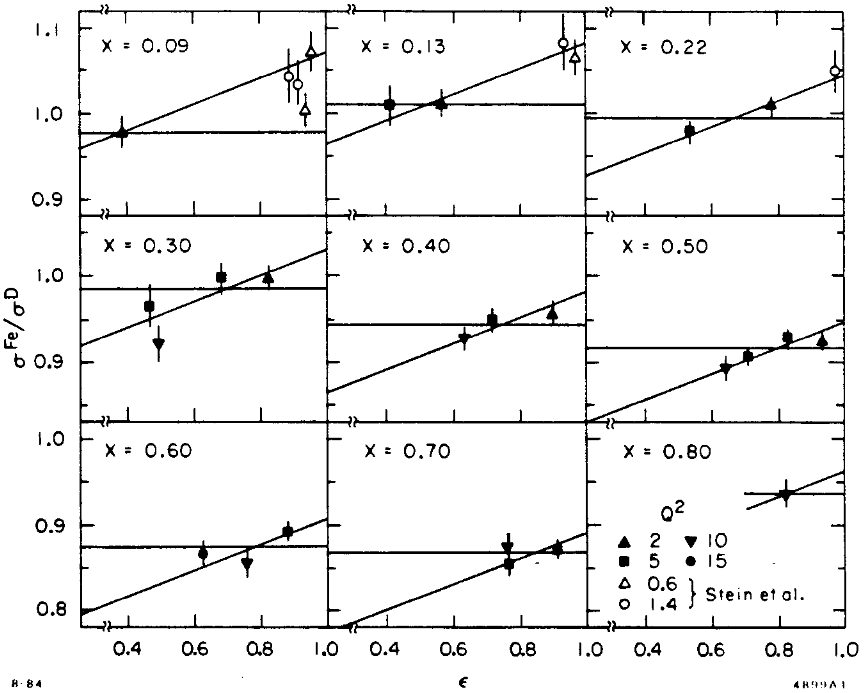

Fig. 2. σ_{Fe}/σ_d as a function of ϵ for various values of x.

Since $R = R(x,Q^2)$ we must be **careful** when averaging these results. The average value of the slope of 0.15 gives $(R_{Fe}-R_d) \sim 0.16\pm0.08$. In Fig. 2 are lines with slope .15 which are separately normalized at each value of x to best fit the data shown ($\chi^2/df = 1.2$). The best horizontal lines ($R_{Fe} = R_d$) have a $\chi^2/df = 2.5$. Remember that we have used statistical errors only and that when systematic errors are included, the worlds data is consistant with no A dependence of R.

Fig. 3a & b show F_2^{Fe}/F_2^d and F_1^{Fe}/F_1^d extracted from our data using $d(\sigma_{Fe}/\sigma_d)/d\varepsilon = 0.15\pm0.12$ with the large error indicating possible x and Q^2 dependence of R. The inner error bars show the errors on the cross section while the outer errors fold in the statistical uncertainty of the R measurement (which are common to all the data points). Systematic errors are still under investigation, but are expected to be smaller than the statistical errors. Our results for F_2^{Fe}/F_2^d are consistant with the muon data for all values of x but with very large errors.

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 $\sigma_A/\sigma_d = (1+b\rho(A))$, where $\rho(A)$ is the average nuclear density[7]. 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.

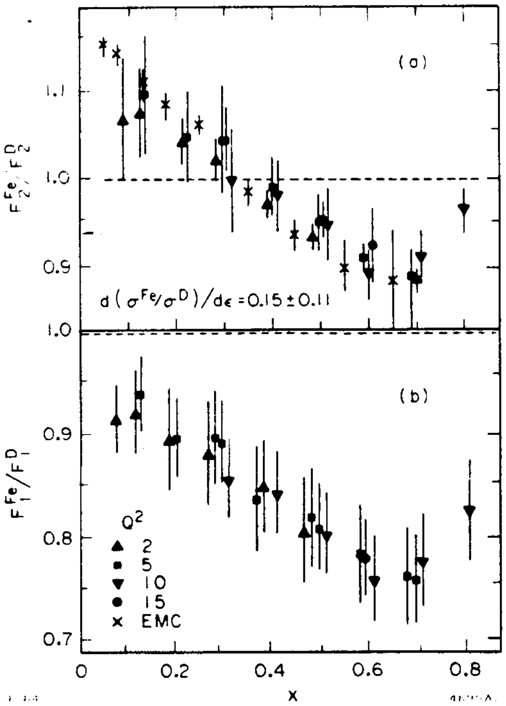

Fig. 3. (a) F_2^{Fe}/F_2^d and (b) F_1^{Fe}/F_1^d as a function of x for various values of Q^2, as well as higher energy muon data from Ref. 1. The outer error bars include the statistical errors in the R measurement.

Theoretical mechanisms[11] 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. The predictions of a model[12] with a larger confining radius for the nucleon bag is shown in Fig. 4.

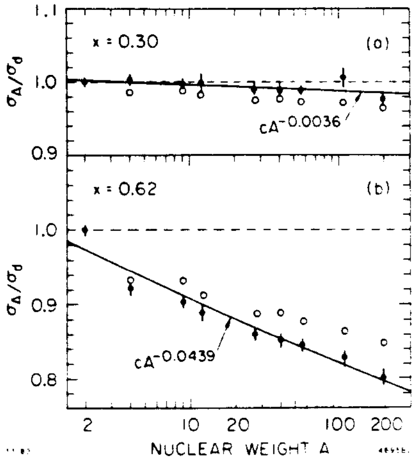

Fig. 4. Q^2-averaged ratios σ_A/σ_d versus A at fixed x. (a) x = 0.3, (b) x = 0.62. The solid line is a fit of the form $\sigma_A/\sigma_d = cA^\alpha$. The errors shown are statistical only. The predictions of Ref. 12 are also shown.

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