Quark Delocalization

In 1999 a remarkable quark effect was discovered. High-energy electrons were scattered from quarks in protons and neutrons. At high energy, the electron-quark interaction is dominantly *magnetic*. It was found, however, that the interaction becomes mainly *charge like* if the quarks are residing in a dense atomic nucleus. This unexpected finding can be explained by assuming that quarks are sometimes delocalized. In other words, the quarks are not always confined to one nucleon.

High-energy electron scattering experiments have led to the discovery of quarks and gluons, the constituents of matter[1]. In such experiments point-like electrons probe the dynamics of quarks and gluons inside the proton and the neutron. The momentum distribution of the quarks has been measured in this way, for instance.

The interaction of a high-energy electron with a quark is mainly magnetic, i.e., the spin of the quark is flipped in the scattering process (see fig. 1). Since the quark carries a (fractional) charge, the interaction between a quark and an electron has a charge-like component as well. However, at the electron energies required to resolve the quark structure of matter, the charge component is much weaker. Hence, it came as a surprise when measurements at the HERMES experiment (DESY, Hamburg) indicated a large enhancement of charge-like electron-quark scattering when the scattering process occurs inside the atomic nucleus ^{14}N. In fact, the ratio R of charged to magnetic electron-quark scattering turned out to be increased by a factor of 5 for quarks inside ^{14}N as compared to its value in deuterium[2]. These results are displayed in figure 2. The value of the ratio R is seen to be enhanced for ^{14}N at small momentum

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[1] J.I. Friedmann, H.W. Kendall, and R.E. Taylor, The 1990 Nobel Prize in physics.

[2] The matter density in ^{14}N is roughly a factor of 4 larger in ^{14}N as compared to ^{2}H.

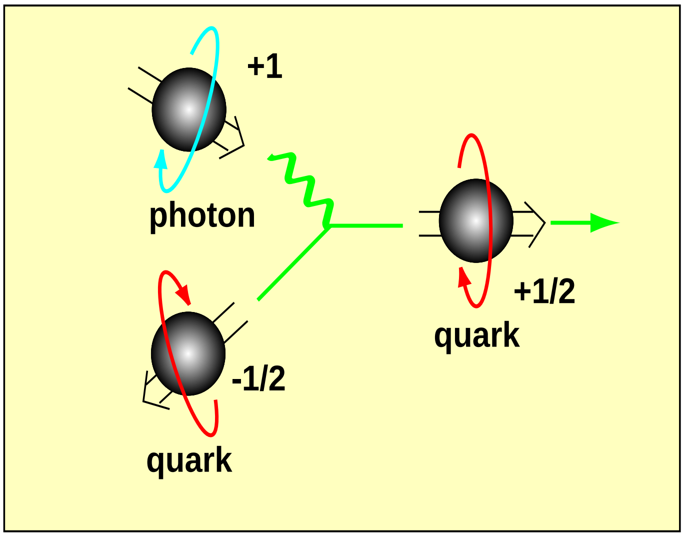

Figure 1: *Electron-quark scattering. In high-energy electron scattering a virtual photon is exchanged between the electron and the quark. The virtual photon is seen to reverse the spin orientation of the quark. Such a spin-flip characterizes the magnetic nature of the electron-quark interaction.*

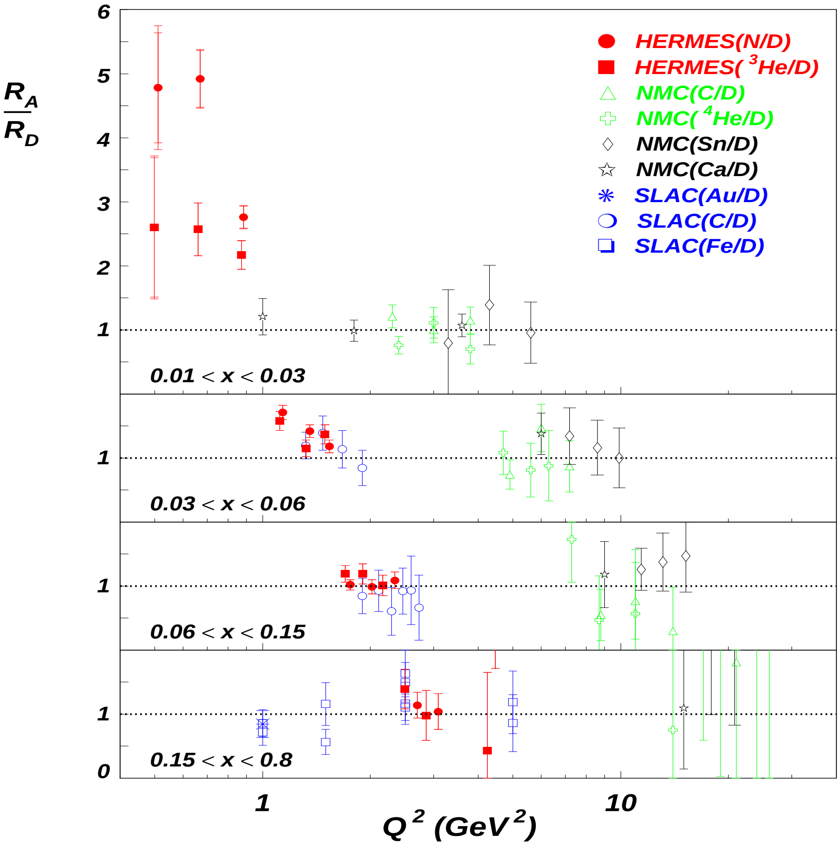

Figure 2: *The enhancement of the ratio* R *of charge to magnetic electron-quark scattering in a dense atomic nucleus as compared to deuterium. The data are plotted versus* Q^2*, the square of the four-momentum that is transferred from the electron to the quark. Each panel represents a different range of values of* x*, where* x *is the fraction of the proton momentum carried by the quark.*

transfers (Q^2), and for small quark momenta[3] (x). A similar enhancement is observed for ^{3}He, albeit less significant. In other words, if the momentum transfer involved is relatively small (or equivalently the wave length of the virtual photon is relatively large), the interaction obtains a fundamentally different character.

One possible interpretation of this new effect assumes that the electron interacts with a pair of delocalized quarks, i.e., a quark and an anti-quark not contained within one nucleon which are exchanged between neighbouring nucleons. If the spins of the quark and the antiquark are aligned in opposite directions, the pair carries no net spin. Consequently, the magnetic interaction will vanish. On the other hand, the fractional charges of the two quarks can add up to non-zero values such as +1 or -1, thus enabling a charge-like interaction. Theoretically, it can be shown that the interaction with such a correlated quark-antiquark pair will have a $1/Q^2$ dependence[4], i.e., it will be enhanced at relatively small momentum transfers.

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[3] The variable Q^2 represents the (square of) the four-momentum transfer from the electron to the quark. It is related to the (inverse of) the wave length of the virtual photon. The variable x is the fraction of the nucleon momentum carried by the quark. In the most simple picture of the nucleon each quark carries $\frac{1}{3}$ of the nucleon momentum, i.e., $x = \frac{1}{3}$.

[4] This $1/Q^2$ dependence comes in *addition* to the normal Q^2 dependence of electron-quark scattering.