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# QUARK DISTRIBUTION DISTORSION IN HEAVY NUCLEI *

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## ABSTRACT

Further consequences of sea-quark pairing are studied by looking at the underlying collective phenomena. We are led to variations of the quark distribution of single protons due to nuclear binding. A new prediction, subject to experimental verification, is discussed.

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The structure function $F_2( x,Q^2 )$ was studied recently for single protons, under the assumption that a non-perturbative mechanism is at play amongst the sea-quarks, in analogy with the well understood behaviour of other manifestations of the quantum liquids [1-2]. In such cases order in momentum space implies the existence of an energy gap $\Delta$ in the spectrum.

The present note intends to extend the earlier work into the important case when the nuclear binding brings several nucleons together into the heavier nuclei. The assumptions ( A-F ) of ref. [ 2 ] have a well known consequence in the quantum liquids: when, for example, two superconductors come into close contact ( junctions ), even their separation by a thin insulator is unable to detain a flux of correlated pairs of valence electrons ( the Cooper pairs ). Let us discuss this situation in the context of the new quantum liquid that concerns us in this note:

( i ) Consider an incident lepton beam on a nucleon 1 of a set of nucleons 1, 2, ..., n interacting in a normal nucleus. As the beam energy is gradually increased, the sea-quark pairs will begin to break up as the momentum transfer Q of the virtual photon reaches an energy $\Delta$, which itself is a function of Feynman's variable x ( cf. Fig. 3 of ref. [2] ). Since we have considered the valence quarks as broken pairs [2, 3], when the sea-quark Cooper pair splits up, there is a finite probability for the formation of a new bound state ( referred to below as a " peculiar Cooper pair " ), between the sea-quark which collided with the incident lepton capable of tranferring momentum $Q \gtrsim \Delta$ GeV, and a valence quark which carried an appreciable amount of momentum of the whole nucleon ( large x-variable ).

( ii ) Within the scope of the correlated sea, already shown to be plausible by looking at the fermion representation of the quarks in the more convenient Valatin-Bogoliubov quasiparticle representation [2], we may consider the ground state wave function $\psi_0$ corresponding to the sea ( the valence quarks would be regarded as " broken pairs " ) [2] :

$$\psi_0 = \prod_k ( u_k + v_k \, q_k^\dagger \, \bar{q}_{-k}^\dagger ) | 0 \rangle \quad , \qquad (1)$$

where $\psi_0$ denotes the BCS ground state [4].
We now suppose that the parameter $V_k$ may be written as

$$|V_k| \exp(i\phi)$$

and $u_k$ is chosen to be real. If we expand the k-product in $\psi_0$ we remark that the terms containing n-pairs will have a phase factor $\exp(in\phi)$. In other words, each occupied pair state contributes a phase $\phi$ to $\psi_0$. Let this wavefunction, say $\psi_0^{(1)}$ represent the essentially condensed nucleon $N_1$, and have phase $\phi_1$. Further, let $\psi_0^{(2)}$ represent $N_2$, similarly defined; both $N_1$ and $N_2$ interact through the nuclear force. If we write the state of the deuteron, for example,

$$\psi_0^{(1,2)} = \psi_0^{(1)} \psi_0^{(2)} \qquad (2)$$

then, by expanding the double product we see that the phase of the part of $\psi_0^{(1,2)}$, which has $n_1$ pairs in $N_1$, and $n_2$ pairs in $N_2$ is:

$$n_1 \phi_1 + n_2 \phi_2$$

$n_1$ and $n_2$ are not separately fixed.

( iii ) Following Josephson [5] , we may assume that the combined system ( in the present case, the deuteron nucleus, but this argument may clearly be generalized to any of the heavier nuclei ) is minimized when $\phi_1 = \phi_2$, due to tunnelling of quarks between the nucleons. Further, a current flows between $N_1$ and $N_2$:

$$\dot{j} = j \sin(\phi_1 - \phi_2) \quad . \qquad (3)$$

This flux of Cooper pairs will provide a larger number of sea-quarks in the collision with the beam of leptons, which raises the energy content of the separate nucleon it impinges upon, creating the necessary phase gradient for the Josephson current to occur.



Having shown in ( i ) to ( iii ) that currents of complete Cooper pairs from the sea would be set up, we proceed to show that we must expect a new experimental prediction ( just as it happens in macroscopic superconductivity ) that is, the actual magnitude of the current is limited, since if it were sufficiently large, then the Cooper pairs which would be passing across from $N_1$ to $N_2$ would have sufficient kinetic energy to break up into unpaired quark and antiquark. Unpaired quarks cannot move under the same circumstances and, therefore, an upper limit on the magnitude of the current is expected. In other words, regardless of the increment of the beam energy we predict that the corresponding increment in sea-quark number will level off for higher values of $Q^2$ .

Sea-quark pairing has another implication with regards to raising the momentum distribution : Before the lepton nucleon collision, the momentum distribution of the sea, as well as the valence quarks is the usual one, the sea-quarks carry a much smaller amount of momentum than the valence quarks. However, when the lepton collides with a given pair, providing momentum transfer $Q \gtrsim \Delta$, it will raise the constituents of the broken pair resulting from the collision, to a momentum comparable with the valence quark momentum. Taking into account the assumptions of the incoherent impulse approximation, we have a picture of two constituents being struck so violently that they have recoiled from their fellow constituents. But, in ref. [2] , we assumed that $q_k^+$ and $\bar{q}_k^+$ interact through some short-range force. Then, in view of the average Hartree-Fock interaction, we may assume that the energy of a pair of oppositely moving quark and antiquark on top, or very near the top of the Fermi distribution ( from $2\mathcal{E}_F$ to $2\mathcal{E}_F - \Delta$ ) will form a bound state. The resulting quark-pair binding energy is [4] :

$$\Delta = 2\delta \exp\left[-\mathcal{E}_F / VN(0)\right] \quad . \qquad (4)$$

The bound state will be analogous to the motion of the two nucleons in the whole deuteron. The peculiar Cooper pair thus formed, will drift into other nucleons as part of the tunnelling current, providing an explanation for the increment in the momentum shared by the remaining particles in the proton thus, in particular, raising the momentum shared by the sea-quarks.

To conclude let us discuss and clarify some aspects of the set of curves $F_2(x, Q)$ for lepton-nucleus scattering, as we have done earlier for lepton-nucleon scattering ( cf. Fig. 2, ref.[ 2 ] ):

( a ) For $Q^2 > \Delta^2$ we followed the experimental points of the $\mu p$ data, in order to complete the curve[ 6 ]. If, instead the QCD fit had been followed up, the only difference would be that a less pronounced slope is obtained. In other words, our previous work is not only limited to values of $Q^2$ smaller than $\Delta^2$.

( b ) Experiments in the kinematic region we are discussing ( low x-region where the sea is dominant, and values of Q up to $\Delta$) may be difficult to perform, since shadowing is expected to occur for the lower values of Q. The shadowing effect is characteristic of nuclear collisions in which the momentum transfer of the reaction is smaller than $R_o$, the target dimension. Such an effect would tend to mask the predicted abrupt violation effect for x and Q small.

( c ) The highest value of $\Delta$ may be seen to occur for $x \sim 0.2$ at $Q \sim 5.6$ GeV ( cf. Fig. 3 and Table I in ref.[ 2 ] ). Presumably, for this sizeable value of Q, the shadowing effect would be minimized with respect to the more pronounced shadowing effect at $Q \sim 1.7$ GeV, corresponding to $x \sim 0.04$ ( cf. Fig. 3 and Table I in ref.[ 2 ] ).

( d ) Our considerations in ( c ), for light nuclei, should be compared with the corresponding lepton-nucleus curves for F ( x, Q ), as displayed in Fig. 2, ref.[ 7 ] . From what was said above ( i ) to ( iii ), the humps observed for lower $Q^2$ ( $Q^2 < \Delta^2$) are due to the Josephson currents of sea-quark pairs.

To summarize, we have seen that ( strong ) pairing of sea-quarks in the presence of ( weak ) nuclear binding is not in contradiction with experiments [ 8 ], which deal with the Q region we are interested in as well as higher values of Q. Further experiments [ 9-10 ] are within our range of Q values. We feel, therefore, that full field theoretic approaches ( i.e. QCD ) should



incorporate non-perturbative effects such as the anomalous correlations $\langle q^+_k \bar{q}^+_{-k} \rangle$. In this manner the observed humps for $Q^2 < \Delta^2$ are understood to disappear gradually as we move away from the low Q region, where the Josephson current of sea-quark pairs occurs. The kinematic region where the abrupt onset of scaling violation sets in is precisely the region where the josephson current disappears due to the diminishing energy gap.

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