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SHORT RANGE PHENOMENA

Summary of Working Group Four presented to the
INTERNATIONAL SYMPOSIUM ON THE THREE-BODY FORCE
IN THE THREE-NUCLEON SYSTEM
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1. Introduction

Working group four quickly decided that the study of the three body force in three body systems at short range was too limiting. At short distances, quark degrees of freedom and relativistic effects became important, and an understanding of how these effects may or may not be interpreted as a three nucleon force probably requires a complete understanding of all short-range phenomena in 3, 6, and 9-quark systems.

Recognition of the fact that quarks and gluons are the underlying degrees of freedom at short range does not necessarily imply that all theoretical calculations must employ these degrees of freedom explicitly. Two different theoretical approaches can be identified:

A. Treat the quark degrees of freedom explicitly, especially at short range. When treating the quarks, relativistic calculations may be necessary.

B. Freeze out all explicit quark degrees of freedom--even at short range. Develop an effective relativistic meson theory, which will probably need to include explicit treatment of excited baryons (Δ, N^*,...) in addition to the familiar mesons (π, σ, ρ, ω,...).

The working group agreed that the choice between approaches A and B will eventually be dictated by experiment, unless it should turn out that there is a duality in the sense that both approaches, when treated in sufficient detail, give approximately similar results. (A suggestion that this might be the case, at least approximately, comes from the observation that QCD, in the limit when the number of colors is infinite, reduces to an effective theory of mesons only, in which baryons appear as soliton solutions of the non-linear field equations. In the sense that 3 >> 1 this suggests some kind of duality.) Even if these approaches are dual, it would still be necessary to find the correct effective meson theory lagrangian and to determine empirically the minimum number of mesons and baryons which are needed, and their masses and coupling constants.

The alternative to duality is that the two approaches give fundamentally different results within some effective confinement range R_c. In this case there should be "smoking gun" experiments which are sensitive to these differences, and experiments which might lead to such results are discussed in section 3 below. Even if this latter possibility should hold, a duality would still result if the range parameter R_c were very small. Finally, while a duality might exist for many phenomena, it is certainly true that one approach or the other may be superior in certain kinematic ranges. For example, all agree that approach A is necessary for the understanding of the inclusive scattering of 200 GeV leptons, while the one pion exchange potential continues to provide a fundamental simple explanation of the longest range part of the nuclear force.

Section 2 contains a summary of the theoretical approaches discussed at the Symposium. One issue of fundamental importance to all approaches is the extent to which charge and current operators can be unambiguously determined from the underlying dynamics. If these operators are not constrained by the dynamics, then the electromagnetic experiments described in Section 3 will be less effective in giving direct information about the underlying physics. Finally, recommendations for future directions made by the working group are summarized in Section 4.

2. Theory

2.1 Approach A.

Two different ways to treat quark degrees of freedom explicitly at short range can be identified. These are

- Cluster Models
- Hybrid Models

Cluster Models - K. Maltman[1] reported on an extension to the three body system of his calculations with Isgur[2]. In this calculation, the 9 quarks were grouped into three nucleon clusters, and quarks were then antisymmetrized. Some of the terms which arise from the antisymmetrization process are shown schematically in Figure 1. If the centers of the three nucleon clusters are located at coordinates R_1, R_2, and R_3, then the unsymmetrized 9-quark wave function is

$$\psi_{9q}(r_1 r_2 r_3;\ r_4 r_5 r_6;\ r_7 r_8 r_9) = \psi_{R1}(r_1,r_2,r_3)\ \psi_{R2}(r_4,r_5,r_6)\ \psi_{R3}(r_7,r_8,r_9) \qquad (1)$$

where

$$\psi_{R1}(r_1,r_2,r_3) = \phi_{R1}(r_1)\ \phi_{R1}(r_2)\ \phi_{R1}(r_3) \qquad (2)$$

Antisymmetrization of this wave function introduces a term in which $r_3 \rightarrow r_4 \rightarrow r_7 \rightarrow r_3$, as illustrated in Figure 1. Matrix elements of this term with (1) will introduce effective terms which depend on the three coordinates R_1, R_2, R_3, and hence play the role of three body forces.

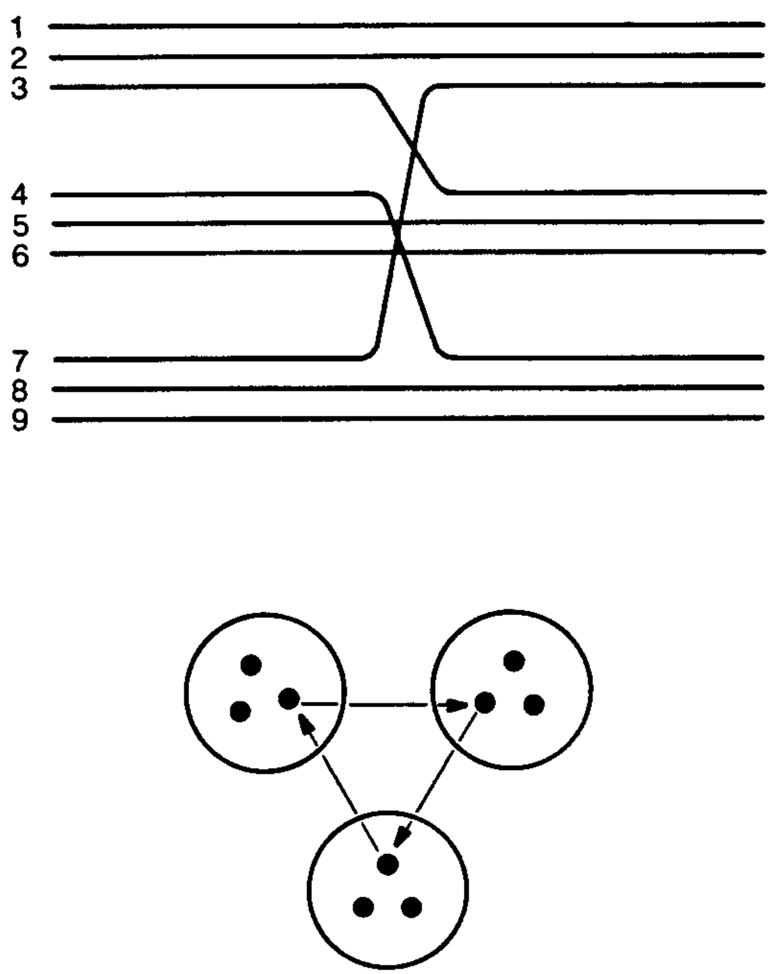

Figure 1

To illustrate how this comes about in a specific case, consider the matrix element of the non-relativistic kinetic energy operator for quark 1, and assume that

$$\phi_R(r) = \sqrt{\frac{1}{R_c^3 \pi^{3/2}}} \quad \exp\left[\frac{-(r-R)^2}{2R_c^2}\right] \tag{3}$$

Then

$$\int \prod_{i=1}^{9} d^3r_i \; \psi_{9q}(r_1r_2r_3;\; r_4r_5r_6;\; r_7r_8r_9) \left(\frac{-\nabla_1^2}{2M_q}\right) \psi_{9q}(r_1r_2r_3;\; r_4r_5r_6;\; r_7r_8r_9) \tag{4}$$

$$= \frac{3}{4M_qR_c^2}$$

while

$$\int \prod_{i=1}^{9} d^3r_i \; \psi_{9q}(r_1r_2r_7;\; r_3r_5r_6;\; r_4r_8r_9) \left(\frac{-\nabla_1^2}{2M_q}\right) \psi_{9q}(r_1r_2r_3;\; r_4r_5r_6;\; r_7r_8r_9)$$

$$= \frac{3}{4M_qR_c^2} \int d^3r_3 d^3r_4 d^3r_7 \; \phi_{R1}(r_7)\; \phi_{R1}(r_3)\; \phi_{R2}(r_3)\; \phi_{R2}(r_4)\; \phi_{R3}(r_4)\; \phi_{R3}(r_7) \tag{5}$$

$$= \left(\frac{3}{4M_qR_c^2}\right) \exp\left[\frac{-(R_1-R_2)^2}{4R_c^2}\right] \exp\left[\frac{-(R_2-R_3)^2}{4R_c^2}\right] \exp\left[\frac{-(R_1-R_3)^2}{4R_c^2}\right]$$

The last term clearly depends on the cluster coordinates of the three nucleons, and could only arise in a calculation based on the effective nucleon coordinates R_1 R_2 R_3 if there were three body forces present. Maltman estimated the size of these three body forces, and found them to vary from 0.10 to about 2 MeV as the cluster radius R_c varies from 0.5 to 0.8 fm. This shows that binding energy effects of this magnitude could conceivably be attributed to quark effects, and that the size of such effects will depend critically on the effective confinement radius R_c. For more realistic estimates, dynamical calculations based on the resonating group equations, similar to those undertaken for the two nucleon system[3], should be applied to the three nucleon system.

Hybrid Models - L. Kisslinger[4] reported on calculations and results of his hybrid model. In this model, meson degrees of freedom are employed outside of the critical radius R_c, and quark degrees of freedom inside. In practice, this means that ordinary non-relativistic two- or three-body wave functions are used until one of the internucleon separations is less than R_c, in which case the wave function is replaced by a spherical 6 or 9 quark cluster as the situation requires. This is illustrated schematically in Figure 2.

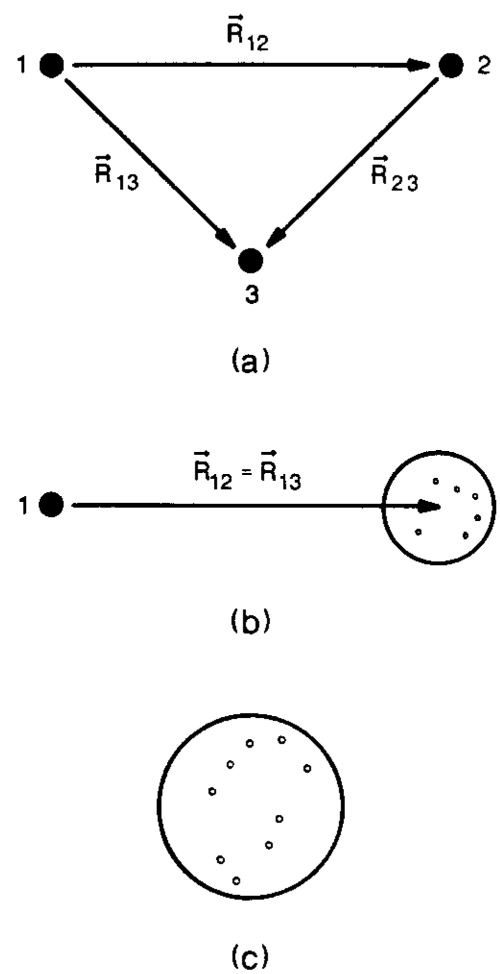

Figure 2. Three cases in the hybrid model corresponding to Eqn. (6a), (6b), and (6c) respectively.

The 3 body wave function in this model can be written

$$\psi_{3N} = \begin{cases} N_1 \, \psi_{NR} \, (R_1, R_2, R_3) \quad |\vec{R}_{ij}| > R_c & \text{(6a)} \\ N_2 \, \phi_N(R_1) \quad \phi_{6q}(r_4 r_5 r_6 r_7 r_8 r_9) \quad |\vec{R}_{23}| < R_c, \; |\vec{R}_{12}| = |\vec{R}_{13}| > R_c & \text{(6b)} \\ N_3 \, \phi_{9q}(r_1 r_2 r_3 r_4 r_5 r_6 r_7 r_8 r_9) \quad |\vec{R}_{ij}| < R_c & \text{(6c)} \end{cases}$$

where $\vec{R}_{ij} = \vec{R}_i - \vec{R}_j$, ψ_{NR} is the non-relativistic function, the one nucleon wave function ϕ_N is obtained from the Faddeev equations with ϕ_{6q} playing the role of the 2 body driving term, and ϕ_{6q} and ϕ_{9q} are 6- and 9-quark wave functions constructed in a manner analogous to Eq. (1) and (2) above (Kisslinger actually uses MIT bag wave functions instead of the simple harmonic oscillator states used in Eq. (2)). The continuity of the current is used to adjust the relative normalization of the three different contributions given in Eq. (6).

The fits to the ^{3}He and ^{3}H form factors obtained from this model are shown in Figure 3. Also shown is the relative contributions of the 6- and 9-quark parts. Clearly the 9-quark part has something to do with the short range part of the three body force, and its relative size in Figure 3 gives some indication of the importance of this contribution.

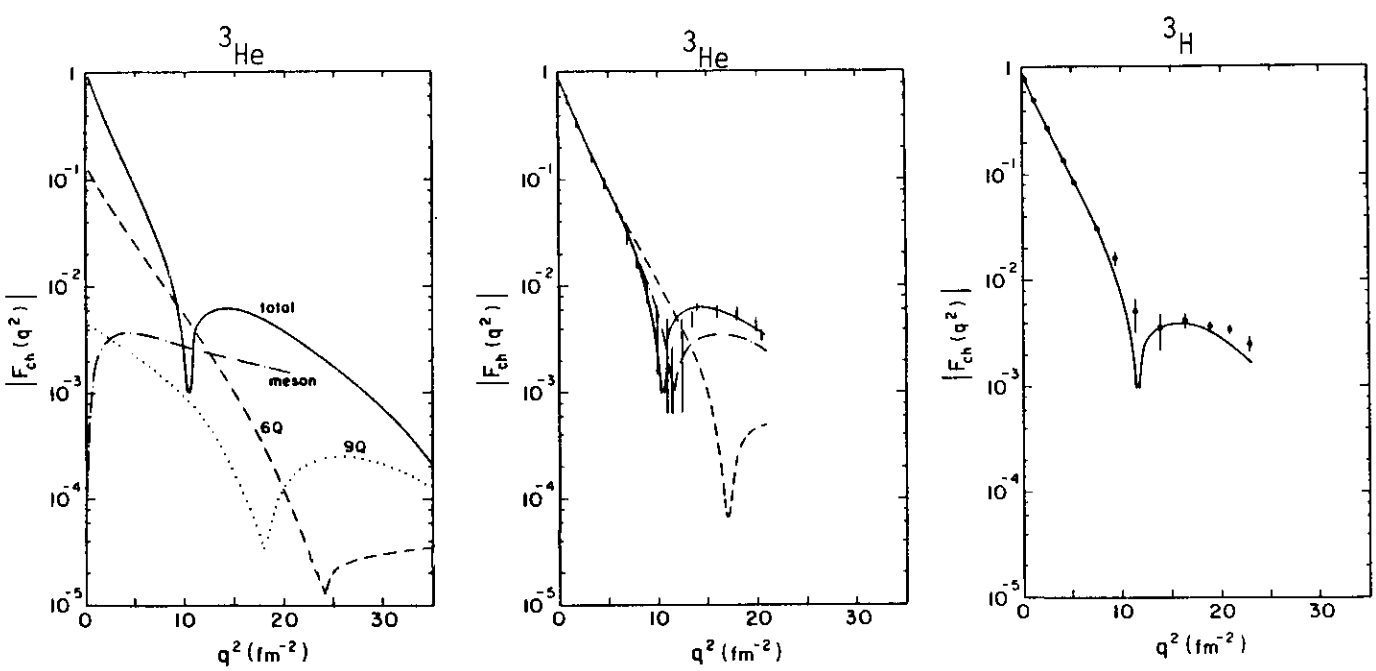

Figure 3

All participants at the workshop agreed that this model currently suffers from two deficiencies. The abrupt change from one form of the wave function to another as $|\vec{R}_{ij}|$ passes through the critical value R_c is unrealistic; it introduces discontinuities in the configuration space wave functions which show up as spurious oscillations in the form factors at high Q^2, making the predictions for $Q^2 \gtrsim 1\ (\mathrm{GeV}/c)^2$ unreliable. In addition, the problem of how to treat the recoil of the 6- and 9-quark bags, which occur when the 3 body wave function absorbs the virtual photon, still has not been solved satisfactorily. This introduces a further uncertainty in the numerical results for the 6-and 9-quark contributions present in Figure 3.

Currents in Approach A - One advantage of Approach A is that the current operator is simpler in principle than it is in Approach B. Gluons do not interact electromagnetically; fundamental carriers of charge and magnetic moments are the quarks, which are point-like. The elementary one-body current operator is therefore very simple

$$j_q^{\mu} = \gamma^{\mu} \left[\frac{1}{6} + \frac{1}{2}\tau_3\right] \tag{7}$$

where $(1/2)\tau_3$ is the third component of the isospin, giving +1/2 for u quarks and -1/2 for d quarks. This is to be contrasted with the one-nucleon current operator, which is

$$j_N^{\mu} = 1/2 \left[F_1^s(Q^2) + F_1^v(Q^2)\tau_3\right]\gamma^{\mu} + \frac{i}{2M} \frac{1}{2}\left[F^s{}_2(Q^2) + F^v{}_2(Q^2)\tau_3\right] \sigma^{\mu\nu} q_{\nu} + H\ (Q^2) \tag{8}$$

where F^v and F^s are the familiar isovector and isoscaler form factors and H is an (unknown) additional term which might be added to account for additional structure when the nucleons are off-shell. The consistent treatment of nucleon and pion structure are an issue for Approach B (see below).

While the elementary quark current is indeed simpler in Approach A (at least for the quark sector), there are other operators involving two quarks or quarks and gluons which must be taken into account and are often overlooked. Some gluon exchange current terms are shown pictorially in Figure 4. They include higher order corrections to the quark-gluon coupling, and 2 and 3 body operators involving gluon exchange graphs which cannot be incorporated into the initial or final state wave functions. While these terms are small at very high Q^2, where the quark-gluon coupling is small because of asymptotic freedom, they are unlikely to be negligible at the more moderate values of Q^2 often encountered in nuclear physics.

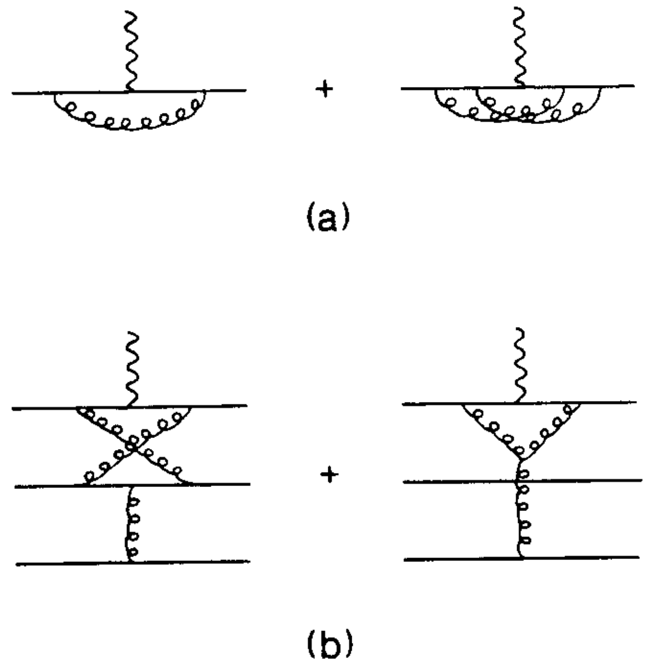

Figure 4

2.2 Approach B

Relativity may be treated either as (1) a correction which must be added to a basically non-relativistic theory, or as (2) a requirement which must be incorporated into the theory from the start. Method (2) incorporates the dynamics from the beginning, and is closely tied to the underlying meson field theory. While this has some advantages, method (1) has the advantage that it provides a way to incorporate relativistic effects into phenomenological non-relativistic models. Both methods suffer from ambiguities which will be discussed below.

Method 1 - F. Coester[5] gave a report on recent progress with an approach which determines relativistic corrections directly from the requirement that the generators of the Lorentz Group (the hamiltonian H, the space translations P, the boosts K, and the rotations J) satisfy the Poincáre Algebra. In the front form of the dynamics, in which the operators

$$P^{\pm} = H \pm P_3 \tag{9}$$

are introduced, P^- plays the role of the hamiltonian so that the "time" translation operator is exp $[-iP^-\tau]$ where $\tau = t + x_3$. The other generators which must contain the dynamics are $J_T = (J_1, J_2)$. The remaining generators are kinematic. (In the more familiar instant form, the dynamical generators are H and K and the kinematic generators are P and J.) As an example, the commutator

$$[J_1, P_2] = i/2\ (P^+ - P^-) \tag{10}$$

shows that if P^- contains dynamical information, J_1 (or P_2) must also. One interesting feature of the front form is that, for particles with non-zero mass, the condition

$$P^+ |0\rangle = 0 \tag{11}$$

uniquely defines the vacuum state, whereas the analogous relations in the instant form

$$P_i |0\rangle = 0;\ J_i |0\rangle = 0 \tag{12}$$

do not uniquely define any state, and hence vacuum fluctuations cannot be ignored.

The central issue for the Symposium was the size of three body forces mandated by Poincáre invariance. If the theory contains two body forces only, and the calculation is required to satisfy cluster separability and Poincáre invariance, then a numerically small three body force is automatically generated. Unfortunately, additional three body forces can then be added, so that this approach does not uniquely define the three body force. This is not unexpected since this method is not constrained by the underlying dynamics.

Constraints imposed by the requirement that J_T satisfy the commutation relations, and that the physical states be eigenfunctions of J^2, were previously an obstacle to the use of the light front method. Coester believes that these problems have been solved, and has a new formula for two and three body form factors, but numerical results are not yet available.

Method 2 - Numerical results for this method have not yet been obtained for the three-nucleon system, so discussions focused on calculations of the two-nucleon system, or calculations for the $NN\pi$ system. Issues associated with relativistic meson theories which were identified by the working group include

- what channels must be treated explicitly in coupled channel calculations?
- how should the medium range kernels (involving 2 and 3 boson exchange) be treated?
- what relativistic wave equation should be used?

Number of Channels - A number of relativistic calculations exist which treat the NN channel, and calculations incorporating Δ's are being developed. If the concept of duality is to hold, it may be necessary to treat other N^* channels explicitly.

Medium Range Forces - The treatment of the two boson exchange (TBE) kernel in the two nucleon sector will have a profound effect on how three body forces should be defined and treated. Some possibilities are illustrated in Figure 5. In Figure 5(a) the one boson exchange (OBE) model is used, generating three nucleon diagrams like 5(b) suggesting that three body forces are absent. If a more realistic model for the TBE kernel is used, as is shown in 5(c) and 5(f), three nucleon diagrams such as 5(d) and (e), or 5(g) and (h) will be generated. All of these can be regarded as three nucleon forces, and raise several interesting issues. If 5(c) is large then it is not clear why 5(d) isn't large also, and this force has not been included in previous work. One reason why 5(d) may be suppressed is that other relativistic diagrams, such as 5(e), may cancel it. (In 5(e), the small circle represents the off-shell contributions from the spectator nucleon; the on-shell piece is included in the iteration of the two body forces and should not be counted as a three body force.) Diagram 5(f) is also large [6], and much of this Symposium dealt with the treatment of the three body force, 5(g), which arises from it. Yet if Δ's are added to the Hilbert space, this is not even a three body force. Finally, the size of 5(f) also suggests that 5(h) should be large, unless it is cancelled by a diagram analogous to 5(e).

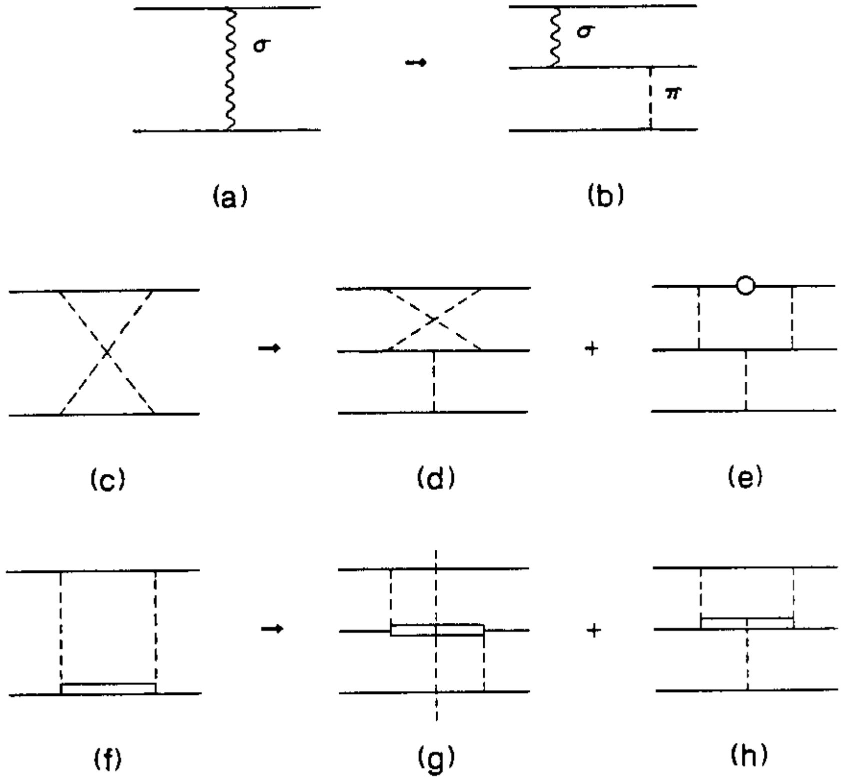

Figure 5

<u>Relativistic Wave Equations</u> - A variety of wave equations can be used to describe the meson interactions. These include the Bethe-Salpeter equation, used extensively by Van Faassen and Tjon[7], in which all nucleons are off-shell, the equation in which only one nucleon is off-shell[8], and methods based on relativistic time ordered perturbation theory used extensively by Holinde and Machleidt[9]. The expected size of three body forces, and their treatment, will depend in detail on which of these equations is applied to the three body systems. The inclusion of form factors at the meson vertices is also an issue which is treated differently in different equations. Other approaches, such as the one being developed by Noyes[16], do not use form factors. Finally, skyrmions, in which nucleons emerge from the non-linear solutions of a classical meson theory, may also have a role someday in the study of three-nucleon and three-body forces.

<u>Currents in Relativistic Meson Theory</u> - As in the study of quarks, the currents are dictated by the structure of the two and three body forces. Figure 6 shows examples of two and three meson exchange currents which can be expected to be

important if the corresponding force diagrams are important. Diagrams 6(a) and (b) are present whenever 5(c) and 5(d) are, and 6(c) and (d) must be included if 5(f) and (h) are. Yet very few calculations have ever attempted to include such currents, and they certainly are not part of the standard approaches employed. Finally, techniques have been developed recently for including phenomenological electromagnetic form factors consistently,[11] but the techniques have revealed that the structure, when treated phenomenologically, introduces additional ambiguities into the current operators.

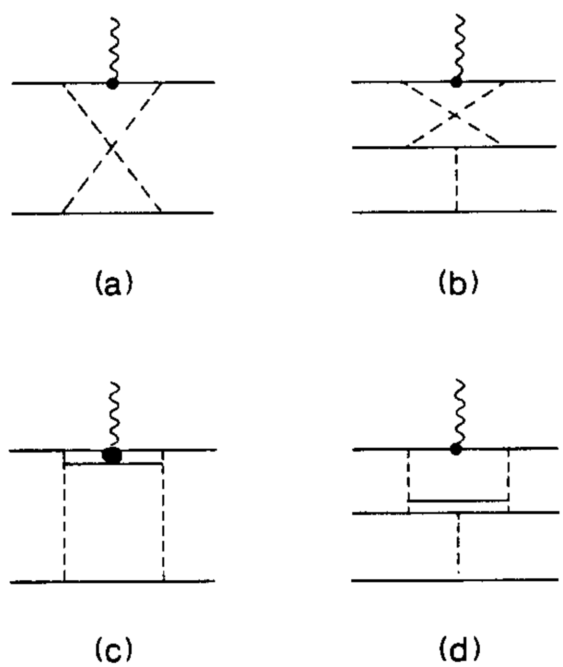

Figure 6

3. Experiment

The experimental information about the three-body force in three-body systems at the high Q^2 (or short wavelength) regime is almost non-existent. Thus, in this section, some of the possible future experiments which might give some information about short-range phenomena in nuclei are discussed. It is hoped that these experiments might be sensitive to the two approaches described in Section 2.

3.1 Experiments Which Test Quark Degrees of Freedom

Measurement of the Neutron Electric Form Factor

The distribution of charge inside the neutron is of fundamental importance for two reasons. Not only is it sensitive to the distribution of quarks in its interior, but precise knowledge of this quantity is needed to extract information about nuclear structure contained in all high-momentum-transfer electron scattering data.

Our present knowledge of G_E^n is very poor. The most precise values of G_E^n have been extracted from an analysis of elastic e+d scattering. This method, however, requires a particular choice of the deuteron wave function which strongly influences the extracted values of G_E^n.

With a longitudinally polarized electron beam, and either a polarized deuteron target or a polarimeter capable of measuring the polarization of recoil neutrons, G_E^n can be measured more precisely. Both of these methods have their advantages and disadvantages, but both appear feasible. In fact, a proposal to measure the recoil neutron polarization has been proposed to be carried out at MIT-Bates.

Another method to extract G_E^n is to scatter the longitudinally polarized electrons from a polarized ^{3}He target, and to measure the asymmetry. With an anticipated polarized ^{3}He target of thickness 10^{18} atoms/cm^3 and polarization 70% (as discussed by R.G. Milner in this Symposium), this would make the measurement of G_E^n feasible in the near future.

The Electric Quadrupole to Magnetic Dipole Amplitude Ratio in the N-Δ Transition

One of the important quantities to be extracted from the photoproduction and electroproduction of pions in the delta region is the ratio of the electric quadrupole amplitude to the magnetic dipole amplitude in the N-Δ transition. Depending on the model used, the value of this ratio ranges from zero to a few percent. For instance, in the simple SU(6) model or the spherical bag model of hadrons, the ratio is zero. On the other hand, the skyrmion model predicts, in a model-independent fashion, the ratio to be about 5%. A non-zero value for the ratio would imply that N or Δ are strongly deformed.

One measurement which appears to be sensitive to this ratio is the asymmetry in the scattering of a longitudinally polarized electron beam from the unpaired neutron of a polarized ^{3}He nucleus. This is feasible with the availability of a polarized ^{3}He target and polarized electron beams in the near future.

Deep Inelastic Lepton Scattering in the Region x>1

Probably the most striking phenomenon in the manifestation of the quark presence in nuclei is the EMC effect. This effect not only has important experimental consequences for the interpretation of present deep-inelastic muon scattering data which relies heavily on the use of nuclear targets, but also raises basic questions in both quantum chromodynamics and nuclear physics.

So far, theoretical explanations for the EMC effect include 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. It is also possible that the EMC effect is largely a result of nucleon binding.

Tests for some of the explanations given above will be discussed later. Here it is suggested that the measurement of deep-inelastic lepton scattering in the Bjorken x-scaling region where x is greater than 1 is useful to test the quark clustering in nuclei. It is clear that there is no cross section from an isolated stationary nucleon for x>1. Earlier SLAC data of ^{3}He (Ref. 12 and 13) and ^{4}He (Ref. 13) shows strong enhancement over results with conventional nuclear theory for x>1, and was used in an earlier effort[14] to demonstrate the role of six-quark clusters in nuclei (see Figure 7). In Ref. 15, Vary shows that the ratiös of the cross sections should exhibit a sudden rise at x=2 or 3 for scattering from a six-quark or nine-quark clusters, respectively. It would be interesting and desirable to have data with good statistics in the x>1 region for a range of nuclear targets. In fact, some preliminary data at high Q^2 and in the x>1 region have recently been taken at SLAC. These data will be useful in assessing the importance of quark clusters in nuclei.

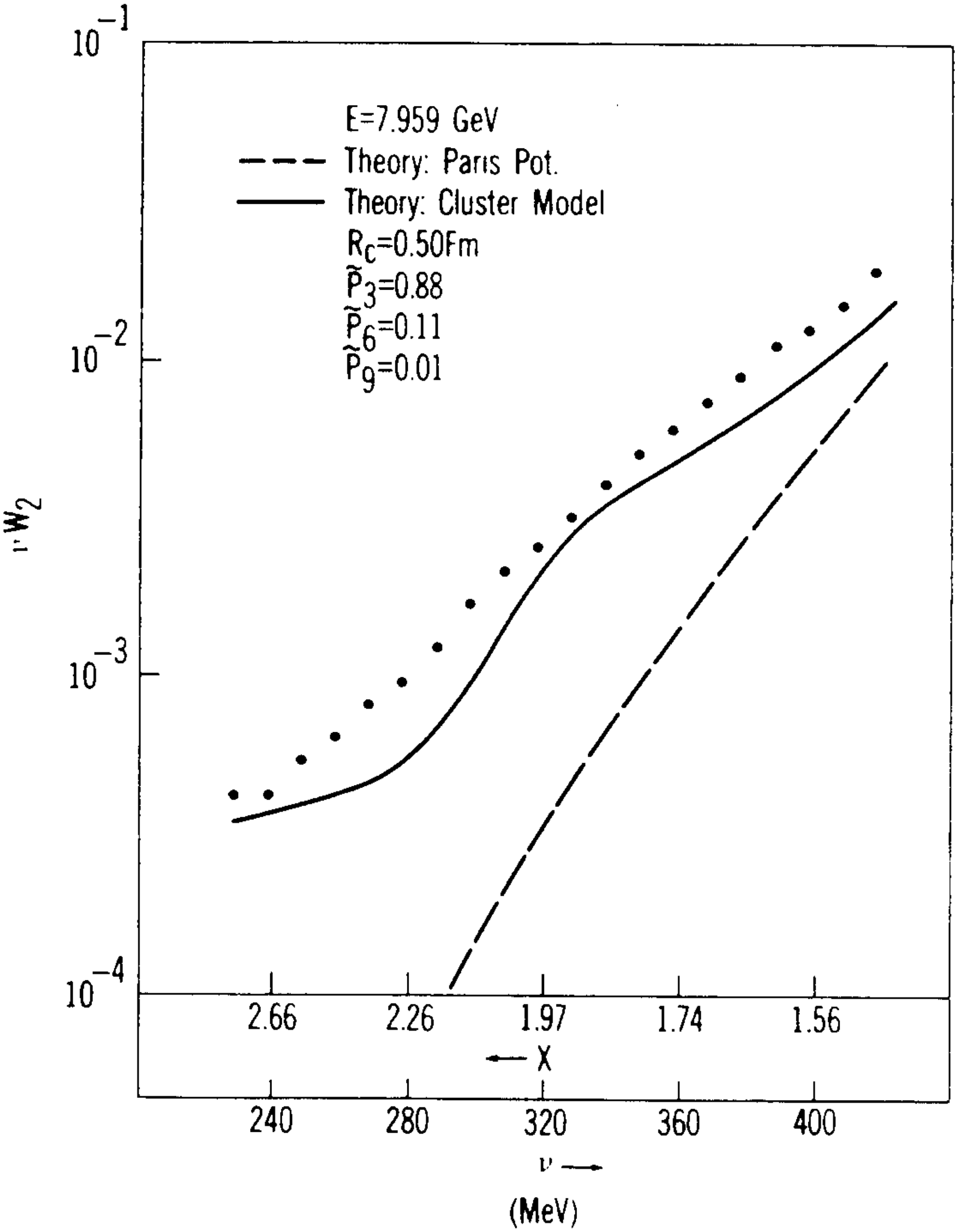

Figure 7

Coincidence Measurements in the Deep Inelastic Region

Deep inelastic lepton scattering in the Bjorken x-scaling region has been very useful in giving direct evidence for the existence of point-like quarks in nucleons. In these experiments the interactions of the quarks in the final state can be ignored. However, since all quarks must eventually recombine into color neutral hadronic clusters, it would be important to know (1) how does the hadronization of the struck quark take place, and (2) how does the nuclear medium affect the hadronization process? These questions can be studied with coincidence experiments in the deep inelastic region where one detects the scattered lepton in coincidence with the various hadronic fragments in nuclei. This study will become possible at CEBAF if its maximum beam energy can be extended to 6 GeV.

3.2 Experiments Which Test Both Approach A and B

Elastic Form Factors of ^{3}He and ^{3}H at Large Momentum Transfer

In the one-photon-exchange approximation, the elastic electron scattering cross section is given as

$$\frac{d\sigma}{d\Omega} = \sigma_M[A(Q^2)+B(Q^2)\tan^2(\theta/2)]. \tag{13}$$

The function $A(Q^2)$ is a combination of charge, magnetic, and quadrupole (for deuterium) form factors, while $B(Q^2)$ is proportional to magnetic form factors only. These form factors together with those of the nucleon will give new and important information on some of the fundamental issues of nuclear structure physics, namely: the size and shape of the nuclear wave functions at large internal momentum; the nature of the nuclear force at small internucleon separations; the possible role of meson exchange currents and relativistic effects; and, at the largest Q^2, the role of the quark substructure of the nucleons in nuclei.

For ^{3}He, $A(Q^2)$ is known out to Q^2=3 (GeV/c)^2, and $B(Q^2)$ is unknown beyond $Q^2 \sim 1.0$ (GeV/c)^2. For ^{3}H, the electric form factor measurements have recently been extended to $Q^2 \sim 1.27$ (GeV/c)^2 both at Saclay and MIT-Bates. It would be interesting to extend the measurements to as high a Q^2 as possible. In fact, an experiment is planned to measure the charge and magnetic form factors of ^{3}H to $Q^2 \sim 2.5$ (GeV/c)^2 using the new SLAC injector (see contribution to this Symposium by S. Rock). It would be nice to have data taken beyond the predicted second minimum in the magnetic form factor of ^{3}H and ^{3}He. Since the cross section is very small, one may have to use the full beam energy at SLAC for this measurement.

The ^{3}He Spectral Function

The ^{3}He(p,2p), ^{3}He(p,pd), ^{3}He(e,e′p), and ^{3}He(e,e′d) reactions at high incident energies have been very useful in providing information on the ^{3}He spectral function. Data with recoil momentum as high as 600 MeV/c have been measured at Saclay. These data seem to disagree with theory above a recoil momentum of 300 MeV/c. Since the short-range behavior of the nuclear interaction, especially two-body correlations, are important at the large recoil momentum region, it would be interesting to extend the measurement to as high a recoil momentum as possible. It would also be interesting to measure the spectral function at a fixed recoil momentum for a range of momentum transfer (or a range of Q^2). The latter experiment would provide additional information on the medium effect on the quasi-elastic scattering which is discussed next.

Possible Modification of the Nucleon in the Nuclear Medium

One possible explanation for the EMC effect is that nucleons are somewhat larger in nuclei than in vacuum. Using a model of relativistic nuclear matter in which the nucleons are assumed to have a quark substructure, Shakin was able to calculate the electromagnetic form factors of the nucleons and showed how these form factors are modified in nuclear matter from their values in vacuum.

One possible experiment which may shed some light on the nuclear medium modification of the nucleon confinement radius is to measure the quasi-elastic (e,e′p) cross section for a range of Q^2 from targets with different A (or density). This is basically a "low-energy" experiment for a high-energy phenomenon, and gives indirect information on the quark degrees of freedom of the nucleon bound in nuclei. Experiments are currently underway at Saclay and MIT-Bates, and could be carried out at higher momentum transfer at CEBAF.

Two-Body Correlations in Nuclei

The one-body momentum distribution at high nucleon momentum as measured in the (γ,p) and (e,e′p) experiments shows strength which is greater than that predicted by the typical one-body mean field potential theory. It is possible that these high momentum components in the nucleus are related to the very strong, short-range collisions between the nucleons where there is significant overlap of the nucleons. Thus, a direct measurement of the relative momentum between two nucleons could lead to important new insights into the nature of the nuclear force in the nuclear medium.

The two-nucleon knockout (e,e′2N) reaction appears to be the most promising and direct way to study the short-range nucleon-nucleon corrections in nuclei. A few studies have been made related to the future CEBAF research program to explore the kinematic conditions which are most suitable for this study. It would certainly be simpler to begin this program with study of the ^{3}He(e,e′pp) reaction. A proposal is planned to be submitted to MIT-Bates.

4. Future Directions

4.1 Theory

Working group four concluded that it was too early to discourage any of the approaches or methods described in this summary. All methods should be developed, and perhaps at the next Symposium in five year's time it will be possible to make a more definitive choice between the various approaches and techniques.

A consistent program of calculations of two and three nucleon wave functions, binding energies, form factors, and structure functions based on a single fully relativistic meson theory is needed, and should be possible to achieve in the next five years. Such results will be essential for analyzing experiments at the new higher energy accelerators, such as CEBAF, and will provide a standard against which quark models results can be compared and "smoking gun" differences sought.

While it is still reasonable to encourage all approaches, it is also time to demand careful, consistent work from the theorists. Calculations in the future should meet high standards:

- currents and forces must be based on a consistent dynamical scheme
- criteria for eliminating ambiguities must be found and applied
- consistent dynamical assumptions must hold for all parts of the program
- approaches must be carefully compared and sources of disagreement and differences isolated
- accurate numerical results must be obtained.

Enormous progress in this area has been made in the last five years; the study of quarks and relativistic meson theory was in its infancy in 1980. The next five years can be expected to show even greater progress.

4.2 Experiment

The next five years should be very exciting for the experimental program directed toward the study of quark degrees of freedom in nuclei. Facilities such as the polarized ^{3}He target, the European Synchrotron Radiation Facility, the Bonn tagged photon facility, the new SLAC injector, and the electron linacs at MIT-Bates, Saclay, and NIKHEF will certainly make most of the inclusive and some of the exclusive measurements possible. The extension of exclusive measurements to high Q^2 region, such as (e,e′N), (e,e′2N), studies of exclusive channels in the x-scaling region, and studies of the photo- and electroproduction of the higher nucleon resonances in nuclei and in free space, will be made at CEBAF, and promise to shed important new light on these issues.

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