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Annual Progress Report, Task B
for May 1, 1975 to April 30, 1976

This is the annual report by the high-energy theoretists in the physics department, Purdue University. This report consists of a list of personnel who have worked on this contract and the annual progress reports prepared by the individuals.

I. List of Personnel:

R. H. Capps	(Professor)
M. Sugawara	(Professor)
A. Tubis	(Professor)
L. A. P. Balázs	(Associate Professor)
E. Fischbach	(Associate Professor)
N. H. Fuchs	(Associate Professor)
T. K. Kuo	(Associate Professor)
B. F. L. Ward	(Assistant Professor)

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II. Annual Progress Reports:

1. R. H. Capps:

My work has been concerned with the possible breaking of color symmetry in the quark model, and with the experimental spectrum of mesons and baryons. Reference 1 below is an extension of an earlier short note by me. In the earlier note it was proposed that the forces between quarks of two of the colors (taken to be red and white) are of shorter range than forces involving quarks of the third color (blue). It was shown that if this symmetry-breaking mechanism is strong, the favored baryon SU(6) representation and parities are $\underline{56}^{+}$ and $\underline{70}^{-}$, in agreement with experimental indications. In Reference 1 it is shown that this prediction also results if the symmetry-breaking is small, in which case the sign of the symmetry-breaking is irrelevant. It is also shown that the discovery of new resonances might enable one to determine the approximate magnitude of the symmetry-breaking. A list of orthonormal quark-model wave functions of specific energies and symmetries was given; this list could be useful in many quark-model calculations.

In Reference 2 this idea is applied to mesons, and it is assumed that the $\Psi(J)$ and Ψ' mesons at 3.1 and 3.7 GeV are color excitations. A simple symmetry-breaking Hamiltonian is assumed, which leads to the prediction that ordinary mesons (like the π) are made primarily of red and white quarks and antiquarks, while the $\Psi(J)$ and Ψ' are made primarily of blue quarks and antiquarks. A total of nine vector and nine pseudoscalar mesons are predicted in the 3-4 GeV region. This is in striking contrast with the predictions of both the standard color-excitation model (with exact color symmetry) and the charm model of the $\Psi(J)$ and Ψ'. The Hamiltonian can be applied to baryons also; using experimental hadron masses to determine the parameters, I estimated the approximate mass of a predicted baryon multiplet [of the second excited quark-model level and the SU(6) representation 70]. Several other predictions of the broken color-symmetry model of the $\psi(J)$ and ψ' are compared with those of the charm model and with experiment. All the simple models have difficulties and all have advantages. The crucial tests of these models are the masses and quantum numbers of the new mesons predicted.

Papers written by R.H. Capps in period May 1, 1975 -- April 20, 1976

1. "Color-symmetry Breaking and the Baryon Spectrum II", Phys. Rev. D12, 3606 (1975).
2. "Color Symmetry-Breaking and the New Mesons", to be published in Phys. Rev. D.

2. M. Sugawara:

CP Violation in Gauge Theory without Charm:

One of the most important current problems in elementary particle physics is the question of whether or not one has to introduce the new quantum number called charm. The most compelling reason for charm stems from the experimental fact that the charged weak current of hadrons changes strangeness, but the neutral one does not appear to change it at all. This absence of the strangeness-changing neutral current is very difficult to understand from the theoretical point of view because the only successful theory of weak interactions is gauge theory[1] which requires that charged and neutral currents participate in weak interactions on the same footing. In fact, this absence cannot be explained in any gauge theory as long as one assumes that the most underlying hadrons are the usual quarks. It can be explained if one assumes the charmed quark in addition, which then introduces a large number of new charmed hadrons. However, none of these charmed particles has been found in spite of extensive search made so far.

I proposed another way[2] to overcome the above difficulty by assuming that the most underlying hadrons are the usual octet of baryons rather than a fewer number of quarks. The point is that an octet of baryons can provide a sufficient amount of flexibility so that we can avoid introducing charm. In order to introduce the Cabibbo angle, however, we must introduce an additional set of intermediate vector bosons. In other words, this new gauge theory must be invariant under twice as many gauge transformations and, hence, is twice as much constrained as the usual gauge theory is. It is because of this added constraint that this new gauge theory allows detailed studies on some important basic questions which are not necessarily possible for the usual gauge theory.

I have studied for the past year the question of how to understand CP violation from the point of view of this new gauge theory. The main conclusion I have reached[3] is that CP violation can arise in this theory in hadrons, but not in leptons, in such a way that this theory provides a specific example of superweak theory[4] of CP violation. In this theory, however, CP violation in $K_L^o \to 2\pi$ and the electric dipole-moment of neutron are not simply related to each other since they are due to independent parameters. Otherwise, there appears no other observable effect of CP violation.

I explain below some of the details of the above study. In this theory, all the complex factors that can arise in the hadronic weak currents can be absorbed into the baryon fields, thereby making all the weak currents CP conserving. In this theory, therefore, all the weak interactions due to exchange of intermediate vector bosons are CP conserving. These CP conserving weak currents then determine how baryons and leptons transform under gauge transformations, which in turn determine how Higgs scalars can interact with baryons and leptons. Since Higgs scalars can have nonzero vacuum expectation values, this interaction of Higgs scalars yields an additional weak interaction of the form of

$$\bar{\Psi}(F + i\gamma_5 F')\Psi \ , \tag{1}$$

where Ψ stands for all the baryons or leptons jointly and F, F′ are Hermitian matrices. Now, CP violation arises if F contains imaginary parameters and also if F′ has real parameters. The matrices F and F′ are determined[2] by the gauge transformations mentioned earlier. Thus, the most general forms of F and F′ express all the possible ways that CP can be violated in this theory.

We must then investigate the effect of a unitary transformation of ψ which can modify the matrices F and F′ in (1), without changing any other interaction of this theory in which ψ appears. This is because those terms in (1) which can be eliminated by this transformation cannot lead to any observable effect. It is this argument that was used[5] to explain why μ-e transformation, such as $\mu \to e + \gamma$, is hard to occur. Incidentally, the interaction (1) for leptons actually contains the terms which allow this μ-e transformation, as well as the terms which violate CP.

We have studied the above unitary transformation in detail with the following conclusion. For leptons, all the terms in (1) besides the lepton mass-renormalization counter terms can be eliminated, because the left-handed components of μ and e appear in this theory completely symmetrically, though μ-e asymmetry arises in the right-handed components. This agrees with the earlier observation[5] that $\mu \to e + \gamma$ is absent because μ and e are so similar.

Thus, this theory allows no CP violation for leptons, nor μ-e transformation. For baryons, however, hardly any term can be eliminated because baryons participate also in strong interactions which must not be affected by this unitary transformation. Most importantly, we cannot eliminate the term

$$id(\bar{n}\,\Xi^o - \bar{\Xi}^o n), \qquad (2)$$

where d is a real parameter contained in F of (1). The interaction (2) has a nonzero matrix-element between $|K^o\rangle$ and $|\bar{K}^o\rangle$, thus being able to explain CP violation in $K_L^o \to 2\pi$ in the same manner as superweak theory does[4]. However, the electric dipole-moment of neutron cannot be due to (2) which is P-conserving, but arises from the CP violating terms contained in F′ of (1). Since the matrices F and F′ are independent of each other in this gauge theory, the electric dipole-moment of neutron does not have to be as small as implied[6] by superweak theory. We also find that the interaction (1) does not appear to produce any other observable effect. Finally, we remark that the interaction (1) can change strangeness by two because ψ stands for the usual octet of baryons, which is not the case if ψ stands for the usual quarks.

1. S. Weinberg, Phys. Rev. Letters 19, 1264 (1967); 27, 1688 (1971).
2. M. Sugawara, Phys. Rev. D13, No. 5 (1976).
3. M. Sugawara, to be published.
4. L. Wolfenstein, Phys. Rev. Letters 13, 562 (1964).
5. G. Feinberg, P. Kabir, and S. Weinberg, Phys. Rev.Letters 3, 527 (1959).
6. L. Wolfenstein, Nucl. Phys. B77, 375 (1974).

4. Arnold Tubis:

Strong-, Electromagnetic- and weak-Interaction Dynamics of Few-Nucleon Systems:

My publications during the past year are listed as references 1-4 below. My research during the past year is detailed in separate subsections below.

A. Parity-Nonconservation Effects in the Two-Nucleon System-Sensitivity to the Short-Range Strong Nuclear Force[1-3]:

(in collaboration with Dr. B.A. Craver, Professors E. Fischbach, Y.E. Kim, P. Herczeg (Los Alamos) and P. Singer (Technion, Israel)).

The effects of parity nonconserving (PNC) nuclear interactions have been studied in recent years in the hope of discriminating among various models of the weak interactions. Since the N-N PNC interaction is of short range, its calculated effects are expected to be sensitive to the short-range correlations of the nuclear wave function. Consequently, the connection between a given weak-interaction Hamiltonian and experiment has very little significance in the absence of a careful study of the sensitivity of PNC effects to the assumed short-range behavior of the strong parity conserving (PC) nuclear forces.

We have calculated P_γ, the proton circular polarizarion in np radiative capture at thermal energies, for a class of weak Hamiltonians and several short-range non-local phase-equivalent transformations[5] (PET's) of the Reid soft-core potential[6] (RSCP). The calculations are done in coordinate space and are exact except for the usual first-order approximations in the weak and electromagnetic interactions. The calculations are greatly simplified by the use of Green's functions for the full strong Hamiltonian. For scattering states, these Green's functions are most conveniently calculated from the physical radial scattering solutions and solutions which have a pure outgoingwave asymptotic form. Once this Green's function is calculated, P_γ for various weak Hamiltonians and (phase-equivalent) strong Hamiltonians may be calculated by a direct quadrature. We have not taken into account the modification of the electromagnetic operators due to the velocity dependence of the phase-equivalent strong Hamiltonians. Since these modifications are of very short range ($r \lessapprox 1$ fm), they should not contribute much to P_γ (which depends mainly on the long-range parts of the strong wave functions).

For the Cabibbo weak Hamiltonian and the RSCP, we find $P_\gamma = 2.28 \times 10^{-8}$ in good agreement, with the value of 2.1×10^{-8} of Desplanques[7] and 2.28×10^{-8} of Lassey and McKellar[8]. For the Cabibbo weak Hamiltonian and the PET of the Reid potential considered, P_γ varies between 0.13×10^{-8} and 25.8×10^{-8}, with similar results holding for other weak Hamiltonians.

In view of the limited number of PET's considered, our results certainly do not preclude the possibility of finding a PET which could reconcile the theoretical value of P_γ with the experimental value[9] $P_\gamma = -(1.30 \pm 0.45) \times 10^{-6}$. The significance of such a result would, in itself, be questionable unless the implications of the modified strong interaction for properties of nuclear systems for $A > 3$, and for parity-violating effects in heavier nuclei, were determined at the same time. For the present our results simply demonstrate the dangers entailed in trying to discriminate amoung various weak Hamiltonians solely on the basis of calculations of P_γ for a given strong interaction.

B. Integral Relations for the Asymptotic Normalization of the Triton[10]

(in collaboration with Dr. C. Sander and Professor Y.E. Kim).

Lehmann and Gibson[11] (LG) have recently derived an integral relation for C_t, the normalization of the n-d tail of the triton wave function and a basic parameter of the trinucleon bound state.[12] We have given a concise alternative derivation of the LG result and an explicit evaluation of C_t in momentum space for the case in which the two-body interaction is not purely local or purely separable.

C. Scattering Theory for Non-Hermitian Potentials[4]

Non-hermitian (complex and/or energy-dependent) potentials arise formally when the equations for scattering in N coupled channels are reduced to ones involving explicitly only the scattering amplitudes for $M(< N)$ channels. In spite of their wide usage in atomic, nuclear and particle physics, there has been, to our knowledge, very little discussion in the literature of the general properties of the S-matrix, the off-energy-shell T-matrix, and the associated question of the orthogonality and completeness properties of the scattering eigenstates.

To a large extent, this deficiency has been remedied by the recent work of McKay and McKellar[13] (MM). We have supplemented the discussion of MM by: 1. showing that many of the important results of MM may be very concisely derived by using formal scattering theory, and 2. outlining direct perturbative proofs of results which MM did not derive--namely the completeness of the eigenstates of a wide class of two-body Hamiltonians with non-hermitian potentials, and the unitarity of the S-matrix for the case of real energy-dependent potentials.

The form of the completeness relation given in our paper is crucial for: 1. providing a foundation for properly carrying out closure sums in nuclear-reaction theory, 2. providing a means for continuing the two-body T-matrix off the energy shell in Faddeev-type calculations for three-nuclean systems[12] when the phenomenological two-nucleon interaction is given an explicitly energy-dependent form,[14] and 3. giving a procedure for doing nuclear-reaction calculations based on three-body formalisms and (non-hermitian) optical model potentials.

1. B.A. Craver, E. Fischbach, Y.E. Kim, A. Tubis, "Parity Nonconserving Effects in Neutron Capture by Protons and the Short Range Behavior of the Strong Two-Nucleon Force, to be published in Phys. Rev. D 13, 1376 (1976).

2. B.A. Craver, E. Fischbach, Y.E. Kim, A. Tubis, "Parity Nonconservation Effects in the Two-Nucleon System--Sensitivity to the Short-Range Strong Nuclear Force", Proceedings of the VII International Conference on Few Body Problems in Nuclear and Particle Physics, Delhi, India, 12/29/75-1/4/76; to be published by North Holland Publishing Company.

3. B.A. Craver, Y.E. Kim, A. Tubis, P. Herczeg, P. Singer, "Parity Violating Asymmetry in the Radiative Capture of Polarized Neutrons by Protons", Proceedings of the VII International Conference on Few Body Problems in Nuclear and Particle Physics, Delhi, India, 12/29/75-1/4/76, to be published by North Holland Publishing Company.

4. Y.E. Kim and A. Tubis, "Scattering Theory for Non-Hermitian Potentials", Proceedings of the VII International Conference on Few Body Problems in Nuclear and Particle Physics, Delhi, India, 12/29/75-1/4/76, to be published by North Holland Publishing Company.

5. J.P. Vary, Phys. Rev. C7, 521 (1973).

6. R.V. Reid, Jr., Ann. Phys. 50, 411 (1968).

7. B. Desplanques, Nucl. Phys. A242, 423 (1975).

8. K.R. Lassey and B.H.J. McKellar, Phys. Rev. C11, 349 (1974).

9. V.M. Lobashov, et al., Nucl. Phys. A197, 241 (1972).

10. C. Sander, Y.E. Kim, A. Tubis, to be published.

11. D.R. Lehman and B.F. Gibson, Phys. Rev. C13, 35 (1976).

12. Y.E. Kim, A. Tubis, Ann. Rev. of Nucl. Sci. 24, 69(1974).

13. C. McKay and B.H.J. McKellar, "Scattering Theory for Energy Dependent Po-

tentials", preprint, Service de Physique Theorique, CEN - Saclay, and School of Physics, University of Melbourne (1975), to be published in Nuclear Physics.

14. G.N. Epstein and B.H.J. McKellar, Phys. Rev. D10, 1005 (1974); K. Erkelenz, Phys. Reports 13, 191 (1974); A.D. Jackson, D.O. Riska, and B. Verwest, Nucl. Phys. A249, 397 (1975); M. Lacombe, B. Louiseau, J.M. Richard, R. Vinh Mau, and R. de Toureill , Orsay preprint (1975).

4: L. A. P. Balázs

During the preceding year several calculations were made within the dual multiperipheral model approach. This sort of model was originally proposed by Huan Lee[1], Veneziano[2] and Chan and Paton[3], and recently more detailed calculations have been made by Chan, Paton, Tsou and Ng.[4] In it one considers the exchange of exchange-degenerate pairs of Reggeons rather than single Reggeons or pions. In generating Reggeons one only sums planar graphs with uncrossed lines (in the quark-duality sense) whereas in generating the Pomeron (P) one must also include nonplanar graphs with crossed lines.

We considered a model for the production of clusters. The elastic absorptive part is then calculated in the usual way by using multiparticle unitarity, which gives a sum of ladder graphs. Duality is then used to relate the couplings of the clusters to the corresponding couplings of Reggeons[4,5] (we do not, however, actually replace the clusters with Reggeons, as was done in ref. 4). The basic inputs then are triple-Regge couplings.

A major problem with dual multiperipheral models has been their inability to generate the f trajectory along with the Pomeron in the vacuum state. We therefore did a calculation in which the effective thresholds associated with the production of clusters were taken into account.[6] The parameters of our model were first adjusted so as to properly reproduce the leading Reggeon trajectory. We then used them to calculate the Pomeron. We find, however, that, in addition to the usual leading real pole at $J \approx 1$, we also obtain a set of complex singularities in the J plane. This leads to a forward absorptive part with a behavior $s^{0.85}$ for $s \leqslant 50$ GeV^2 and s^1 for $s \geqslant 50$ GeV^2, at least below ISR energies. We are thus able to simulate the conventional P + f description without actually having an f singularity in the J plane. In addition, we are able to actually calculate all the parameters needed to describe the cross section in this energy range and obtain results in good agreement with experiment.

The above approach also permits us to make bootstrap calculations of Reggeon parameters, similar in spirit to the planar bootstrap of Veneziano.[2] So far the only calculations we have done are ones in which pion exchange is taken explicitly into account, but the exchange of other Reggeons is only included indirectly through a technique based on finite-energy sum rules. In this kind of calculation it is not possible to calculate the Regge trajectory α, but it is possible to calculate the Regge residue self-consistently. This turns out to be in good agreement with experiment in the forward direction.

In addition to the above program work was done (in collaboration with P.D. Rittmann) in an ongoing project to use f/P universality to correlate the different triple-Regge terms which are needed to describe the data for inclusive processes in the triple-Regge region.[7] Specifically it was argued within the framework of a two-component picture of the Pomeron that the usual f/P universality must be modified when relating PPP and PfP to other triple-Regge terms. We found that this led to an improvement in the predicted deviation from scaling of the pp → pX cross section.[8]

An alternative description of pp → pX is one based on the results of our dual multiperipheral model, where we saw that we have an effective P trajectory with intercept $\alpha \simeq 0.85$ at intermediate energies instead of the usual P + f with $\alpha_P = 1$. This effective P is, however, still related to the f trajectory that would result if we left out nonplanar graphs, which in turn is related to ω exchange through exchange degeneracy. We thus have a description which involves the same number of parameters as the one described in the preceding paragraph. An analysis of the pp → pX data by P.D. Rittmann showed that this description is as good as the one based on the conventional P + f picture.

Finally, dynamical calculations were made (in collaboration with P.D. Rittmann) of the triple-Regge couplings which come into the process $\pi\pi \to \pi X$. The procedure was first to use a Deck-type model to calculate the contributions coming from various Regge exchanges to the inclusive cross section for low missing mass M; this is the only region where we expect such a model to be valid, since many other contributions are expected to come in for high M. We can then actually calculate all of our triple-Regge couplings by inserting our Deck contributions into finite-mass sum rules and using f/P universality. These couplings can be related through factorization and exchange degeneracy to the corresponding couplings for pp → pX, which then give cross sections in reasonable agreement with the data. Reasonable results are also obtained if we use an effective P with intercept $\alpha \simeq 0.85$ instead of the conventional P + f.

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2. G. Veneziano, Phys. Lett. 43B, 413 (1973).

3. Chan Hong-Mo and J.E. Paton, Phys. Lett. 46B, 228 (1973);

4. Chan Hong-Mo, J.E. Paton, Tsou Sheng Tsun and Ng Sing Wai, Nucl. Phys.

B92, 13; B86, 479 (1975).

5. L.A.P. Balázs, Phys. Lett. 29B, 228 (1969); Phys. Rev. D2, 999 (1970).
6. L.A.P. Balâzs, Thresholds of the Pomeron in a Dual Multiperipheral Model, to be published in Phys. Lett. (1976).
7. L.A.P. Balázs, Phys. Rev. D11, 1071 (1975).
8. L.A.P. Balâzs, and P.D. Rittman, A Modified Version of f/P Universality in the Triple-Regge Region, to be published in Phys. Rev. (1976).

5: E. Fischbach:

A. Elastic Neutrino-Proton Scattering:
(with S.P. Rosen)

We have completed the lengthy analysis of $\nu p \to \nu p$ which we described earlier, and are on the verge of submitting this for publication. As noted previously, elastic neutrino-proton scattering provides a means of discriminating among models of the weak neutral current through measurements of the average momentum transfer $\langle t \rangle$ and the proton polarization $\vec{P}$. Since the differential cross section $d\sigma/dt$ vanishes in the forward direction for S,P couplings but in the backward direction for V,A couplings, $\langle t \rangle$ should be "large" if the neutrino coupling is S,P and "small" if it is V,A. It has been shown through the t-dependence of $d\sigma/dt$ arising from the kinematic differences between V,A and S,P,T couplings can in principle be obscured by both the dynamical t-dependence arising from (unknown) form factors, and by experimental cuts on the data, a kinematic distinction between V,A and S,P,T survives in the end. Our results are presented in terms of a series of detailed graphs. Concerning the polarization $\vec{P}$, the effects arising from different couplings can differ by $\sim$ 100%. Hence polarization effects can in principle give very clear signals, if such experiments can actually be carried out.

B. Helicity-Flipping Neutral Currents and $\gamma\gamma \rightarrow \nu\bar{\nu}$:
(with S.P. Rosen)

The process $\gamma\gamma \rightarrow \nu\bar{\nu}$ has often been considered as a mechanism for stellar cooling but its rate has generally been found to be smaller than the rates for other competing processes. This result has its origins in a theorem due to Gell-Mann which states that in the limit of zero neutrino mass the amplitude for $\gamma\gamma \rightarrow \nu\bar{\nu}$ vanishes when the charged-current weak interaction is local and V-A in structure. In this paper[1] we point out that this theorem breaks down if the helicity-flipping S or P covariants are present in the neutral current. In this case the process $\gamma\gamma \rightarrow \pi$ or $\eta \rightarrow \nu\bar{\nu}$ can take place and the resulting amplitudes can have a pole at the location of the π^o or η mass. For the π^o this leads to an enormous rate of energy loss at temperatures of order 10^{11} °K. This contribution could be significant in the theory of the early universe and of supernovae, and recently some interest has developed in this mechanism on the part of astrophysicists.

C. Parity-Nonconservation in High-Transverse-Momentum Collisions:

In this paper[2] we suggest that the suppression of strong interaction cross sections at high transverse momenta might make it possible to detect parity-nonconserving weak effects in high-energy collisions. This suggestion is motivated in part by the observation that some purely hadronic cross sections have already been measured down to levels characteristic of weak interactions. Interestingly enough no calculation of this effect had been undertaken previously. In collaboration with George Look an analysis of several such processes was undertaken which led to the following results. A calculation of the longitudinal polarization of the proton $\mathcal{P}$ (a parity-violating effect) shows that the magnitude increases monotonically from 5×10^{-5} at

$X_\perp = 2p_\perp /\sqrt{s} = 0.24$ to 1×10^{-3} at $X_\perp = 0.62$. Similar results are obtained for the asymmetty A arising from the difference in the invariant cross-sections for initially ± polarized protons. These results are interesting because the magnitudes of the expected effects are such as to suggest that they could be detected by presently available techniques. Should this be the case, then potentially valuable information on the factor model specifically, and high energy scattering in general, could be obtained from a comparison of theory and experiment.

D. Parity-Violation in $np \to d\gamma$:[3]

See report of A. Tubis.

1. E. Fischbach, J.T. Gruenwald, S.P. Rosen, H. Spivack, A. Halprin, and B. Kayser, Phys. Rev. D13, (in press).

2. E. Fischbach and G.W. Look, Phys. Rev. D13, 752 (1976).

3. B.A. Craver, E. Fischbach, Y.E. Kim, and A. Tubis, Phys. Rev. D13, (in press).

6: N.H. Fuchs:

A. SU(6) Classification for "In" and "Out" States:

We have previously investigated[1] the possible relation in the context of interacting quark models between the algebra of $SU(6)_{W,\text{currents}}$, whose generators F_i^α are integrals of the local currents which describe the electromagnetic and weak interactions of hadrons, and the algebra of $SU(6)_{W,\text{strong}}$ degenerate multiplets.

Unfortunately, our results in the interacting quark model were not expressed in a form convenient for further phenomenological investigation of the effects of interaction. We have developed an expression for the transformation connecting current and constituent quark bases which displays the dependence on interaction in a rather transparent manner. Thus we may gain an understanding of the relation of the quark-parton picture to the traditional quark model for hadronic structure.

Within the context of the quark model with interaction, SU(6) algebras classifying "in" and "out" states have been constructed[2] and the unitary transformation relating these algebras to the $SU(6)_{W,\text{currents}}$ algebra generated by integrals of local currents has been given simply. The formulation is general so that one may separately study the kinematic effects arising from the angular requirements on the generators of the classification algebras and the dynamical effects arising from the nature of the interaction.

B. Current and Constituent Quark Phenomenology:

There have been two completely disjoint approximations used heretofore in making phenomenological use of the relation between current and constituent quarks. The approach of Melosh[3] and his followers has been to ignore (or argue away) the effect of interaction, while including the effects of the transformation V_{free}. The approach of Yan[4] and others has been to ignore the distinction between current and constituent quark bases by setting $V_{free} = 1$, while including the effects of interaction which are generated by the dressing operators; this approach is reasonable in the context of scalar quarks.

Within the context of the formalism developed (Ref. 1), we have been able to do better[5] than these extreme approximations have been able to do. Since we know V_{free} explicitly for the spin ½ quark model, we have been able to include its effects completely in an interacting quark model while making some hopefully realistic approximation so as to account for the effects of interaction to some degree.

The transformation relating the expansion of hadronic states in the current and constituent quark bases is studied in the context of the vector gluon model. A phenomenological approach is used to estimate the effects of interaction on the algebraic structure of matrix elements describing pionic, electromagnetic and weak transitions of hadrons. Contributions of terms with exotic transformation properties are found to be negligible in most instances, but are important for higher moments of deep inelastic structure functions. The magnitude of such exotic terms is related to that of the mass splitting of SU(6) multiplets.

1. N.H. Fuchs, Phys. Rev. D11 1569 (1975).
2. N.H. Fuchs, paper submitted to Phys. Rev.
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4. T.-M. Yan, Phys. Rev. D7 1780 (1973).
5. N.H. Fuchs, Phys. Rev. D13, 1309 (1976).

7: T.K. Kuo:

A. Classical Solutions of Field Theory:

There has been considerable interest[1] recently in the classical solutions of non-linear field theory equations. The so-called soliton solutions are interesting since they might provide us with insights into the quark confinement problem. Specifically, the classical soliton solutions may be regarded as the ground states of extended hadrons. Small deviations, or quantum fluctuations, around these non-trivial classical solutions are then the excited states of hadrons.

We considered the classical equation of motion for field theories of massive fermions with general Fermi interactions in one space and one time dimension. Exact solutions are presented.[2] Quantization of these solutions using the WKB approximation has also been discussed in detail.[3]

1. R. Dashen, B. Hasslacher and A. Neven, Phys. Rev. D10, 4114 (1974); 10, 4130 (1974); 10, 4138 (1974). J. Goldstone and R. Jackiw, Phys. Rev. 11, 1486 (1975). N. Christ and T.D. Lee Phys. Rev. D12, 1606 (1975).
2. S.Y. Lee, T.K. Kuo and A. Gavrielides, Phys. Rev. D12, 2249 (1975).
3. S.Y. Lee and A. Gavrielides, Phys. Rev. D12, 3880 (1975).

B. Generalized Gauge Invariance:

Traditionally, in the treatment of internal symmetry, the group space does not play any role. On the other hand, recent developments in gauge group theories suggest a close relationship between space-time and group space coordinates. Thus, in the discussion of classical gauge field equations and monopoles,[1] the boundary condition as well as the solution are mixed in the space-time and group space indices.

We wish to generalize these results by giving the group space coordinates a genuine physical meaning. Let us assume, erected at each space-time point X, an internal symmetry group coordinate ξ . We will consider a field theory for which the field depends on both x and ξ: $\Psi(x,\xi)$. We ask the question: Can one construct a gauge invariant theory using these fields $\Psi(x,\xi)$? The answer is affirmative and we showed how such a theory may be constructed.[2]

Physically, $\Psi(x,\xi)$ describes a series of fields with differential internal quantum numbers. For instance, if we consider U(1) for charge conservation, $\Psi(x,\xi)$ would describe a series of fields with charges $Q, Q \pm 1, Q \pm 2, \ldots$. We applied our ideas to other hadronic symmetry groups. Possible applications are discussed.

1. G. t'Hooft, Nucl. Phys. B79, 276 (1974).

2. A. Gavrielides, T.K. Kuo and S.Y. Lee, Nuovo Cimento Letters (to appear).

C. Ghost Problem in Field Theory with Higher Derivatives:

Recent efforts in formulating gravitation as a gauge theory[1] calls for a Legrangian density in the form $(\Box\phi)(\Box\phi)$, rather than the traditional $\phi(\Box\phi)$. Similarly, for quark confinement theories, where the potential is supposedly linear in r, a quartic Lagrangian is needed. However, the canonical quantization procedure, when applied to these kinds of higher derivative field theories, invariably leads to ghost solutions.[2] Such discussions usually suffer from very complicated technicalities, especially in cases where there are interacting terms in the Lagrangian.

We have reconsidered this problem using the path integral method.[3] The existence of ghost solutions was shown explicitly. It was further shown, in a very simple way, that the ghosts couple with the non-ghost solutions. We conclude, therefore, that the recent proposals of gauge gravitational theories and quark confinement theories using higher derivative Lagrangians are manifestly non-unitary.

1. C.N. Yang, Phys. Rev. Letters 33, 445 (1974).

2. C. Bernard and A. Duncan, Phys. Rev. D11, 848 (1975).
J.E. Kiskis, Jr., Phys. Rev. D11, 2178 (1975).

3. A. Gavrielides, T.K. Kuo and S.Y. Lee, Phys. Rev. D. (to appear).

8: B.F.L. Ward:

Asymptotic Limits in Renormalizable Quantum Field Theory;
The Large Momentum Transfer and Large Coupling Limits:

During the past year, I continued my investigations of the large momentum transfer limit of renormalizable quantum field theory. Simultaneously, I continued to develop and apply my approach to strong coupling in theories of this type.

More specifically, the differential dispersive aspect[1] of the renormalization group equation, applied to the inverse photon propagator $D^{-1}_{\mu\nu}$, has now been shown[2] to provide a basis for understanding the following: (1) the sharp rise in the ratio

$$R = \frac{\sigma(e^+e^- \to \text{Hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

(the slope of this rise is predicted to be the value of R for $1_+ \leq s \leq 10_+ (\text{GeV})^2$, not inconsistent with observation); (2) the position of the beginning of this rise (the position is given as $s \simeq 10_+ (\text{GeV})^2$, consistent with observation); and (3) the final asymptotic value[3] of R. This final value of R, R_f, by which I mean the value of R for s values above the $\Psi/J, \Psi'$, and etc., is seen in my approach[3] to be related to, but not simply the same as, the sum over the squares of the hadronic fundamental fermion charges. And, in fact, the experimental value of $R_f \simeq 5\text{-}6$ is entirely consistent with the conventional fractionally charged p,n, and λ quark model description of the scaling limit of the hadronic electromagnetic current, as is the value of R for $1_+ \leq s \leq 10_+ (\text{GeV})^2$.

In addition, the new mass scale of the Ψ/J and its associated excitations has been computed[4] from the conventional quark mass scale, the enlargement of the mass scale being given by the factor $\exp c_\theta/2b_o$, where c_θ and b_o are pure Q.E.D. numbers determined by the coefficient functions γ_θ and β, respectively, in Weinberg's formulation[5] of the renormalization group equation. The Ψ/J mass is computed to be

$$m_{\Psi/J} = 2m_q \exp c_\theta/2b_o .$$

It is well-known that $c_\theta/b_o = 9/2$. Thus, with $m_q = 163(\text{MeV})$ we obtain the mass of the Ψ/J. This helps to explain the remnant scaling behavior of $\sigma(e^+e^- \to \text{hadrons})$ just off the Ψ's, for throughout the region $S \geq 1_+ (\text{GeV})^2$, one is dealing with quarks of mass ~ 100 MeV, even though singularities (Ψ/J, etc.) are occurring with masses ~ 3 GeV. Thus, in this view, no new heavy quark or new quantum number is necessary to understand the new particles in $e^+e^- \to X$. I do not take as exact the value $m_q = 163$ MeV, although it should not be off by much. The important point is that the appearance of a new set of heavy narrow states is expected from my new dimensional analysis violating[1] terms in the partial differential equations of renormalizable quantum field theory.

I use the word narrow with quantitative justification, for the states Ψ/J and etc. appear as real zeros in the differential dispersive solution for $D^{-1}_{\mu\nu}$, corresponding to zero widths. This is an artifact of my having stopped the calculation of the violation of dimensional analysis at the lowest order in α at which it occurs. In higher orders, the zeros will move off the real axis. But, this can be at most an order α effect, maintaining the sharpness of the states.

In addition to determining the precise widths of the Ψ/J and etc., the higher order effects of dimensional analysis also appear[6] to afford the possibility of further suppressed new states in the e^+e^- annihilation channel at values of s given by

$$\sqrt{s_n} = n m_{\Psi/J}\,, \quad n = 2,3,\ldots N_o$$

as well as

$$\sqrt{s_{n_1 n_2}} = 2n_1 m_\mu \exp c_\theta/2b_o + n_2 m_{\Psi/J}\,,$$

where $n_1 = 1,2,\ldots, n_2 = 0,1,\ldots$ with $n_1 + n_2 \leq N_o$ and $n_1 > 1$ when $n_2 = 0$. N_o is a number determined by the order N_{Dyson} in α at which the Feynman-Schwinger series for $D_{\mu\nu}^{-1}$ ceases to be reliable. N_{Dyson} is expected to be large. (I should mention that a state with $n_1 = n$, $n_2 = 0$ is naively expected to occur at the same order as the Ψ/J. The absence of such a state would seem to imply a lack of symmetry between quarks and leptons in nature.)

It appears that the state $\sqrt{s_2} = 2m_{\psi/J}$ may have been found.[7] However, all of the remaining states $s_{n_1 n_2}$ continue to lack experimental support, although no definitive statement exists. Hopefully, this will change in the not-too-distant future. The strict theoretical statement about the existence of all of these states $s_{n_1 n_2}$ is under investigation.

It should also be pointed-out[3] that the application of the theory of differential dispersion relations to the inverse of the weak interaction vector boson propagators would appear to afford the possibility of new heavy particles with the quantum numbers of the K, π, ρ^+ etc. All of these effects are under analysis.

As I stated above, simultaneously with these investigations of differential dispersion relations, I formulated[8] and applied [9,10] an approach to strong coupling in renormalizable field theory. The principal result to date is the complete decoupling of fermions from bosons in this formulation of the strong coupling limit of renormalizable theories. This means that the confinement results of various authors[11] would appear to be artifacts of their particular approximations.

The decoupling theorems provide a strict understanding of Bjorken scaling, for quarks would behave canonically in any boson-mediated theory for which large momentum transfer corresponds to large coupling. On the other hand, the confinement of these quarks would appear to require an entirely new perspective. This confinement problem and the further implications of this approach to strong coupling are all under investigation.

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5. S. Weinberg, Phys. Rev. D8, 3497 (1973).
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7. Private communication from researchers at Fermi Lab about a seminar by Dr. Innes, January, 1976.
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11. See, for example, W. Bardeen et al., Phys. Rev. D11, 1094 (1975).