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Work under our contract has continued at the accustomed pace and variety. It was especially gratifying this year that several of our graduate students have now reached the stage when they could contribute to published research papers. The activities of the seven post-Ph.D. researchers continued to involve collaboration with a large number of institutions around the world. The list of institutions or conferences at which collaboration or exchange of views (in the form of colloquium or seminar talks) occurred is as follows: SLAC, University of Washington, Saclay, Argonne National Laboratory, Portland State University, Purdue University, Lawrence Livermore Laboratory, University of Wisconsin, Ruder Boskovic Institute in Zagreb, University of Chile, International Summer College in Pakistan, National Fermi Accelerator Laboratory, Rutherford Laboratory, University of Durham, Westfield College in London, University of Cambridge, University of Liverpool, International Conference on the Few-Body Problems in Austria, University of Southampton, University of Birmingham, Imperial College, Rencontre de Moriand in France, University of Bielefeld, Orsay, Ecole Polytechnique in France, University of Glasgow, International Conference on Multiparticle Processes in Czechoslovakia, University of Tel Aviv, Los Alamos Meson Physics Facilities, California Institute of Technology, University of Chicago, University of California at Berkeley, McGill University, and CERN.

It should be noted that most of the travel expenses were not covered by the grant under our contract. Obviously, it would have been impossible to make international contacts of such a wide range within the budget limitation of our foreign travel fund. A large portion of the travel funds was provided by the Rutherford Laboratory in England where R.C. Hwa spent his sabbatical leave.

Although our group is relatively small in size, the breadth and depth of the work done here is considerable. Though some of these areas are clearly related to each other, we will outline the work in each of them separately.

A. The Parton Recombination Model

The model originated earlier in our group and has recently been used extensively by other groups working on inclusive hadronic processes. The model, which can predict quantitatively the longitudinal momentum distribution of mesons produced in the large Feynman x region, is simple enough for experimentalists to make instant comparisons of its predictions with data. The model has been generalized to cover resonance production (209). When the model is applied to inclusive reactions initiated by mesons rather than protons, it yields the first phenomenological determination of the pion structure function (204,207).

DISCLAIMER

B. Lepton Pair Production

This reaction has become a center of interest both because data has become available and because QCD allows to calculate. Work in our group covered both theoretical and phenomenological aspects. Features in the large transverse momentum region of the lepton pair were studied as a generalization of the parton model to large k_T and as a manifestation of the universality among various virtual photon processes (211,212), or in terms of the hydrodynamic properties of hadronic collisions (208), the latter giving good fits yet using hardly any new parameters. The field as a whole was also reviewed (206) and a critique of the QCD calculations was offered (203). It was also shown (210) that sum rules and moments for lepton pair production will, when data become available, offer rather clean tests of the validity of the Drell-Yan mechanism. Work is underway to find polarization tests of the Drell-Yan model in the muon-pair production in proton-proton collisions, with very encouraging results. Several types of calculations have been intercompared to explore the Q_T dependence of lepton production in hadron-hadron collisions at large transverse momenta within the Drell-Yan mechanism.

C. Perturbative QCD

The currently fashionable QCD calculations, in the perturbation approximation, have been applied to a number of hard collision processes. Studies were done in our group (205) of the parton k_T in such a calculation, and it was found that if we consider the inclusive distribution, the commonly accepted factorizability for lepton-pair production does not hold for arbitrary transverse momenta. However, it reduces to factorizability in the special kinematic regions where the property is known to be true. The nature of scaling violation was also exhibited for k_T distributions consistent with the solution of the renormalization group equation.

D. Quark Models for Hadrons

Electromagnetic properties of hadrons were calculated hitherto in a nonrelativistic approximation which is unlikely to be good for light quarks. New calculations (220) used the spherical cavity approximation to the static MIT bag model to evaluate MI transitions. Since the magnetic moment of the proton is 30% too low in the usual bag parameterization, we introduced a new parameter into the bag energy, thus getting the right moment. With this modification we then calculated masses, radii, magnetic moments, charge radii, and axial vector coupling constants for all low lying SU(4) states. Altogether 38 different MI transitions were evaluated.

In another effort, the transverse separation of quark-partons in the nucleon are calculated and it was found that the transverse charge radius of the u quark in a proton (as viewed in the infinite momentum frame used in the parton model) is about $(240 \text{ MeV})^{-1}$. The charge radius of d quarks is about 4% smaller. The results are based on the measured values of the derivative of the electromagnetic form factor $F_1(Q^2)$ of the neutron and the proton at $Q^2=0$. The work also involved correcting some errors in the previous literature.

E. CP Conservation in Strong Interactions

It was pointed out recently that if instantons exist, then strong interactions in QCD would violate CP invariance unless the theory possessed an additional $U_A(1)$ symmetry. In the simplest modification of the standard weak interaction theory, such symmetry would mean that either the mass of the up-quark is zero, or that there is a low-mass weakly interacting pseudoscalar boson (axion). The latter alternative is not substantiated by present experimental evidence. The former has been objected to on the basis of current algebra, but we have shown (215) that this objection is not compelling, and in fact the former alternative can lead to a successful determination of the mass of the $\sigma(970)$.

F. Current Algebra

Since quantum chromodynamics contains as input parameters the various quark masses and a universal coupling constant, the estimate of these masses from some symmetry principle is of importance. This is attempted (216) in the SU(4) x SU(4) current algebra. The simple sigma model is unreliable because of the large symmetry breaking, and so a more general method is used with the masses of D, F, and η_c as inputs. It is surprising that the resultant bare mass m_c turns out to be only three times larger than m_s.

The SU(4) symmetry breaking is measured by the decay constant F_D of the D meson, but it cannot be determined from the branching ratio for $D\to\mu\nu$ because the latter is too small. Therefore a method is suggested (217) to find F_D from $D\to K+\mu+\nu$, using current algebra and the soft K theorem, similarly to the Callen-Treiman relation.

The rate of the decay $\eta'\to\eta\pi\pi$ has been a puzzle for some time, since using soft pion theorems, the rate is given off-shell by the expectation value of the σ term $\sim\langle\eta'|\sigma|\eta\rangle$ where $\sigma^{ij} = [F^i_s, A_j]$, but this gives a rate at least two orders of magnitude smaller than the experimental result. This problem was resolved (218) by showing that the extra poles in the amplitude make the extrapolation to the on-shell value very subtle, one can construct an amplitude with the correct off-shell behavior which can account for the experimental features of the decay, e.g., rate, two-pion distribution, and eta-pion distribution.

G. Unified Gauge Models

An indispensible ingredient in the experimental verification of unified gauge models and thus of the Weinberg-Salam model is the observation of the Higgs phenomena. If such a theory has more than one Higgs doublets, a charged $Q^{\pm}$ should exist, and with this in mind, we studied its properties (219). It also was shown that the Hsu-Sudarshan way of quantizing the Weinberg-Salam model leads to Feynman rules identical to the standard ones.

H. Field Theories

A simple and direct construction has been given (223) for the functional integral representation, over anticommuting variables, of Greens functions for field theories, thus clarifying the previous and rather indirect derivations of this representation.

Two technical problems in the large order behavior of perturbative theory in quantum mechanics and quantum field theory in Lipatov's method have been investigated (222). First, it was shown how the contour of the integral used in the saddle point approximation can be adjusted so that the integral remains convergent at each stage, thus eliminating the embarrassing divergence encountered previously. Second, in the actual computations of corrections to the Lipatov result, when one calculates the effects of the fluctuations in the coupling constant and in the fields $\phi(x)$ about the saddle point g_c, $\phi_c(x)$, it is shown how the fluctuations in g can be integrated over exactly, thus leaving only the fluctuations in $\phi(x)$ to be treated perturbatively.

I. The Few-Body Problem

A review has been prepared of progress made in the few-body problem in microscopic physics as reflected in the proceedings of the seven international conferences on this subject held since 1959. Four subtopics: The deuteron, the three-body bound state, break-up reactions, and electromagnetic effects, were analyzed in detail. Conclusions too numerous to be listed here are given with respect to questions pertaining to the epistemology of this subject, the positon of this field in the whole of physics, theoretical developments, experimental developments, and the scientific community working in this field (214).

J. Polarization Phenomena

A new view of polarization phenomena was formulated (213) in order to interface theory and experiment and in order to eliminate unnecessary steps in the extraction of a maximal amount of data from polarization experiments. Two general theorems are given and proven. The first says that it is always sufficient to measure polarization quantities along only two quantization directions in order to determine the reaction amplitudes. The second shows that given a specific theoretical prediction for the amplitudes of a given but arbitrary reaction, one can always choose a quantization direction with respect to which if we measure the number of particles in one single projection state, we have a null-experiment to test the theoretical predictions.

An investigation is being carried out on the polarization quantities in elastic electron-deuteron scattering at high (SLAC and higher) energies with two purposes in mind: a) to find convenient observables that separate the three formfactors; b) to find observables which are particularly sensitive to the meson-current contributions, the magnitudes of which are uncertain as given by theoretical estimates. The use of polarization is also being investigated in deep inelastic scattering as treated by the parton model and, specifically, in the Drell-Yan mechanism in various reactions.

K. Fermi-Motion Effects in the Deuteron

The so-called West correction for reactions involving deuterons has occupied an ambiguous position: on the one hand, it has been used to interpret actual experimental data; on the other hand, its existence has been questioned by several papers. Investigations in our group, which are almost concluded, indicate that such corrections do not exist in hadronic reactions, but they do exist in electron-induced reactions.

L. Euclidean Pseudoparticles

Self dual pseudoparticle solutions for the classical Yang-Mills field equation with finite action have been constructed in Minkowski space (224). It was shown that the topological structures apparent in Euclidean space are not present in Minkowski space. Topological charges become fractional, leading to unquantized axial charge violation in processes involving fermions.

M. Parity Violation and Neutrinos

Ever since parity non-conservation was discovered some twenty years ago, it was suspected that there is a connection between this phenomenon and the existence of the neutrino. During the last year, a physical mechanism (neutrino pairing) was found which causes the usual low energy structure of weak interactions (with its maximal parity violation) to emerge as a condition that the neutrino stay massless (225). The same mechanism also leads to the usual Weinberg mixing pattern. This work is based on the group $SU(4)_L \times SU(4)_R \times U(1)$, and as such it is a natural development of our work on the group $SU(4)_L \times U(1)$ which was described in our last annual report. Essentially, that previous work has been reconstructed so that parity be a spontaneously broken symmetry. In addition, however, the weak interactions now emerge as the local gauge extension of the strong interaction chiral flavor group, and thus connects the problem of strong interaction symmetry breaking with weak interactions. Neutrino pairing could open the way to a dynamical determination of the Cabbibo angle.

N. Coherent Photon Production with Storage Rings

Perhaps the most promising method to produce coherent X-rays would be to pump an X-ray laser with synchrotron radiation. This method, suggested earlier, was studied in more detail during the past year in collaboration with the Lawrence Livermore Laboratory. The results obtained so far are only partial. They seem to be in essential agreement with the cruder calculations performed during the preceding year.

An important technical problem which limits synchrotron radiation experiments at this time has to do with X-ray diffractive gratings. New approaches are called for and are opening up in the preparation of such gratings. These have been surveyed (226).

Once X-ray lasers become a reality they will, in turn, greatly improve the opportunities for X-ray holography. This subject was reformulated in the language of potential scattering (227). Such reformulation makes it more accessible to researchers whose main activity lies outside the field of classical optics, and enables one to derive results without reference to classical optical instruments.

It was shown that the intensity of synchrotron radiation would be increased by two to three orders of magnitude (up to the soft X-ray region) if the circulating electron beam were to be appropriately illuminated with an optical laser producing radiation with a suitable wavelength. Furthermore, it was found that the required laser light intensity could be decreased by several orders of magnitude if the beam distribution in four dimensional (x, x', E, ϕ) phase space is properly changed before it is allowed to interact with the optical laser.

Publications, October 1977 - October 1978

The numbering (N) in the first column represents the last number in the code number of the publications written under our grant; that is, RLO-2230T5- N .

N	Authors and Titles
203	R.C. Hwa A Review of the Theory and Phenomenology of Lepton Pair Production Proc. XIII Rencontre de Moriond, 1978, Vol. I RL-78-044
204	R.C. Hwa and R.G. Roberts Pion Structure Function from Low p_T Hadron Production Zeits. f. Physik C (to be published). RL-78-078
204	R.C. Hwa and J. Wosiek Nonfactorizability of Inclusive Distributions in Perturbative QCD RL-78-079
206	R.C. Hwa Recent Theoretical Developments in Lepton Pair Production Proc. IX Int'l Symp. on High Energy Multiparticle Dynamics, Tabor, Czechoslovakia OITS-95
207	R.C. Hwa Parton Recombination Model Proc. IX Int'l Symp. on High Energy Multiparticle Dynamics, Tabor Czechoslovakia OITS-94
208	R.C. Hwa and C.S. Lam A New Approach to Lepton Pair Production Phys. Lett. (to be published)
209	R.G. Roberts, R.C. Hwa, and S. Matsuda Parton Recombination Model Including Resonance Production RL-78-040
210	R.C. Hwa Sum Rules and Moments for Lepton-Pair Production Phys. Rev. Lett. 40, 1218 (1978) RL-78-008/A
211	R.C. Hwa, S. Matsuda, and R.G. Roberts Quark Parton Model with large Parton k_T Zeits. f. Physik C (to be published) RH.2456 CERN
212	R.C. Hwa, S. Matsuda, and R.G. Roberts Generalization of Quark Parton Model: A Study of σ_L/σ_T and Large k_T Phys. Lett. 76B, 347 (1978)

213 G.R. Goldstein and M.J. Moravcsik
Interfacing Theory and Experiment in Polarization Studies
Phys. Rev. (to be published)
OITS-99

214 M.J. Moravcsik
Twenty Years of the Few-Body Problem
Proceedings of the International Conference on the Few Body Problem, Graz, 1978 (to be published)

215 N.G. Deshpande and D.E. Soper
Is the Up-Quark Mass Zero?
Phys. Rev. Lett. 41, 735 (1978)
OITS-85

216 K.P. Das and N.G. Deshpande
A Determination of the Chiral SU(4) x SU(4) Breaking Parameters
Phys. Rev. (to be published)

217 N.G. Deshpande and D. Iskandar
A Proposal to Measure the D Meson Decay Constant F_D
Phys. Rev. (to be published)
OITS-96

218 N.G. Deshpande and T.N. Truong
Resolution of the $\eta' \to \eta\pi\pi$ Puzzle
OITS-97

219 N.G. Deshpande and P. Kielanowski
A Note on Quantization of Weinberg-Salam Unified Field Theory
Acta Polonica (to be published)
OITS-90

220 R.H. Hickman, N.G. Deshpande, D.A. Dicus, and V.L. Teplitz
M1-Transitions in the MIT Bag Model
Phys. Rev. (to be published)

221 J.F. Gunion and D.E. Soper
The Average Transverse Distance between Partons as Measured by Nucleon Form Factors
Phys. Lett. 73B, 189 (1978)

222 D.E. Soper
Perturbation Theory at Large Order: The Choice of Interaction Contours
Nucl. Phys. B. (to be published)
OITS 89

223 D.E. Soper
Construction of the Functional Integral Representation for Fermion Green's Functions
Phys. Rev. D (to be published)

224 Ilmun Ju
What Does the Euclidean Pseudoparticle do in Minkowsky Space?
OITS-93 (1978)

225 P. Mannheim
Parity Violation and the Masslessness of the Neutrino
OITS-98

226 P.L. Csonka
Improved(Transmission) Gratings
Workshop on X-ray Instrumentation for Synchrotron Radiation Research, Stanford Linear Accelerator Center (1978)

227 P.L. Csonka
Holography Explained in the Language of Potential Scattering
SSRL Report 78-03, Stanford Linear Accelerator Center (1978)