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Report of Technical Progress under
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Principal Investigator: A. Pais
Rockefeller University, New York, N.Y., 10021

The following is a necessarily incomplete review of work done under the present contract. The cut-off date is approximately February 1, 1972. Footnote numbers refer to the list of papers completed, see pages 9-13.

Principal Investigator Dr. A. Pais, and Drs. M.A.B. Beg, N.N. Khuri, and H.R. Pagels have spent at least 1/4 of their time on work related to this contract. This is expected to continue for the remainder of the current term.

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(I) Scaling

Several and diverse studies were made related to the scaling properties observed in total deep inelastic electron-nucleon and neutrino-nucleon scattering experiments.

- a) Attempts have been made to view scaling, and possibly other very high energy phenomena, as a manifestation of a "broken dilatational symmetry". Here the important question arises how (and if) it is possible to assign a "scale dimension" to certain operators. It was found¹ that vector and axial vector currents can be assigned a scale dimension if the trace of the energy momentum tensor is soft enough to permit certain commutator conditions to hold. It was also shown^{1,5} that for the case of unconserved currents anomalies emerge which disrupt these commutator conditions.
- b) The related question of the Johnson-Low-Bjorken limit was analyzed on the basis of the general requirements of analyticity, unitarity and current conservation. Some general conditions for the validity of this limit as well as for the existence of operator Schwinger terms were obtained.⁵
- c) An extension of the scaling hypothesis for the virtual off-shell Compton amplitude was made to a complex analyticity domain.^{2,4} This leads to new and useful sum rules which in fact a) test whether scaling occurs when $|q^2| \rightarrow \infty$ in certain complex directions, b) impose new restrictions on the Regge fits for electroproduction data. A detailed evaluation of.

these sum rules, using data from the SLAC-MIT collaboration, is currently in progress.

d) Ladder models were investigated for the purpose to understand whether certain classes of dynamical models do or do not exhibit scaling properties.⁴

e) It has been suggested to view scaling as a manifestation of a so-called light cone algebra. A further test for this algebra was proposed.³⁰ A speculation was pursued as to whether this algebra might also manifest itself in the analysis of meson-baryon scattering.³¹

(II) Other features of inelastic lepton-nucleon scattering

a) A Regge model for deep inelastic lepton-nucleon collisions was developed which provides predictions for the behavior of the scaling structure functions for both diffractive and non-diffractive components. (See ref. 9 and also H. Pagels, Phys. Letters 34B, 299, 1971).

b) Simple experimental tests were proposed to examine whether or not certain helicity conservation properties, known under circumstances to occur in hadronic collisions, also play a role in inelastic lepton-nucleon processes.^{10,14}

c) Implications of a possible combined validity of scaling and of Regge behavior (in certain kinematic regions) were pursued further.³⁴

d) Isospin constraints were derived for semi-inclusive neutrino reactions. (Their important hadronic analogs were also analyzed).³⁵

e) Finite energy sum rules were discussed in the context of inelastic electron scattering.¹¹

(III) Hadronic scaling

A further scaling property in purely hadronic processes has been conjectured. In this connection, a new and simple derivation of Feynman's results on the behavior of single particle spectra at the boundary of phase space was obtained from a Regge model.¹⁷ From an analysis of experimental data evidence was adduced for a scaling law of the form factors describing the hadronic transitions of the nucleon to isobaric states in diffractive processes.²²

(IV) Chiral symmetry breaking

Work has been done on the theory of chiral symmetry breaking and the breaking of SU(3) symmetry. It was observed that if the fundamental internal symmetry of the hadrons is a chiral symmetry with a Nambu-Goldstone

realization, then one cannot use power series expansions in the symmetry breaking parameters for matrix elements since they are non-analytic functions of these parameters.¹⁶ An alternative approach which takes this non-analytic character of chiral symmetry breaking into account was developed, providing a means of exactly computing some matrix elements to leading order in the symmetry breaking. Further, a new approach to the breaking of SU(3) symmetry was developed emphasizing the importance of the Goldstone phenomena.²⁶

New results on the breaking of SU(2) x SU(2) symmetry have been found. The non-analytic properties of the Σ -term in pion-nucleon elastic scattering have been computed. (H. Pagels and W. Pardee, Phys. Rev. D4, 3335, (1971)).

(V) Electromagnetic topics

a) It has been shown that the semi-inclusive treatment in one-quantum annihilation of an electron-positron pair may be used for the study of properties originally revealed in weak processes, namely a) the possible validity of PCAC in a new energy regime, b) the possibility to determine the spectral functions associated with the weak axial vector current and with the vector-isovector current from annihilation data.²

The same methods were also used to obtain information on W-boson properties.⁷

- b) The possibility has been raised that the electromagnetic current may have an isospin two component. An extensive study has been made of the implications of such a component for numerous photo - and electroproduction processes.²⁷
- c) An improved and optimal bound for the hadronic contributions to the muon magnetic moment was obtained.³³

(VI) Weak Interactions

- a) A review was prepared on high energy quasi-elastic and inelastic neutrino reactions.³
 - b) Studies have been made of rigorous bounds for the K_{L3} -decay form factors which are relevant for ruling out some experimental numbers.^{13,18}
 - c) It has been shown²³ that the observed CP-violating effects cannot be sensibly understood in terms of the so-called spontaneous breakdown mechanism.
 - d) Stimulated by recent experimental findings, the discussion of second class current effects has been reviewed and extended for β -radioactivity phenomena.²⁵
- The implications of the possible existence of such effects in high energy neutrino reactions have also been investigated.²⁷

e) New implications of the isotopic spin structure of the weak $\Delta S=0$ and ± 1 currents have been obtained.²⁷

(VII) Other topics

Under this heading miscellaneous items are collected which do not lend themselves so readily to rubrication.

a) A study was made of the Regge-eikonal approximation from a discussion of high energy scattering in the ladder approximation.⁶

b) Some open questions in current algebra were reviewed and discussed.⁸

c) A historical essay was prepared dealing with the first fifty years in the development of the theory of the electron.²⁰

d) A review was given of the problematics for colliding e^+e^- beam experiments which arise from the so-called two photon mechanism.¹² These and other theoretical aspects of colliding e^+e^- beams were also discussed in a recent conference report.²¹

e) Some rigorous consequences of a violation of the Pomeranchuk theorem were analyzed (G. Auberson, T. Kinoshita and A. Martin, Phys. Rev. D3, 3185, 1971).

f) A new approach to S-matrix dynamics was proposed, in which analyticity is de-emphasized by the introduction of extended unitarity relations expressing the imaginary part of a connected N-point function of all real values of the $3N-10$ invariant kinematical variables.²⁸

g) New asymptotic bounds were obtained on the absorptive parts of the elastic scattering amplitudes.²⁹

h) A rigorous theorem on the scaling laws for nucleon electromagnetic form factors was obtained.³²

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3) NYO-4204-3	Weak Interactions at High Energies Ann. of Physics, <u>63</u> , 361 (1971)	A. Pais
4) NYO-4204-4	The Deep Inelastic e-p Structure Functions in a Ladder Model with Spin 1/2 Nucleons Phys. Rev. D <u>3</u> , 510,(1971).	S. Blaha
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