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PROGRESS REPORT FOR A RESEARCH PROGRAM
IN THEORETICAL HIGH-ENERGY PHYSICS

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ABSTRACT

Last year's research program dealt with a variety of topics including the application and generalization of the eikonal model (diffractive particle production, Blankenbecler's theorem, multiplicity distributions, bremsstrahlung production); high-energy multiparticle phenomena (perturbative treatment of diffraction dissociation, antibaryon production and the rising pp total cross section, rising inclusive plateau); solutions of Reggeon unitarity from the S-matrix approach; dynamical aspect of diffractive production; dual resonance models (low-energy partial-wave parameters); implications of neutral currents; dynamics of permanently bound quarks (perturbative expansion, corrections to the mass spectrum); model theories with composite particles; broken gauge theories of the weak and electromagnetic interactions; topics in general relativity; as well as other studies involving the strong, electromagnetic, and weak interactions of elementary particles.

Progress Report for a Research Program
in Theoretical High-Energy Physics

The Department of Physics of Brown University, with the support of the U. S. Atomic Energy Commission under Contract AT(11-1)-3130 [formerly AT(30-1)-2262] has been carrying out a research program in Experimental and Theoretical High-Energy Physics since 1958. The Theoretical Program has been under the direction of David Feldman, Professor of Physics. This report serves to summarize the progress which has been made during the present contract year (1 September 1973 - 31 August 1974) by the Theoretical Group (Task A).

The report is divided into three sections:

- I. Present Status of the Theoretical Group;
- II. Theoretical Papers Published During the Preceding Year and Papers in Press;
- III. Scientific Personnel Associated with the Theoretical Program.

I. Present Status of the Theoretical Group.

During the past year, the overall scope of the theoretical program remained essentially unchanged from that of previous years. Thus, the major effort continued to be devoted to theoretical studies in the physics of high-energy phenomena, the properties and interactions of elementary particles, and quantum field theory. Other problems of current interest such as applications of field-theoretic methods to the general theory of relativity were also considered.

During the past year, Professor Fried carried through two independent studies of eikonal models for diffractive particle production which exhibit Blankenbecler's theorem¹ (the total cross section decreases with a rapidly increasing diffractive cross section) and which also suggest possible generalizations. In the first construction (Ref. 289),²

1. R. Blankenbecler, Phys. Rev. Letters 31, 964 (1973).

2. References cited are listed in Section II of this report.

which was formulated in collaboration with Mr. Kirby, that diffractive production was incorporated which one would expect on the basis of the hadronic bremsstrahlung model (hbm), previously found useful for large momentum transfers; here, neutral vector mesons are emitted directly from the scattering nucleons (Ref. 300). The second construction represents a generalization of a previous eikonal model³ in which "heavy" nucleons are diffractively produced. Although partially phenomenological, the model is sufficiently soluble so as to exhibit, again, Blankenbecler's theorem, along with some multiplicity generalizations. Portions of this latter work appear in the doctoral theses of Mr. Kirby ("A Unified Model of High-Energy Hadronic Scattering") and of Mr. Soh ("Eikonal Models of Diffractive and Non-Diffractive Particle Processes").

In an investigation by Professors Fried and Tan of multiplicity effects and predictions within the context of the eikonal model, a simple experimental test of the relevance of the Cheng-Wu tower-graph approximation to scattering reactions at ISR energies was suggested (Ref. 291). In this paper, a new and convenient formula relating certain aspects of asymptotic elastic and inelastic processes was employed; a second paper (Ref. 296) contains its derivation by Professor Fried. In collaboration with Professor Y. Hahn, Professor Fried developed a formulation of the eikonal formalism in potential theory in which a method of automatically generating corrections to the simple Glauber theory was given, along with some machine computations which check the validity of the potential-theory approximations (Ref. 302). Finally, Professor Fried has noted three newly-measured experimental effects at large momentum transfers which seem to follow the hbm predictions (Ref. 304)⁴⁻⁶; the trends of

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3. R. Blankenbecler and H. M. Fried, Phys. Rev. D 8, 678 (1973) (Report No. C00-3130TA-262).
 4. H. M. Fried and H. Moreno, Phys. Rev. Letters 25, 625 (1970) (Report No. NYO-2262TA-221).
 5. H. M. Fried and T. K. Gaisser, Phys. Rev. D 6, 2560 (1972) (Report No. C00-3130TA-261); Phys. Rev. D 7, 741 (1973) (Report No. C00-3130TA-268).
 6. H. M. Fried, B. Kirby, and T. K. Gaisser, Phys. Rev. D 8, 3210 (1973) (Report No. C00-3130TA-274).

these new experiments are definitely at variance with existing parton-model predictions, but can be easily understood on the basis of the hba.

The research of Professor Guralnik was devoted mainly to a continuing program of investigation of the model of permanently bound quarks (Ref. 293). This model has the property that quarks are bound by a particular relativistic generalization of an r^2 potential in such a way that it is impossible to decompose matter into its quark constituents. As a result, the model has very unusual but self-consistent properties, e.g., the Green's functions do not exist in coordinate space. Together with Professors C. M. Bender and J. E. Mandula, Professor Guralnik has established that the solutions in the lowest approximation to this theory contain states with free non-interacting mesons. They have developed a systematic and new perturbation theory and have examined the first-order corrections to the lowest-order results; it was found that the "meson states" undergo interaction and decays but do not decompose into asymptotic quark states. Professor Guralnik and collaborators have evaluated explicitly the meson decay formula in a two-dimensional model and have found the remarkable dynamical result that cascade-type decays of a meson into a heavy particle and a light particle are preferred to decays into particles of nearly equal mass. They have confirmed further by explicit calculation that the first-order corrections are consistent with crossing symmetry, and that to this order matter does not decay into its quark constituents. With Messrs. Kasdan and Snyderman, Professor Guralnik has also been working on some problems involving the application of renormalization-group techniques to model theories with composite particles.

It is well known that the field-theoretic approach of the Reggeon calculus⁷ yields solutions satisfying the Regge-cut discontinuity formulae for a Pomeron pole with intercept one. In view of the

7. V. N. Gribov, Sov. Phys.--JETP 26, 414 (1968).

seemingly general nature of the discontinuity formulae (Reggeon unitarity), Professor Kang, in collaboration with Dr. A. R. White, attempted to find solutions of Reggeon unitarity from the S-matrix approach (Ref. 301). The conclusion was that the best solution of two-Pomeron unitarity is that in which two CDD zeros are present in the Reggeon scattering amplitude and the triple-Pomeron vertex vanishes linearly; this structure leads to the factorization of the total cross section to order $(\ln s)^{-2}$. The rising proton-proton cross section observed at ISR has continued to be a puzzle, with most theoretical efforts stressing the dynamical aspect of diffractive productions and their effect on the total cross section; in this connection, we have already made reference to Blankenbecler's theorem.¹ Professor Kang has given a systematic discussion of the threshold effects of diffractive production on the total cross section within the context of a generalized unitarization scheme for the production amplitudes (Ref. 303); it was found that the diffractively produced inelastic states can lead to an increase in the total cross section at high energies unless the elastic cross section is bounded by a certain constraint for all energies. Finally, under Professor Kang's direction, Mr. Rizvi has been studying the theoretical foundations of spontaneously broken gauge field theories unifying the weak and electromagnetic interactions; particular attention has been paid to the study of the implications of the neutral current of the Weinberg-Salam model for deep inelastic electron and neutrino scattering within the context of the quark-parton model.

The phenomenological successes of the "two-component" picture of hadronic production have suggested that threshold phenomena are still important at NAL and ISR energies. A major effort was carried out by Professor Tan to examine these effects by use of perturbative techniques. First, in collaboration with Professors W. R. Frazer and D. R. Snider, he formulated a perturbative expansion in which the multiperipheral production is the zeroth-order approximation (Ref. 290); this provided not only a justification for the two-component picture, but led also to a sensible catalogue of diffraction-dissociation phenomena. Next, with Dr. T. K. Gaisser, Professor Tan studied the role of the multiperipheral production of antibaryons and its possible connection to the observed rise of the pp total

cross section (Ref. 294); they found that the $N\bar{N}$ production is delayed in energy due to mass effects, and they estimated that the $N\bar{N}$ cross section alone could account for the rising pp total cross section at ISR.

Encouraged by these findings, Professors Tan and Tow then applied these perturbative techniques to the study of pion inclusive distributions (Ref. 298). They found that the inclusion of $N\bar{N}$ production and/or diffractive dissociation into high mass gives rise to an approximate inclusive plateau whose height rises like $\ln s$, in agreement with preliminary experimental data at ISR; they also proposed methods to differentiate these rising mechanisms from the traditional Mueller approach and discussed the implications for inclusive phenomenology. Finally, with Drs. T. K. Gaisser and H. I. Miettinen, Professors Tan and Tow contrasted the results which obtain from the multiperipheral production of $N\bar{N}$ pairs with those which follow if pair production occurs in central collisions (Ref. 306); it was shown that current ISR experiments can easily distinguish between the multiperipheral and the geometrical models of multiparticle production.

Professor Westervelt has been continuing his study of the induction field of laser-generated gravitational waves and has presented some of his findings in two talks (Refs. 307, 308). He has shown that ultrarelativistic bodies do not radiate gravitational waves in the forward direction, and has extended this work so as to apply to circular orbits. Even if low efficiency of generation precludes direct observation of asymptotic gravitational waves, indirect evidence for their existence is available, as given by a recent analysis⁸ of Shapiro's fourth test of general relativity. Professor Westervelt has also recently established that energy and momentum can be transmitted in the forward direction via the induction (non-asymptotic) field.

Dr. Chung and Professor Feldman have shown that the low-energy partial-wave parameters for all classes of dual, elastic scattering amplitudes can be readily derived by simple use of Rodrigues's formula for the Legendre polynomials (Ref. 295). Mr. Choi, under Professor Feldman's direction, has begun a study of the determination of particle masses within the context of broken gauge theories of the weak and electromagnetic interactions.

8. P. J. Westervelt, Acta Phys. Polon. 35, 203 (1969) (Report No. NYO-2262TA-178).

II. Theoretical Papers Published During the Preceding Year and Papers
in Press.

- TA-289 B. J. Kirby and H. M. Fried, "Eikonal Construction with Radiative Corrections," Phys. Rev. D 8, 2668 (1973).
- TA-290 W. R. Frazer, D. R. Snider, and C.-I Tan, "Perturbative Treatment of Diffractive Dissociation at High Energies," Phys. Rev. D 8, 3180 (1973).
- TA-291 H. M. Fried and C.-I Tan, "Koba-Nielsen-Olesen Scaling and Eikonal (Tower-Graph) Approximations," Phys. Rev. D 9, 314 (1974).
- TA-292 K. S. Soh, "Model Approach to the High-Energy Asymptotic Limit," Phys. Rev. D 8, 3169 (1973).
- TA-293 C. M. Bender, G. S. Guralnik, and J. E. Mandula, "Permanently Bound Quarks--New Solutions to Old Field Equations," Phys. Rev. Letters (submitted).
- TA-294 T. K. Gaisser and C.-I Tan, "Perturbative Treatment of Threshold Contributions to a Rising pp Total Cross Section," Phys. Rev. D 8, 3881 (1973).
- TA-295 B. K. Chung and D. Feldman, "How to Calculate Low-Energy Partial-Wave Parameters of Dual Resonance Amplitudes," Phys. Rev. D 9, 1845 (1974).
- TA-296 H. M. Fried, "Approximate Dynamical Relation Between Elastic and Inelastic Eikonal Cross Sections," Nucl. Phys. B (in press).
- TA-297 K. S. Soh, "A Physical Interpretation of Fugacity," Phys. Rev. D (submitted).
- TA-298 C.-I Tan and D. M. Tow, "Rising Plateau and the Perturbative Treatment of High-Energy Inclusive Reactions," Phys. Rev. D 9, 2176 (1974).
- TA-299 H. M. Fried and K. S. Soh, "Local and Global Effects of Diffractive Production," Phys. Rev. D (in press).
- TA-300 H. M. Fried and B. J. Kirby, "Bremsstrahlung Model of Diffractive Production," Phys. Rev. D (in press).

- TA-301 A. R. White and K. Kang, "CDD Zeroes in the Pomeron Scattering Amplitude," Phys. Rev. D (in press).
- TA-302 H. M. Fried and Y. Hahn, "Generalized Eikonal Functions in Potential Theory," Phys. Rev. D, (in press).
- TA-303 K. Kang, "Unitarity and Threshold Effects of Diffractive Production," Phys. Rev. D (in press).
- TA-304 H. M. Fried, "Large Momentum Transfer Reactions, without Partons," *Proceedings of the XVIIth International Conference on High-Energy Physics, London, England, 1-10 July 1974*, submitted; Phys. Letters (in press).
- TA-305 C.-I Tan, "Nucleon-Antinucleon Production as the Cause of σ_{pp}^{tot} Rise at ISR," *Proceedings of the IXth Rencontre de Moriond, Méribel-les-Allues, France, 3-15 March 1974*, in press.
- TA-306 T.K. Gaisser, H. I. Miettinen, C.-I Tan, and D. M. Tow, "Is $\bar{p}$ Production Peripheral or Central?" Phys. Letters (in press).
- TA-307 P. J. Westervelt, "Gravitational Radiation by Ultrarelativistic Bodies," *Gravitational Radiation and Gravitational Collapse*, C. De Witt-Morette, Editor (D. Reidel Publishing Co., Dordrecht, Holland, 1974), in press.
- TA-308 P. J. Westervelt, "Gravitational Wave Analog to the Parametric Acoustic Array," J. Acoust. Soc. Am. 55, 576A (1974).

III. Scientific Personnel Associated with the Theoretical Program.

1 September 1973 - 31 August 1974

D. Feldman - Professor
H. M. Fried - Professor
G. S. Guralnik - Professor
P. J. Westervelt - Professor
K. Kang¹ - Associate Professor
C.-I Tan - Assistant Professor
D. M. Tow - Assistant Professor (Research)
B. K. Chung² - Research Associate
S. C. Choi - Graduate Research Assistant
S. Kasdan - Graduate Research Assistant
B. J. Kirby³ - Graduate Research Assistant
S. M. A. H. Rizvi - Graduate Research Assistant
N. J. Snyderman - Graduate Research Assistant
K. S. Soh⁴ - Graduate Research Assistant

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1. Promoted to Professor 1 July 1974.
 2. Until 31 December 1973.
 3. Until 15 January 1974.
 4. Until 31 May 1974.