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PROGRESS REPORT

UNIVERSITY OF MINNESOTA
SCHOOL OF PHYSICS AND ASTRONOMY

EXPERIMENTAL AND THEORETICAL HIGH ENERGY PHYSICS
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MASTER

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1. Introduction.

The investigations in experimental and theoretical high energy physics at the University of Minnesota have as their general goal the improvement of our understanding of interactions among sub-nuclear particles. Theoretical work in the past year has ranged from attempts to understand aspects of the basic mathematical structure of field theories to a program of integrating the latest experimental results on charmed particles into current theoretical models. The experimental effort has necessarily been concentrated on a few topics, but that list includes measurements of the electromagnetic couplings of vector mesons, a study of several phenomena involving hyperons and an investigation of the spin dependence of the strong interaction using polarized beams. A new project of the experimental group is an experiment to search for the decay of protons and bound neutrons in a way which would be sensitive to a lifetime of 10^{32} years. This experiment is important both to test unified field theories and to provide information important to cosmological models. A more complete description of all this work can be found in the following pages.

2. Theoretical High Energy Physics.

(Professors Stephen Gasiorowicz, Donald Geffen, Jonathan Rosner and Hiroshi Suura, Research Associates Jonathan Schonfeld and Warren Wilson, Research Assistants Emmanuel Haqq, Richard Robinett and C. N. Leung).

Applications of octonions to particle physics (Jonathan Rosner, with M. Gell-Mann).

A ten-element algebra of projection operators for quarks and leptons was constructed, based on outer products of two sets of mutually commuting complex octonions. This system was recognized to be a Kantor algebra.[1] It belongs to a matrix representation of a Jordan algebra and in that sense is not exceptional. However, the system as constructed still does not possess a full color SU(3) symmetry. (Cf. 1977-78 Progress Report). Enlargement to a 20-element algebra is possible; this enlarged system does not appear to be representable in terms of Jordan products of matrices. It remains to be seen whether this peculiarity has practical consequences for quantum chromodynamics or for relations between quarks and leptons. This work is still in progress.

Multilepton final states and the weak interactions of the fifth quark (Jonathan Rosner, with C. Quigg).

Evidence was summarized for the properties of a fifth quark, denoted as b, which is a constituent of Υ (9.4 GeV/c^2). It was shown how an analysis of the lepton content of final states arising from unbound ($b\bar{b}$) production can yield the relative strengths of the $b \rightarrow u + W^-$ and $b \rightarrow c + W^-$ weak-current transitions.[2]

Mass dependence of Schrödinger wave functions (C. N. Leung with Jonathan Rosner).

It was shown that for nonrelativistic central potentials of specific forms, the bound state wave functions u(r) have the property that

$$G(r) \equiv \int_0^r dx\ u(x)\ (\ \partial u(x)/\partial\mu\ ) \geq 0$$

for all r. Here μ is the reduced mass. Thus, for such potentials, the probability that a particle lies within a spherical shell of radius r is a monotonically increasing function of μ . The forms for which this property was established[3] are (a) $V(r) = Cr^{\varepsilon}$, $-2 < \varepsilon < \infty$; (b) $v(r) = C\ \ln r$, and (c) S waves in the potential $V(r) = -V_0$ ($0 \leq r < a$), $V(r) = 0$ ($a \leq r < \infty$). For all monotonically increasing potentials, $G(r) > 0$ for nodeless states. It was shown explicitly that G(r) could not be nonnegative for all bound states in an arbitrary monotonically increasing potential. The question was pursued further regarding the widest class of potentials for which G(r) is nonnegative for all bound states. Potentials investigated included $V(x)= -V_0/\cosh^2 ax$, the Hulthén potential, the exponential potential, and the finite square well (for $\ell > 0$). No answer has been obtained yet for any of these. This work is still in progress.

Signs of baryon-resonance photocouplings (Jonathan Rosner, with John Babcock).

New baryon-resonance photocouplings[4] were analyzed[5] from the standpoint of single-quark-transition selection rules. A previous conclusion[6] was strengthened: The pionic decays of 56, L = 2 resonances appeared from this analysis to be dominated by $\Delta L_z = \pm 1$ transitions, in contrast to the conclusion that would be drawn from analysis of $\pi N \to \pi\Delta$. Both P13 (1810) and F35 (1890) photocouplings were important in drawing this conclusion.

Implications of the Υ States (Jonathan L. Rosner).

The Υ family of vector mesons was interpreted as a system of $b\bar{b}$ bound states (b = charge -1/3 quark), with the help of new data on Υ' presented at the 19th International Conference on High Energy Physics in Tokyo, August, 1978.[7] Implications of the new quark for heavy particle spectroscopy, and for the existence of other possible quarks, leptons, and Higgs bosons, were discussed. This material, presented by J. Rosner at the Tokyo Conference, is published as part of a summary, "New Particles, Theoretical" of session B8 of the conference.[8]

Charmed particle lifetimes (Jonathan L. Rosner).

Conventional estimates were reviewed for charmed particle lifetimes. Free quark models give values of (a few) x 10^{-13} sec to (a few) x 10^{-12} sec. The shorter of these values also follows from an extrapolation based on $D \to Ke\nu$. Possible differences among the lifetimes and production rates of D^0, D^+, F^+, C_0^+, the heavy lepton τ, and the fifth quark b were discussed. The predictions were discussed in the light of some current experimental results, and it was estimated that $\sigma(pp \to \text{charm}) \simeq 10\ \mu b$ at 400 GeV/c.[9]

Inequalities for rates and polarizations in semileptonic decays (Jonathan L. Rosner, with Warren J. Wilson).

In decays of the form $A \to \ell^+ \nu_\ell + B$, if the lepton pair is coupled via the usual V-A weak current, it was shown that $d\Gamma(A \to \ell^+_{\lambda=1}\ \nu_\ell + B)/dm_{\ell\nu}$ is monotonically decreasing in the lepton mass m_ℓ. (The helicity λ refers to the $\ell\nu$ c.m. system, in which the total $\ell\nu$ energy is $m_{\ell\nu}$). By transforming to the rest system of A, it was shown that this theorem could be converted to useful (approximate) inequalities relating ratios of semileptonic decay rates and lepton polarization in the rest system of A, e.g., $\Gamma_{e^+}/\Gamma_{\mu^+} \gtrsim (1 + P_{\mu^+})/2$. Implications were noted in particular for charmed-meson decays.[10]

Quantum mechanics with applications to quarkonium (Jonathan L. Rosner, with C. Quigg).

A review article was written for Physics Reports describing some methods of nonrelativistic quantum mechanics which are particularly useful for studying the variation of bound-state parameters with constituent mass and excitation energy. These techniques are of general interest, but were applied in particular to the study of bound systems of a heavy quark and antiquark. Properties of the interquark interaction were extracted from information about masses and leptonic widths of the ψ and Υ families. It was shown how general methods could be applied to the determination of the electric charge of quarks and to the prediction of properties of new families.[11]

Resource letter on new particles (Jonathan L. Rosner).

A review of the growth in the number of "elementary" particles since the discovery of the J/ψ in November of 1974 was completed for the Resource Letter series of the American Journal of Physics. An attempt was made to combine references to initial discoveries, to reviews of theory and experiment, and to elementary discussions in a way that could be useful at a wide variety of levels.[12]

Constructive evidence for flavor independence of the quark-antiquark potential (Jonathan L. Rosner, with C. Quigg and H. B. Thacker).

The masses and leptonic widths of vector mesons may be used to construct quark-antiquark potentials by means of an inverse-scattering method. This technique has been applied to the charmonium system.[13] A corresponding potential was constructed from Υ and Υ' and found to be in substantial agreement with that constructed from ψ and ψ' if the Υ is composed of a charge -1/3 quark and the corresponding antiquark. This agreement could be interpreted as evidence for flavor independence of the quark-antiquark potential. Predictions for a hypothetical family of higher-lying vector mesons also were noted.[14] These results were presented in part by J. Rosner at the EPS International Conference on High Energy Physics, Geneva, Switzerland, June 27-July 4, 1979.

Properties of symmetric reflectionless potentials constructed by inverse scattering methods (Jonathan L. Rosner, with Waikwok Kwong, Jonathan F. Schonfeld, C. Quigg, and H. B. Thacker).

Symmetric reflectionless potentials V(x) = V(-x) with bound state energies $\epsilon_i = -\kappa_i^2 \quad (\kappa_1 > \kappa_2 > \cdots > \kappa_n)$, and the corresponding wave functions $\psi_i(x)$ of definite parity, were shown to have particularly simple forms of practical use in the construction of such potentials with large numbers of levels. Straightforward combinatorial arguments led to expressions for V(0), $\psi_i(0)$ (i odd), and $\psi_i'(0)$ (i even) and relations among them, e.g.

$$V(0) = -2\,(\kappa_1^2 - \kappa_2^2 + \kappa_3^2 - \cdots \pm \kappa_n^2)$$

and

$$V(0) = -4 \sum_{i\ \mathrm{even}}^{n} |\psi_i'(0)|^2 / \kappa_i ,$$

The last, valid only for even n, is especially useful in discussions of S wave bound states in three dimensions (e.g. quark-antiquark systems, for which leptonic decay rates are proportional to $|\psi_i'(0)|^2$).

This work is still in progress. The results will be employed to shed light on the possibility of pointwise convergence of approximations to infinitely rising potentials.

Semiclassical discussion of mass dependence of Schrödinger wave function normalization (Peter Moxhay with Jonathan L. Rosner).

Studies were begun of the semiclassical behavior of $|\Psi(0)|^2$, which governs leptonic widths of quark-antiquark systems like ψ and Υ . The topic is of particular interest in the extraction of the electric charge of any new heavy quark from electron-positron annihilation data. (The method of Ref. 15, for example, was applied to the data of Ref. 7 to conclude that the Υ is composed of a charge -1/3 quark and the corresponding antiquark.)

In the course of this work a generalization of the WKB quantization formula was obtained for power-law potentials $V(r) = A\, r^{\epsilon}$:

$$E_{n,\ell} \sim (n + \gamma_\ell(\epsilon))^{p(\epsilon)}$$

where

$$\gamma_\ell(\epsilon) = \begin{cases} \dfrac{2\ell-\epsilon-1}{2(2+\epsilon)} & -2 < \epsilon < 0 \\[2ex] \dfrac{\ell}{2} - \dfrac{1}{4} & 0 < \epsilon < \infty \end{cases}$$

and

$$p(\epsilon) = \frac{2\epsilon}{2+\epsilon} .$$

This result was reported in Ref. 11. Other aspects of the work are still in progress.

Proton lifetime (Richard Robinett and Jonathan L. Rosner.)

Mr. Robinett is starting to work through the literature on baryon decays to determine independently the probable range of variation of theoretical estimates for the proton lifetime. This work will form part of his thesis and is still in progress.

References

1. I. L. Kantor, Sov. Math. Dokl. 14, 254 (1973); Trudy Sem. Vektor Tenzor Anal. 16, 407 (1972).
2. C. Quigg and Jonathan L. Rosner, Phys. Rev. D19, 1532 (1979).
3. C. N. Leung and J. Rosner, J. Math. Phys. 20, 1435 (1979).
4. I. M. Barbour, R. L. Crawford, and N. H. Parsons, Nucl. Phys. B141, 253 (1978).
5. John Babcock and Jonathan L. Rosner, Phys. Rev. D18, 4027 (1978).
6. J. Babcock, J. Rosner, R. J. Cashmore, and A. J. G. Hey, Nucl. Phys. B126, 87 (1977).
7. J. K. Bienlein et al., Phys. Lett. 78B, 360 (1978); C. W. Darden et al., Ibid, 78B, 364 (1978).
8. J. D. Jackson, C. Quigg, and J. L. Rosner, in Proc. of the 19th Int. Conf. on High Energy Phys., Tokyo 1978, ed. by S. Homma, M. Kawaguchi, and H. Miyazawa (Physical Soc. of Japan, Tokyo, 1979), pp. 391-408.
9. Jonathan L. Rosner, in Cosmic Rays and Particle Physics - 1978 (Bartol Conference), AIP Conference Proceedings No. 49, Particles and Fields subseries No. 16, ed. by T. K. Gaisser (American Institute of Physics, New York, 1979), pp. 297-316.

10. Jonathan L. Rosner and Warren J. Wilson, Phys. Rev. D19, 3308 (1979).

11. C. Quigg and Jonathan L. Rosner, Fermilab-Pub-79/22-THY, February 1979, to appear in Physics Reports.

12. Jonathan L. Rosner, "Resource Letter NP-1: New Particles", University of Minn. report, April, 1979 (revised August, 1979), submitted to American Journal of Physics.

13. H. B. Thacker, C. Quigg and J. L. Rosner, Phys. Rev. D18, 274, 287 (1978).

14. C. Quigg, H. B. Thacker, and Jonathan L. Rosner, Fermilab-Pub-79/52-THY, July 1979, submitted to Phys. Rev. D.

Soliton Masses in Supersymmetric Theories (Jonathan F. Schonfeld).

I found that in a large class of field theories, the conventional definition of the quantum corrections to soliton masses -- the familiar sum of frequencies[1] -- is unacceptably sensitive to the details of the infinite-volume limit. I found general methods with which to solve this problem; but only in supersymmetric theories did I find an approach that would not be impractical in spacetimes of dimension greater than two. I applied this semi-algebraic technique to a large class of two-dimensional models and, where practical, checked the results using other methods. The quantum corrections to the soliton mass turned out to be independent of the particular model chosen. My results disagreed with others' work, which I showed to be internally inconsistent. I proved the self-consistency of my own calculations by explicitly verifying a Ward identity. In the course of this work I succeeded in characterizing the way in which broken spacetime symmetries are restored in quantum field theory as the size of the quantization volume becomes infinite.

1. R. Dashen, B. Hasslacher and A. Neveu, Phys. Rev. D10, 4130 (1974).

Vierbein Singularities in CP^2 (Jonathan F. Schonfeld).

The manifold CP^2 attracted attention last year as a model of a gravitational instanton and as an example of a spacetime in which fields of half-integer spin could not be globally defined.[1] I identified the topological anomaly responsible for the latter phenomenon -- CP^2 twists in characteristic ways near certain two-spheres known in algebraic geometry as "complex lines". Any vierbein -- a tetrad of orthonormal vector fields that plays a central role in the theory of spinors -- must be singular on every complex line. My analysis allowed me to construct an example of a vierbein with the smallest possible set of singularities, and to explain in an elementary way the observation of Hawking and Pope[1] that in the presence of an appropriate electromagnetic background, fields of any spin can be defined on CP^2 provided their electric charges are quantized, but with the charges allowed to half-integral-spin fields differing from those allowed to integral-spin fields.

1. S. Hawking and Pope, Phys. Lett. 73B, 42 (1978).

Dynamical Symmetry and Magnetic Charge (Jonathan F. Schonfeld).

I rediscovered a nonrelativistic system (originally discussed eleven years ago by Zwanziger[1]) involving both an interaction with a central force and with a magnetic charge, that exhibits a dynamical O(4) (or O(3,1), depending on the energy and the sign of the coupling) symmetry analogous to that of the Kepler system. (When the magnetic charge vanishes these systems coincide). As is well known[2] the (classical and quantum-mechanical) O(4) symmetry of the Kepler system can be realized explicitly by stereographically projecting velocity space onto the surface of a three-dimensional sphere (or hyperboloid when the group is O(3,1)). I discovered the corresponding projections for the magnetic systems. What is novel is that when the magnetic charge is nonzero the point of projection does not lie on the sphere (or hyperboloid) as it does when the charge is zero. This work has practical application to the analysis of small fluctuations about 'tHooft-Polyakov monopoles in supersymmetric gauge theories and to the calculation of Green's functions of quantum fields in certain curved spacetimes.

1. D. Zwanziger, Phys. Rev. 176, 1480 (1968).
2. M. Bander and C. Itzykson, Rev. Mod. Phys. 38, 330 (1966).

Inverse Problem for Symmetric Reflectionless Potentials (Jonathan Schonfeld with W. Kwong and J. Rosner of Minnesota and C. Quigg and H. Thacker of Fermilab).

The calculation of symmetric reflectionless one-dimensional potentials in terms of their bound-state spectra plays a central role in a technique conceived by my collaborators for systematically reconstructing phenomenological quark-antiquark potentials from experimental data.[1] On the mathematical side it also forms the foundation of a promising new approach to a general theory of approximations to unbounded functions. (Techniques such as Fourier analysis apply only to functions that decay rapidly enough to zero at spatial infinity.) In earlier work[1] reflectionless potentials were represented by determinants whose numerical evaluation was prohibitively complicated in most cases of physical or mathematical interest. We found combinatorial identities that permitted the derivation of much simpler formulae for the same potentials. The new formulae made possible a much more detailed examination of the approximations' convergence than had been feasible before.

1. J. Rosner, C. Quigg and H. Thacker, Phys. Rev. D18, 274 (1978).

The Nonabelian Perfect Conductor (Jonathan Schonfeld).

I carried out a careful analysis of the quantization of Yang Mills theories in finite volumes. I chose boundary conditions analogous to those at the surface of a perfect conductor: Nonabelian normal B = nonabelian tangential E = 0. With this choice I derived a very simple representation of the Feynman path integral in the axial gauge (A_z=0). This expression improves on the results of earlier studies of the axial gauge[1] in that no ill-defined infinite integrals of operators are involved, and there are no *ad hoc* elements in the fixing of residual (z-independent) pure gauge degrees of freedom. Applications of this work include the study of long-range effects in gauge theories, and the regularization of spatially divergent integrals appearing in the collective-coordinate Jacobians of solitons in gauge theories.

1. For example, see N. Christ, A. Guth and E. Weinberg, Nucl. Phys. B114, 61 (1976).

Semiclassical Formalisms that Preserve Supersymmetry (Jonathan F. Schonfeld).

There are a number of interesting unanswered questions regarding the quantum mechanical spectra of solitons in supersymmetric field theories.[1] These would ordinarily be settled by semiclassical analysis. In the conventional approach to semiclassical quantization,[2] Fermi fields are first integrated out of the Feynman path integral leaving an effective theory that involves only bosonic fields, and that is more complicated than the original. This is not a desirable way in which to approach supersymmetric models because the supersymmetry is not manifest in the effective theory. Even if one does not inegrate out the Fermi fields there is this additional problem: The DHN semiclassical theory is based on the path integral expression for Tr exp ($-iHT/\hbar$), in which the boundary conditions on the Bose fields and Fermi fields are not symmetric -- Bose fields are periodic in time with period T, while Fermi fields change sign with period T. I found a class of quantities about which a similar semiclassical theory could be developed and which require that the same periodic boundary conditions be imposed on all fields. This work is still in progress.

1. B. Schroer, T. Truong and P. Weiss, Nucl. Phys. B154, 140 (1979).

2. R. Dashen, B. Hasslacher and A. Neveu, Phys. Rev. D12, 2443 (1975).

Algebraic Geometry and Gauge Fields (Jonathan Schonfeld with R. Speiser of the University of Minnesota Mathematics Department).

In the mathematical literature, significant papers on instantons usually begin with the articulation of a problem in algebraic geometry equivalent to the PDE of self-duality. The nontrivial connection between these two versions of the problem is rarely stated and never in terms accessible to most physicists. We worked out an elementary account of this connection. We are planning to use this work as the core of a contribution to Reviews of Modern Physics.

1. For example:

M. Atiyah and R. Ward, Commun. Math. Phys. 55, 117 (1977);

R. Hartshorne, Commun. Math. Phys. 59, 1 (1978).

Relativistic Wave Equation and Spectrum of Heavy Mass Quark-Antiquark Systems (H. Suura, W. J. Wilson and B. L. Young (Iowa State University)).

We argued previously[1] that the conventional S-wave and D-wave decomposition of the relativistic wave equation for 1^{--} mesons may not be appropriate in the presence of the confinement potential. We solved a set of coupled differential equations for an alternative pair of amplitudes and obtained a very satisfactory result for the charmonium spectrum. We decompose 4 x 4 matrix wave function as

$$\chi = \chi_1 \rho_1 + \chi_2 \rho_2 + \chi_3 \rho_3 + \chi_4 I$$

where ρ_i (i = 1, 2, 3) are a set of Pauli matrices. For the 1^{--} trajectory we write

$$\chi_{1,2} = r^{-1}\sigma\cdot r\, Y_{JM}\, C_{1,2} + (r\,\sigma\cdot\nabla\, Y_{JM})\, D_{1,2}$$

We find that the pair of amplitudes C_1 and D_2 satisfy a set of coupled wave equations and certain boundary conditions at the boundary r = R, where M = V(R), M being the mass eigenvalue. The coupling between C_1 and D_2 vanishes for the vanishing quark mass. We rotate among C_1 and D_2 and define a new pair, say α and β in such a way that the coupling between them vanishes for the infinite quark mass. It turns out that α and β are essentially S and D wave respectively. We solved for α and β neglecting the coupling. Exact solutions obtained from C_1-D_2 equations confirm that this approximation is surprisingly good. The spectrum obtained for the potential

$$V(r) = Kr - \frac{g^2 r}{r^2 + a^2}$$

with K = .2 GeV^2, g^2 = 0.5 and a = .1 GeV^{-1} is given as a function of quark mass in the following graph. Considering that the magnetic interaction is not included, the overall fit is remarkably good. It is to be noted that $^3S_1$ and $^1S_0$ are separated by about 150 MeV, a result which cannot be obtained in the standard fine structure approximation.

1. Progress Report, University of Minnesota 1978.

Equation of Motion for String Operators in Quantum Chromodynamics (H. Suura).

I derived from the QCD lagrangian differential laws describing motions and interactions of an infinite set of string operators -- locally gauge invariant color-singlet operators. A string operator consists of end points (quark and/or anti-quark operators) and vertices (electric or magnetic field strengths) which are connected by strings defined by

$$U(y,x) = P\exp\left(i\int_x^y \vec{A}(z)\cdot d\vec{z}\right)$$

where

$$\vec{A}(x) = \sum_{a=1}^{8} \frac{\lambda_a}{2}\vec{A}^a(x)$$

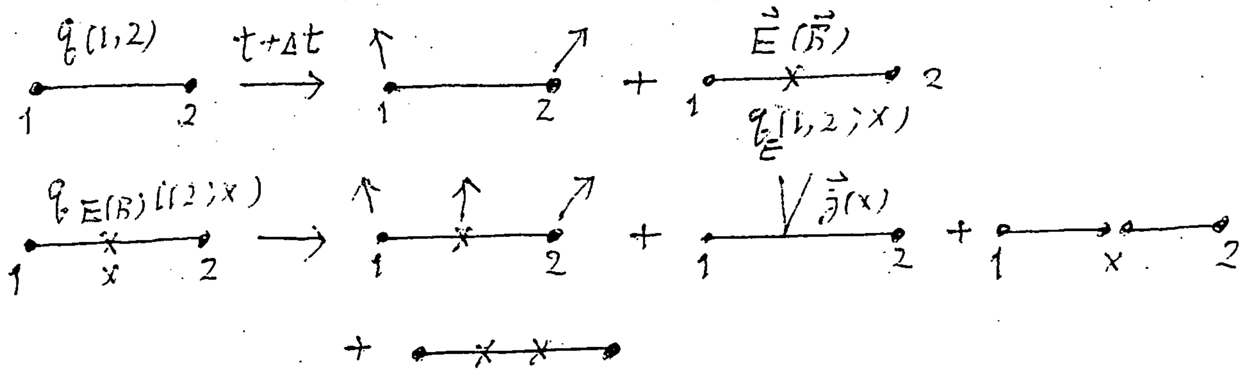
and the ordered (P-symbol) line integral is to be taken along the straight line connecting two points x and y. Thus, the set of meson string operators consists of a q-$\bar{q}$ operator

$$q(1,2) = tr^c\left[U(2,1)\,q(1)\,q^+(2)\right],$$

a q-$\bar{q}$-gluon operator

$$q_{\vec{E}(\vec{B})}(1,2;x) = tr^c\left[U(2,x)\,\vec{E}(x)\,(\vec{B})\,U(x,1)\,q(1)\,q^+(2)\right]$$

and so forth. tr^c means the trace with respect to color-spin. Time derivative of these operators can be calculated from the QCD lagrangian and gives the equations of motion of the string operators. They are schematically represented by

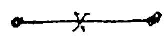


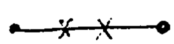
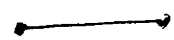
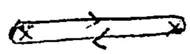
Significant elements of these equations are:

1. The end points and the vertices move according to the free Dirac and Maxwell equations, respectively. (the first terms on the right-hand side of the equations).

2. There is a potential energy $K'r$ (r: length of the string) corresponding to electric flux represented by the string.

3. The interaction manifests itself in creation of a new vertex along the string and also conversion of the field vertex into the quark current.

4. The latter can be rearranged into two terms, creation of color and flavor singlet current $\vec{j}(x) = q^{+}(x)\,\vec{\alpha}\,q(x)$ and splitting of the string at the point x. (2nd and 3rd terms in the equation for ). The singlet current couples to I = 0 vector mesons and also to the electromagnetic field. Thus, I predict that the jet fragmentation occurs in two processes, splitting of the string and creation of $I = 0$ vector mesons without splitting of the string.

5. Two-vertex operator  can be reduced to a product of  and a glue ball operator  plus the irreducible $q\bar{q}$ gg operator.

Neglecting certain terms I derived the wave equation for a q-$\bar{q}$ system to determine its spectrum, and also matrix elements for a jet fragmentation. (To be published in Phys. Rev. D20, No. 10, (1979).

I = 0 Transition Moment in A String Model of Hadrons Based on QCD (H. Suura).

I have shown in a previous paper[1] that the equations of motion for string operators derived from the QCD lagrangian leads to a coupling of the quark singlet current $\vec{j}(x)$ to the string. The matrix element for a transition of a q-$\bar{q}$ system from a state u(1,2) to another state u'(1,2) under the influence of $\vec{j}$ is given by

$$M = \frac{ig^2}{6} \iint d^3x_1\, d^3x_2\, u'^{+}(1,2)\, \mathcal{O} \int_1^2 d\vec{x} \cdot \vec{j}(x)\, u(1,2), \qquad (1)$$

where $\mathcal{O}$ is a certain operator acting on x_1, x_2 and x. $\vec{j}(x)$ couples to I = 0 vector mesons. Hence, the matrix element describes emission of I = 0 vector mesons, predominantly in the direction perpendicular to the jet (string) axis. $\vec{j}(x)$ also couples to the electromagnetic field $\vec{a}(x)$ via

$$\vec{j}(x) \sim -ie\,(-\partial^2)\,\Pi(-\partial^2)\,\vec{a}(x), \qquad (2)$$

where

$$\int d^4x\, e^{ik\cdot x} \langle 0 | (j^{a\lambda}(x), j^{\mu}(0))_+ | 0 \rangle$$

$$= (g^{\lambda\mu} k^2 - k^\lambda k^\mu)\, \Pi(k^2). \qquad (3)$$

Thus (1) directly gives a transitional moment, in addition to the normal transition moment arising from the interaction of quarks with the electromagnetic fields. It also gives the lepton pair production, again predominantly in the direction perpendicular to jet axis. This is in addition to the lepton pairs due to the Drell-Yan mechanism.

I calculated the transition moment μ_a for a neutral vector meson $\rightarrow$ a pseudoscalar + γ using (1). The ratio to the normal transition moment μ_n is given by, in the Pauli approximation,

$$\frac{\mu_a}{\mu_n} = -\frac{g^2}{3}\frac{\Pi(0)}{i\,Q_f} \qquad (4)$$

where $Q_f e$ is the charge of the quark in the q-$\bar{q}$ system.
The fact that R in e^+e^- collision approaches a constant indicates that we may use a perturbative calculation in evaluating (3). Then we would obtain

$$\Pi(0) = \sum_f \frac{i\,Q_f}{3\pi}\ln\left(\frac{\Lambda^2}{m_f^2}\right)$$

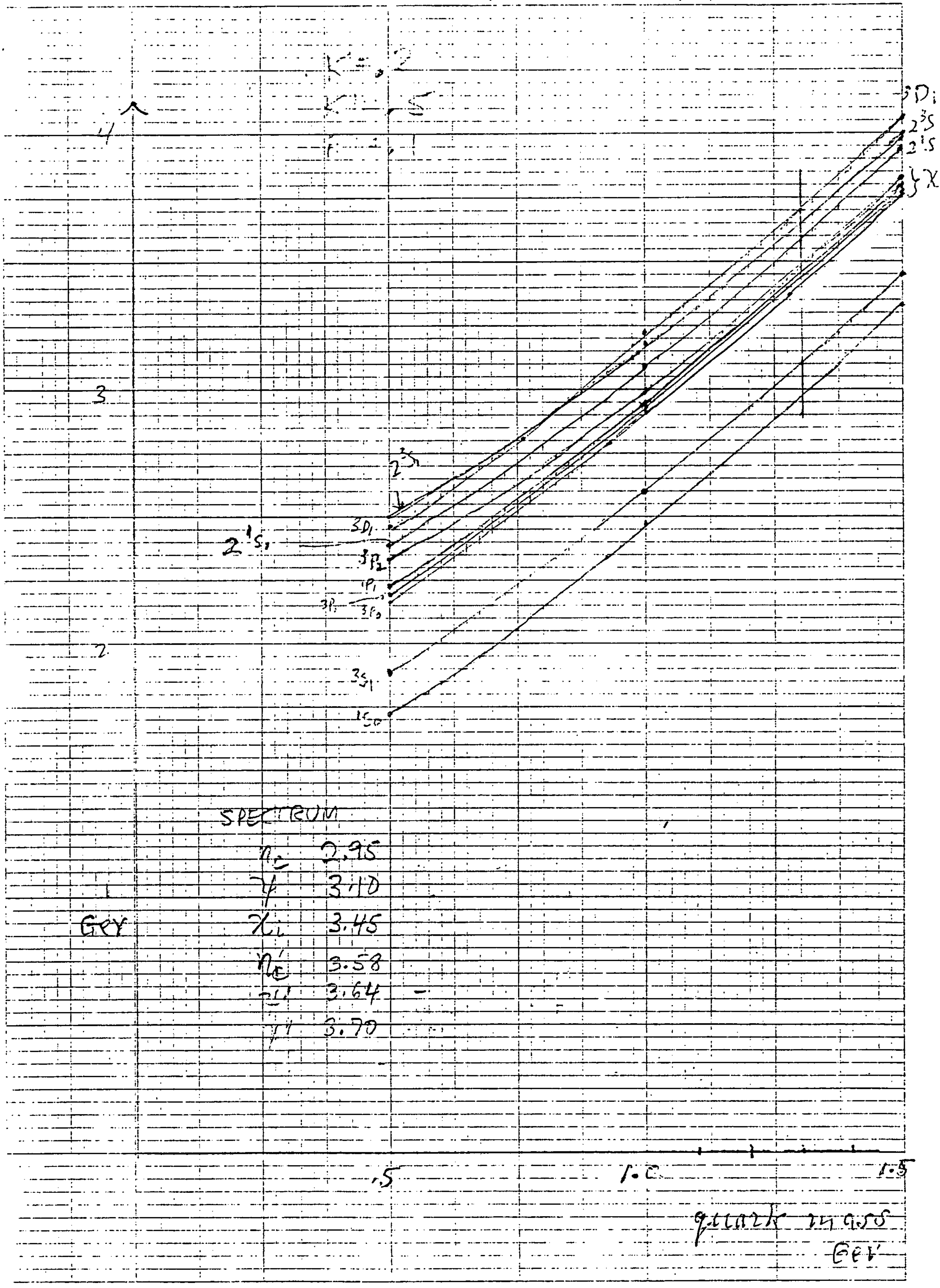
where the summation is over the flavor of all existing quarks. $\Pi(0)$ would be independent of the cut-off Λ only when $\sum_f Q_f = 0$. g^2 must be renormalized. A very plausible final answer would be

$$\mu_a/\mu_n = -(9\pi Q_f)^{-1}\sum_{f'}\alpha_s(m_{f'}^2)\,Q_{f'}\,\ln(\Lambda^2/m_{f'}^2)$$

where $\alpha_s(m^2)$ is a running coupling constant. It is to be noted that the relative sign is minus, which is exactly what one would like to have, according to the analysis by Geffen and Wilson.[2]

1. H. Suura, Phys. Rev. D20, No. 10 (1970; Also a report in the present Progress Report.

2. D. A. Geffen and W. Wilson, Progress Report 1979.



k' = .2
k' = .5
4
3
2
GeV
³D₁
2³S
2¹S
χ
2³S
³D₁
2¹S₁
³P₂
¹P₁
³P₁
³P₀
³S₁
¹S₀
SPECTRUM
ηc 2.95
ψ 3.10
χ1 3.45
ηc' 3.58
ψ' 3.64
ψ' 3.70
.5
1.0
1.5
quark mass
GeV

Angular correlations in the decay $\tau \to \nu_\tau \rho\pi$ (D. A. Geffen and W. J. Wilson).

Continuing our previous work[1] on the decay $\tau^+ \to \nu_\tau \rho^\circ \pi^+$ in more detail, we have proposed the measurement of two angular asymmetry parameters. When measured these asymmetries should help elucidate the helicity behavior of the decay and determine whether the decay is or is not dominated by the elusive $\rho\pi$ resonance, the A_1, and shed light on the possible existence of a π'. We give explicit formulas for the asymmetries in terms of general lorentz invariant amplitudes, and give rigorous bounds on how large they might be. These results are published in Ref. 2.

1. D. A. Geffen and W. J. Wilson, Phys. Rev. D18, 2488 (1978).
2. D. A. Geffen and W. J. Wilson, Phys. Rev. D19, 2211 (1979).

Magnetic Properties of the Low-lying Hadrons (D. A. Geffen and Warren J. Wilson).

We have found that an effective anomalous magnetic moment of quarks in hadrons is an essential ingredient for understanding the deviations from SU(6) of both the transition $V \to P + \gamma$ and the magnetic moment of baryons. We suggest that this anomalous moment is due to quark interactions with gluons making it the same for both u and d quarks. This added contribution changes the ratio μ_u/μ_d from -2, the ratio of u and d electric charge, to the order of -1.7. We are then able to explain the large ratio of decay widths, $\Gamma(\omega \to \pi\gamma)/\Gamma(\rho \to \pi\gamma)$ = 14.1 ± 2.0, instead of the quark or VDM prediction of 9. New, more accurate measurements of the magnetic moments of the Ξ° and Σ^+ have completely upset the simple SU(6) description for the baryon magnetic moments. We have explored broken SU(6) models in order to fit the existing data for baryon moments. Our most significant result is that, despite the freedom of using arbitrary mixtures of 20 and 70 wavefunctions within each I-spin multiplet, we are unable to find a satisfactory fit to the data as long as we restrict $\mu_u / \mu_d = -2$. This remains true even when we assign an arbitrary error to the proton and neutron moments of as large as 5%. When the ratio μ_u / μ_d is left free, we find an excellent fit with $\mu_u/\mu_d \sim -1.6$, a result which is consistent with that found for $V \rightarrow P + \gamma$ decays and implies an equal anomalous magnetic moment for u and d quarks in hadrons of the order of $3\frac{1}{2}$ to 7% that of the u quark.

Our results are being submitted for publication in the Physical Review Letters.

The Infra-Red Behavior of Propagators in QCD (S. Gasiorowicz).

During the past year I studied the Schwinger-Dyson equation for the gluon propagator in the approximation proposed by J. Ball and F. Zachariasen.[1] The object was to see:

(i) Whether work in the axial gauge, defined by $n_\mu A_\mu = 0$, was simplified, if an averaging over gauge-directions was performed, and

(ii) What the form of the solution took in 3 dimensions, where the theory is super-renormalizable.

The conclusions were that (i) no simplification occurred in the gauge-direction averaging. The principal-value definition of the treatment of 1/n.a singularities implies that

$$< \left(\frac{1}{n \cdot a} \right)^2 > = - \frac{2}{a^2}$$

and as a consequence other averages are quite complicated. For example

$$< \frac{1}{n\cdot a\cdot n\cdot b} > = - \frac{2}{\sqrt{a^2b^2-(a\cdot b)^2}} \tan^{-1} \frac{\sqrt{a^2b^2-(a\cdot b)^2}}{a\cdot b}$$

and the integral equation becomes very complicated.

(ii) In n-dimensions the integral equation is just as complicated as before. I did, however, succeed in solving the Ball-Zachariasen "Toy Model" which they use to illustrate the confining solution for the gluon propagator. In n dimensions the propagator in the infra-red region behaves like

$$(q^2)^{-1-\alpha}$$

and we find that $\alpha = \frac{n}{2} - \frac{3}{2}$ for arbitrary n. No particularly interesting conclusions can be drawn from the Toy Model about the behavior of the true solution of the B.Z. integral equation.

Lattice QCD in the Large N_{color} limit (S. Gasiorowicz).

I spent some time studying QCD on a lattice for large N. Certain simplifications became evident:

(a) In the Euclidean approach favored by Wilson, the quantities of interest are of the form

$$< U_i^{\ j}\, U_k^{\ell} \ \ldots\ U_a^{+\,b}\, U_c^{+\,d} \ \ldots >$$

where the brackets denote averages over the space of group parameters, e.g., an appropriately selected set of Euler angles. In the large N limit the expressions simplify in that the $< \ >_{irred} \to 0$, so that, for example

$$< U_i^{\ j}\, U_k^{\ell}\ \ U_a^{+\,b}\, U_c^{+\,d} > \to < U_i^{\ j}\, U_a^{+\,b} > < U_k^{\ell}\, U_c^{+\,d} >$$

$$+ < U_i^{\ j}\, U_c^{+\,d} > < U_k^{\ell}\ \ U_a^{+\,b} >$$

and so on. This is analogous to the assumptions made in the Hartree approximation. (b) In the Hamiltonian approach used by Kogut and Susskind, in which the "magnetic" energy is treated as a perturbation, a calculation of the kinetic energy of states of the form $U_i^{\ j} \ldots U_a^{+\ b} \ldots \mid 0 >$ shows that the gap between the singlet energy and the color non-singlet energy grows with N. Both of these results suggest that confinement is at least as likely for large N as it is for small N.

Encyclopedia Article on Elementary Particle Physics (S. Gasiorowicz).

A change in the publisher and publication schedule for Encyclopedia of Physics has allowed me to up-date and rewrite the lead article for the section on Elementary Particle Physics. In this summary of the developments of the field and its present status, I have extended the discussion of heavy quarks and the quark-lepton symmetry, as well as included a discussion of the grand unified theories, with their promise and difficulties.

3. Experimental High Energy Physics.

(Professors Hans Courant, Kenneth Heller, Marvin Marshak, Earl Peterson and Keith Ruddick; Research Associates Yousef Makdisi, Michael Shupe, and John Whittaker; Research Assistants J. Bartelt, B. Collick, T. Copie, S. Heilig, S. Heppelmann, T. Joyce, W. Kung, B. Mossberg, S. Sherman and T. Walsh).

The major effort of the experimental group during the past year has been concentrated at the Fermilab Meson Detector Building. An experiment in the M1 line has studied coherent production processes in order to determine the electromagnetic couplings of vector mesons through the Primakoff effect. A series of experiments have performed precision measurements using the neutral hyperon facility in the M2 beam line. In 1979, a major new effort was started to build a large water Cerenkov detector to search for baryon decay sensitive to lifetimes of order 10^{32} years. Other efforts included analysis and publication of data previously acquired using the polarized proton beam of the Argonne ZGS and a hyperon experiment at the Brookhaven AGS.

Fermilab E-272: "Coherent Production of Vector Mesons".

Over the past 15 years, considerable progress has been made in relating the various sub-nuclear particles through symmetry models. Although the qualitative aspects of these models have worked well, the subject has matured to the point where future progress is dependent on a detailed, quantitative understanding. One particular problem area has been the electromagnetic couplings of the vector mesons. Symmetry model predictions for the width $\Gamma_{\rho\pi\gamma}$ yield 90 keV as a minimum value. The existing experimental value is 35 ± 10 keV, a significant disagreement with theory. However, the experiment had significant systematic difficulties, which could account for the discrepancy. We have, therefore, decided to repeat the earlier experiment under conditions that would permit a more accurate measurement.

Searching for the decay $\rho \rightarrow \pi\gamma$ in a background of $\rho \rightarrow \pi\pi^0$, $\pi^0 \rightarrow \gamma\gamma$ is almost impossible. The width is best measured by the inverse Primakoff process

$$\pi + Z \rightarrow \rho + Z$$

where the interaction is between the incident π and a virtual photon from the nuclear Coulomb field. The experiment is best performed at very high energies where the relative ratio of Primakoff cross-section to strong interaction background is larger. Our experiment is at incident momenta of 150 and 250 GeV/c, whereas previous measurements were made at Brookhaven AGS energies.

In collaboration with the University of Rochester and Fermilab, we have built a high-resolution forward spectrometer with both charged and neutral particle detection capability. Data have been collected with both positive and negative beams at 150 GeV/c and with a negative beam at 250 GeV/c. In addition to the coupling, the data will yield information about the coupling for $K^*K\gamma$ and about the coherent production processes (both electromagnetic and strong) for A_1, A_2, B and other high mass mesons.

The current status of the experiment is that all data taken before the "mesopause" has been kinematically analyzed and cross-sections for ρ production have been determined. Preliminary analyses indicate a $\rho \rightarrow \pi\gamma$ width of 60 ± 7 keV, but an analysis to separate the electromagnetic and strong interaction events is continuing with a final uncertainty of $\pm$ 3 keV likely. A full spin-parity analysis using the Illinois partial wave programs is being made of the A_1 data. New data collection is scheduled for September, 1979.

Hyperon Experiments

Together with our collaborators, we are pursing a program designed to understand the large polarization found in inclusive Λ° production at high energies and to exploit this polarization as a tool to probe the structure of hadrons. As part of this program, two experiments were run last year, E495 at Fermilab and E717 at Brookhaven.

The Fermilab experiment was a collaboration with Brookhaven, Michigan, Rutgers and Wisconsin to measure the inclusive polarization of Ξ° from $p + Be \rightarrow \Xi^\circ + X$ using 400 GeV incident protons. The experiment is also a precise measurement of the Ξ° magnetic moment, the Ξ° decay asymmetry parameter α_{Ξ° and the production spectrum. The Ξ° magnetic moment measurement is a test of the naive quark model since the proton, neutron, and lambda moments are very precisely known. The Ξ° measurement, in conjunction with the new measurement of α_{Ξ^-} by the CERN charged hyperon group, will test the $\Delta I = \frac{1}{2}$ rule for nonleptonic weak decays. This experiment was successfully completed and the data is now being analysed.

The Brookhaven experiment was a collaboration with Brookhaven, Massachusetts and Michigan to measure the lambda polarization in the inclusive reactions $p + p \rightarrow \Lambda^\circ + X$, $p + d \rightarrow \Lambda^\circ + X$ and $p + Be \rightarrow \Lambda^\circ + X$ with incident proton energies of 28.5, 24, and 20 GeV. A comparison with the Fermilab results and those from the CERN PS and ISR will determine the energy and target dependence of this still unexplained phonomenon. The experiment was successfully completed and is now being analysed.

We currently are collecting data for Fermilab E-361, an experiment to measure all of the decay asymmetry parameters and the branching ratio for lambda beta decay using a polarized Λ° beam. Greater than 10^5 beta decays are expected to be measured in this experiment.

ZGS Polarized Beam Experiments:

During the past year, we have completed the analysis of a series of very fruitful experiments using the polarized beam at the Argonne ZGS. We have recently published the first study of high energy elastic scattering using a polarized deuteron beam and completed the analysis of a proton-neutron elastic scattering experiment, which used a deuteron target. The analysis of a measurement of the depolarization parameter in pp elastic and inelastic scattering has also been concluded. With the exception of some further analysis of the deuteron beam data and preparation of several extended papers summarizing the results of our program of polarized beam research, this work completes our measurements at the Argonne ZGS.

a) Proton-neutron elastic scattering:

This experiment measured the analyzing power (equal to the polarization) in large angle pp and pn elastic scattering using a polarized proton beam with momenta of 2, 3 and 6 GeV/c and a liquid deuterium target. The pp results are in agreement with previous measurements which indicates the validity of the new pn measurements. These data at all three incident momenta indicate a smooth transition from a positive analyzing power in the forward direction to a negative analyzing power for backward scattering. These data have been analyzed in terms of spin-dependent scattering amplitudes and Regge pole phenomenology.

b) Depolarization Parameter in pp Scattering at 6 GeV/c:

The D parameter in pp scattering is strongly dependent on the parity naturality of the exchanged particle in the scattering process. Previous measurements have been limited to elastic scattering. This experiment measured D for elastic scattering, N^* production and general inclusive processes. The most striking feature of the data is the change in D as a function of missing mass from near unity for elastic scattering to a negative value at the N^* (1232). These data have also been analyzed in terms of amplitudes and triple-Regge inclusive phenomenology.

c) Analyzing Power in Polarized Deuteron-Proton Elastic Scattering:

Several models have been proposed to provide a detailed understanding of pd elastic scattering at incident kinetic energies near 1 GeV. These approaches include multiple scattering models, the Kerman-Kisslinger model which hypothesizes the existence of N^* components in the deuteron wave function and triangle graph models which relate pd elastic scattering to virtual πp scattering. Fits to the differential cross-section are possible with all these approaches but a description of the spin-dependent amplitudes would provide a more definitive test of each model. In this experiment we made the first use of the ZGS polarized deuteron beam (both vector and tensor polarized) at three incident momenta near 1 GeV equivalent pd bombarding energy. The results of the experiment indicate that none of the models give the correct spin dependence using current values for the nucleon-nucleon scattering amplitudes. Further study of this phenomenology is currently in progress.

Baryon Decay:

During the past year, we have designed an experiment to search for baryon decay in collaboration with Harvard University, Prudue University and the University of Wisconsin. This experiment will provide a crucial test for current theoretical models unifying the strong, weak and electromagnetic interactions. The experiment is more fully described in the Proposal for 1980 on this contract. A complete proposal is included in the document entitled "A Multi-Kiloton Detector to Conduct a Sensitive Search for Nucleon Decay."

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Report on Sabbatical Leave of Hans Courant

During the Academic Year 1978-79

During the leave I was a visitor at L.A.P.P.* based in Annecy, France. This laboratory is located about 35 miles from CERN† (in Geneva Switzerland) and is maintained through the French CNRS†† for the support of research at CERN. Although I lived in France I commuted to CERN three or four days a week.

While at LAPP I was involved in three projects. The first is a part of a major European collaboration of eleven institutions and CERN. This effort is directed toward the preparation of an experiment, UA1, in which protons and antiprotons at high energy will be brought into lead-on collision at the CERN S.P.S. (Super Proton Synchrotron). The resulting interactions will be observed and recorded by a massive apparatus which essentially surrounds the interaction region. The role of L.A.P.P., my host institution, in this project has so far been the design and the fabrication of one major component of this detector. In this effort I have been able to contribute, particularly in the design and design-testing of the concept for the "electromagnetic endcaps".

The two other projects in which I participated are both at CERN and were undertaken in the Willis/Fabjan research group there. One of these, experiment 806', is a continuing program to increase data taken in a previous experiment bearing on the evidence for direct photon production in proton proton interactions. In working on this experiment I had the opportunity to learn about the construction and operation of large liquid argon calorimeters, as well as to participate in conducting an experiment at the CERN interacting storage ring facility.

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In addition to the above-mentioned activities I also prepared and ran some preliminary tests on "transition radiation detectors". These detectors make use of radiation in the soft X-ray range which is emitted when the trajectory of a highly relativistic charged particle undergoes an abrupt transition from one medium into another. The emitted radiation is very sensitive to the extremely small differences in velocity between different particles at highly relativistic velocities and thus may be used to select and identify particles at high energies. Until now transition radiation has been used to identify high energy electrons of 1 GeV or more. It is hoped that it will be possible to build counters based on this phenomenon whose velocity threshold is low enough to identify energetic mesons. However, the development of such counters presents mechanical, chemical, and electronic problems. My efforts at CERN have been directed at some of these.

All three activities mentioned here are programs which are continuing at CERN. I hope to be able to maintain some contact with my colleagues who are presently continuing the work at various laboratories throughout the world.

String Flip-Flop and Quark Matter*

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Abstract

Quarks are bound by strings attached to them. When two strings come close, a rearrangement of connections takes place. This effect plays an important role in a dense ensemble of quarks, quark matter. A phase transition from nuclear matter to quark matter occurs at the nucleon density $\rho < 5\rho_0$ where ρ_0 is the density of the ordinary nuclear matter.

The string flip-flop causes a new type of attractive interaction between hadrons at short distances or among quarks at high density. This interaction can produce multiquark bound states such as dibaryon or dimeson resonant states.

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