lifetime is 2.5×10^{-6} sec at 300° K and 20 torr, under conditions such that diffusion to the walls took much longer than this time. In general these conclusions were supported by the work of R. B. Cundall and A. S. Davies (Nottingham) and B. Stevens, M. S. Walker and E. Hutton (Sheffield).

A rather detailed account of molecular relaxation processes was presented by W. G. Robinson in which he examined the analogy between a solid and a large molecule in which electronic relaxation is efficient as compared with a vibrationally deficient smaller molecule in which electronic relaxation does not readily occur without the intervention of an environment. Benzene was considered as being intermediate between these extremes although the theory does not admit the lifetime anomaly mentioned above. Some general expressions for the vibrational overlap factors that are the crucial portion of the electronic relaxation matrix elements were presented by W. Siebrand (NRC, Ottawa) who was able to derive a simple isotope rule for radiationless transitions involving a change of multiplicity as well as demonstrate the involvement of C-H and C-D stretching.

David L. Dexter (Rochester) and W. B. Fowler (Lehigh) showed radiative lifetimes are influenced by the relaxation processes involving environmental states. Determinations of the quantum yields of intersystem crossing in isolated molecules is a most important endeavor, and a technique dependent on a kinetic analysis of triplet-triplet annihilation processes gave a value of 0.8 for this yield in phenanthrene vapor (G. L. Powell, R. C. Janagin and M. Silver; North Carolina). G. Finger, O. Z. Khamiri, J. Olmstead and A. B. Zahlan (American University, Beirut) presented a new method for measuring the fractional yield of excited singlet states produced by triplet-triplet encounters in the gas phase; they obtained a most interesting result for anthracene vapor in which the fractional yield was found to increase with increasing pressure.

Energy-transfer details for triplet states in rigid solutions and solids represented a significant portion of the symposium. R. E. Kellogg (DuPont) presented some elegant results on the interaction potential linking donor and acceptor molecules involved in triplet-singlet energy transfer; he demonstrated that the transfer efficiency showed no measurable deviation from an inverse-sixth dependence on the distance transferred, indicating the exact behavior predicted by T. Forster some years ago.

Some new notions regarding energy transfer studies arose from the theoretical work presented by J. S. Avery and J. C. Packer (Imperial College) who used a Green's function method to analyze the time-dependent luminescence of a random collection of donor and acceptor molecules. The general area of energy transfer in fluid media was reviewed by C. A. Parker (Admiralty Materials Laboratory), and in crystals—from rare gases to anthracene—by Stuart A. Rice (Chicago).

Since the spin-orbit coupling mechanisms in molecules are complex and not yet subject to confirmation, it is vital to find other methods of knowing properties of triplet state wave functions to test theoretical predictions. One such way is triplet-triplet absorption spectroscopy in which an effective ground triplet level is maintained by external radiation. Careful measurements of intensities and band structure over wide energy ranges are required and such results were in fact presented by Maurice W. Windsor and J. R. Novak (TRW Systems) on molecules in plastics. Some beautiful T-T absorption spectra of anthracene were presented and discussed by R. Astier and Y. H. Meyer (École Polytechnique), who found a reasonably good correlation with known theory in regard to energy and intensity. The polarization of the naphthalene T-T transitions in different solvents was determined by S. Seigel and H. S. Judeikis (Aerospace).

In the realm of new kinds of triplet states, J. Tanaka (Nagoya) demonstrated the presence of strong, localized-triplet-state-electron-transfer-state interactions in certain charge-transfer complexes.

What is the status of the triplet state? It is clear that a decent documentation of properties, especially of dynamic properties now exists. Many new characteristics have become predictable, at least on a semiempirical basis, even though there still exists a great deal of uncertainty with respect to the radiative transition mechanisms: No lifetime calculation has yet been successful. The microscopic theories of radiationless transitions tend to explain only selected phenomena—and whether the unexplained phenomena even relate to the question is not yet certain. We know the triplet skeleton fairly well; only the body remains to be built.

The proceedings of the symposium will be published as: *Proceedings of the International Symposium on the Triplet State,* Cambridge University Press (1 Sept. 1967).

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High-Energy Symmetry Principles at Coral Gables

Participants at this year's Coral Gables conference on Symmetry Principles at High Energy placed their bets on current algebra and superconvergence with Regge poles making a good recovery. Several papers were devoted to obtaining mass spectra with infinite representations of noncompact groups. The useful though reluctant quarks that have been discussed at previous conferences of this series, provide a more easily visualized realization of the abstract hadron symmetries, but they failed to appear explicitly at this conference. Nevertheless the apparitions of these ghost-like creatures could be seen to walk in the famous current-commutation relations proposed by Murray Gell-Mann.

The conference, which was held last January for the fourth successive year, was under the auspices of the University of Miami Center for Theoretical Studies and also had sponsorship from five government organizations.

The current-commutation relations are algebraic equations, postulated to hold at a given time among a set of generalized currents—namely, an octet of four-vector currents and an octet of axial four-vector currents that are assumed to have SU(3) transformation properties. (In a more conservative version, the equations are postulated

only for a set of generalized charges, these being defined as the space integrals of the fourth components of the currents.) These relations are in fact abstracted, or rather heuristically extended, from the relations that hold for the analogous currents appearing in a field theory of free quarks. With the PCAC (partially conserved axial-vector current) hypothesis, stating that the four-divergence of the axial current is proportional to the pion field (as well as CVC—conserved vector current) this approach has had notable successes in obtaining low-energy properties of hadrons. Almost everyone has heard of the calculations by S. L. Adler and W. I. Weissberger giving the correct ratio of the axial-vector and vector coupling constants of beta decay, G_A/G_V.

Dynamical approaches, on the other hand, like dispersion relations and parametrization in terms of Regge-pole exchange, have given quantitative descriptions of some aspects of high-energy scattering. Several papers at the conference tried to relate these quite different methods to the current algebras. Susumu Okubo (Rochester), for example, tried to generalize the equal-time commutation relations of currents to commutators of local currents whose arguments lie on each other's light cone. Invariance requirements alone do not determine this extension completely but only put some limits on its form. Okubo then assumes his form applies to the current commutators that arise naturally in reducing the scattering matrix by the method of Lehmann, Symanzik and Zimmermann. He is then able to obtain a number of sum rules for total and differential scattering cross sections that agree with those obtained from the Regge-pole model. Furthermore he is able to write expansions of the form factors, part of which consists of a sum of terms that look like Regge poles; the other part is an equal-time commutator. Asymptotically, at high energy, it is expected that only the Regge poles remain.

Yuval Ne'eman (Tel Aviv) began with a summary of his recent work with Cabibbo, Horwitz, and Kokkedee in obtaining high-energy cross-section relations that previously were obtained with the quark model. They assume dominance of the exchange of two unitary-spin nonets of meson Regge trajectories, coupled universally to scalar and vector currents, that satisfy certain commutation relations appropriate to the problem considered—the rest group algebra of $\tilde{U}$ (12). Ne'eman then attempted to identify the required scalar unitary singlet as a part of the energy-momentum tensor of gravitation.

Vector-meson dominance and current-algebra results were compared in a very clear and beautiful paper, by J. J. Sakurai (Chicago). A survey of strong interactions (for example, pion-nucleon *s*-wave scattering lengths), electromagnetic interactions (for example $\eta\to2\gamma$ and $\eta\to\pi\pi\gamma$) and weak interactions (for example, *s*-wave hyperon decay and $K\to2\pi$ decay showed that current algebra soft-pion results and vector dominance results are identical. At least this statement holds for those successful current-algebra calculations that are based on *integrated* current densities, that is, generalized charges. Sakurai argues that both current algebra and vector-meson-dominance models are useful since the former, although free of models, makes the unrealistic assumption of considering pions with zero four-momenta.

The implications of the locality assumptions in Gell-Mann's current algebra were discussed by J.D. Bjorken (SLAC). In connection with the high-energy neutrino experiments being conducted in Utah, South Africa and India, lower limits are predicted for interaction cross sections at large neutrino energies. The cross sections are essentially those expected from a point-like nucleon, and they agree reasonably well with what is observed. Also a muon energy spectrum like E^{-1} is expected to arise from the neutrino spectrum like E^{-3}. Similarly a Rutherford-type cross section for electron-proton inelastic scattering is predicted at sufficiently high energy. This appears, at present energies, to be about an order of magnitude too high, but more work at higher energies will settle this question.

Experimental. Several experimental reviews were on the program. That of Gerson Goldhaber (Berkeley) was concerned with the search for resonances that could not be described as either quark-antiquark or three-quark systems. Possible examples of such systems would be doubly charged or doubly strange bosons, requiring at least two quarks and two antiquarks, or positive-strangeness baryons, requiring at least four quarks and one antiquark. Several possible candidates for such resonances appear in the literature but a very careful review of the evidence by Goldhaber led him to the conclusion that there is no compelling reason at present to believe in their existence. For some cases a convincing kinematical explanation was found for the observed bumps in cross sections. In the case of a $T = 0$ mass peak in K^+N at 1560 MeV, found by Rodney Cool and his colleagues with very good statistics, bubble-chamber experiments at Berkeley and elsewhere are in progress to study individual inelastic cross sections that may provide an explanation of this peak. A similar program has explained an $I = 1$ peak near this same energy.

Donald H. Miller (Berkeley) gave a talk on recent work on boson resonances, especially those in the mass range of about 1 to 2 GeV. The most sensitive way of detecting these resonances appears to be the missing-mass-spectrometer method of Maglic and his collaborators, but detailed study of their properties still remains largely the task of the bubble chamber, expecially when there are multiparticle decay models. For example, as cited by Miller, recent work has confirmed the $I = 0$, $J^P = 0^-$ properties assigned to η' (the $\eta\pi\pi$ resonance of mass 960 MeV). In the decay mode $\eta'\to\pi^+\pi^-\gamma$ the ρ^0 is clearly seen, and the angular correlation of ρ^0 and γ is a $\sin^2\theta$ distribution corresponding to the magnetic-dipole transition $0^-\to1^-$. In the decay mode $\eta\pi\pi$, the π-π system is seen to be peaked at the σ meson mass, with good statistical significance. On the question of the δ meson, however, reported by Maglic and his associates, the production cross section appears to be too small for the particle to show up in bubble-chamber experiments, especially as it may well appear in the η-π channel, where a much larger number of events is needed than are presently available.

In the final experimental paper S.J. Lindenbaum (BNL) discussed elastic scattering measurements at the highest energies now available (PHYSICS TODAY, May, page 63).

Analyticity. A. Martin (CERN) then gave a beautiful theoretical talk on the difficult subject of general analytic properties of scattering amplitudes. Starting with the "classical" results of axiomatic field theory he showed how adding the unitarity postulate enlarges the domain of proved analyticity, until the last results can now be summarized: In terms of the Mandelstam variables *s, t,* and *u* the Mandelstam representation is proved to be a good approximation for small *s or* small *t or* small *u*. In addition, one can give rigorous bounds on asymptotic scattering amplitudes as well as limits, at present not yet realistic, on quantities like the strength of the pion-pion interaction.

Julian Schwenger opened what may well be (who knows?) a door into the future. In a contribution entitled "Sourcery," he described a new kind of particle theory that does not make the usual field-theoretical or S-matrix assumptions. A "source" is merely a space-time region from which particles can emerge (like an accelerator) or can be absorbed (detector). A source in which, say, two particles enter and three emerge is a phenomenological description of particle creation. Only real (not virtual) particles are considered. It will be interesting to see what follows from this theory.

Lorentz groups. We come now to what is probably the most significant contribution of this particular Coral Gables conference. At each of the previous conferences a particular theme was insistently evident in the form of a cluster of independent contributions calling attention to a new direction. For example, in the first conference there were several attempts to obtain finite particle representations by combining internal symmetry, like SU(3), with the Lorentz group in a nontrivial way within a larger group. This was later proved to be impossible, first by McGlinn and then by others (the strongest version of this theorem being presented at the 1967 conference by Sidney Coleman, Harvard). At the 1967 conference there was a similar emphasis on the importance of unitary representations of the Lorentz group, with papers by A. O. Barut, S. Fubini, F. Gürsey and Y. Nambu.

The Lorentz group is noncompact because of the presence of both plus and minus signs in forming its metric; so it can be shown that the unitary representations are of infinite dimension. In terms of particle theory this fact implies a multiplet, or multiplets, containing an infinite number of particles. Before turning away in horror, the reader should recall at once that a very familiar system, the hydrogen atom, exists in an infinite number of states, having different masses, various spins and both parities. It has also been known for many years that the "accidental" degeneracy of the *l* states of the nonrelativistic hydrogen atom (so familiar to beginning students of quantum mechanics) as well as the degeneracies that survive even in the Dirac hydrogen atom, are related to the invariance of the Hamiltonian under the four-dimensional Euclidean rotation group SO(4). The question arises, therefore, whether the observed particle states, which display such intriguing symmetry (perhaps, like hydrogen, as a result of a hidden composite structure), can be treated by similar methods. Since, however, we have no knowledge of such internal structure, nor are we even sure of its existence, it becomes relevant to ask whether we can treat known composite systems (hydrogen, harmonic oscillator) by looking at them only from the outside, so to speak; that is, by symmetry methods alone.

That, at least, was the motivation of Yoichiro Nambu (Chicago), who was led in this way to consider infinite-component wave equations. An Italian physicist, Majorana, first considered such equations in 1932 to construct a Dirac-type theory that did not contain antiparticles. This appeared to be desirable before the discovery of the positron. As Nicola Cabibbo (Rome) suggested in his summary talk, the physical purpose for the use of infinite unitary representations may be similar in elementary-particle physics; that is, to minimize the role played by virtual antiparticles or, in other words, to suppress multiparticle intermediate states.

Asim O. Barut (Colorado) and F. Gürsey (Yale) also provided variations on the same theme of use of noncompact groups however, from the S-matrix point of view, rather than the field-theoretic approach. In Barut's case the most remarkable success was obtained in calculating the nucleon form factors, the threshold behavior being entirely correct.

We refer finally to the work of S. Fubini (Turin) who closed the circle with a paper entitled "Superconvergence, Current Algebra and the Lorentz Group" in which the first and last contributions referred to in this report are brought together. In the first place, he showed that when an amplitude may have pure Regge behavior asymptotically, one gets one or more homogeneous superconvergence rules of the form: an integral over energy of the imaginary part of the amplitude, multiplied by a power of the energy, is equal to zero. On the other hand, when the amplitude depends on currents in such a way that, because of divergence conditions on the currents, asymptotically pure Regge behavior is *not* possible, then inhomogeneous terms are necessary, these last being form factors related to equal-time commutators. He next considered the question of solving a set of superconvergence equations by introducing a set of single-particle intermediate states and neglecting continuum contributions, so that the problem becomes an algebraic one. He concludes that it is possible to solve the equations using the particles contained in a single finite representation of the Lorentz group; however, these are fake solutions because the coupling constants of some of the particles must be imaginary. The only way out appears to be to use a representation containing an infinite number of particles; the simplest appears to be the unitary representation of the Lorentz group, all particles appearing with positive metric. Work along these lines by Fubini and his collaborators is now in progress and is restricted to multiplets of equal-mass particles. So the mass spectrum problem, considered by Nambu, has not been attacked.

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The conference was organized by Behram Kursunoglu and associates.

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