

Fundamental Particles at High Energy

The five Coral Gables Conferences on Symmetry at High Energy have now been succeeded by The Conference on Fundamental Interactions at High Energy, held 22-24 January at Coral Gables. This shift in emphasis is evidence, on the one hand, of the successful assimilation of symmetry notions like $SU(3)$ into the bloodstream of particle physics and to the recognition, on the other hand, of the increasing appetite for more dynamical approaches. The fundamental interactions—gravitation, electromagnetism, strong and weak CP-conserving and nonconserving interactions—still offer a dazzling challenge to the physicist with their pattern of disparate strengths, their hierarchy of symmetry properties, and their universality still to be explained.

The classical long-range electromagnetic forces are well described by Maxwell's equations and so well mastered that our own electromagnetic miracle, the brain, can perceive the image focussed upon an electronic eye circling just above the moon. This same field, quantized, produces the atom, whose dynamics we understand with great precision. Yet there remain mysteries. Why is electromagnetism universal or, if you prefer, why is charge quantized (and is the quantum e or $e/3$)? Some high-energy experiments probe the electromagnetic properties of the elementary particles (their charge and magnetic-moment distributions). From the electrons and muons (leptons) we have found that our theory of the electromagnetic field is very accurate, and using this knowledge we map out the evidences of the structure of the strongly interacting baryons and mesons (hadrons).

Analogously, the weak interactions exhibit both a lepton and a hadron side and possess a universality that can be quantitatively formulated. The parity-violating character of weak interactions is fundamental. Although the electromagnetic object is a conserved neutral (that is, charge-conserving) vector current, the weak object is a combination of a conserved charge vector current and

charged axial vector current that is as conserved as possible. (Let's face it, it is not conserved.) The presence of axial currents and strangeness-changing currents permits the probing of hadron structures not accessible to electromagnetism.

In the purely hadronic processes, however, one is faced with the problem of probing the unknown with the unknown, and this problem is reflected in the existing theories. These are either purely phenomenological, like Regge-pole theory, or models, like so-called "phenomenological Lagrangians," or generalizations, such as current algebra, which uses information obtained from weak and electromagnetic processes. An approach that is exceptional in striving to be fundamental is the "bootstrap" program, which asks for a self-consistent solution for scattering amplitudes satisfying the requirements of analyticity, crossing symmetry and unitarity—with the hope that such a solution exists, is unique, and represents the real world.

Equations of Motion. P.A.M. Dirac opened the conference with the question "Can Equations of Motion be Used?" Although agreeing that Heisenberg's 1925 view (that only observable quantities should be used in formulating a physical theory) can be a good guiding principle, he felt it nevertheless unlikely that the S -matrix would be the final answer in high-energy physics. Someday we would be discussing equations of motion like $dA/dt = f(A)$, where A would be one object, possibly only remotely related to experimental quantities; in this sense there would be determinism, subject only to the usual quantum-mechanical measurement uncertainties. He thought this prophecy would come to pass because of his "feeling for the unity of physics," and because of the important role played by equations of motion in all other branches of physics.

Lagrangian field theories, which yield equations of motion, are in some disfavor because of the infinities that make some of their predictions meaningless without high mo-



BEHRAM KURSUNOGLU (right) talking with Eugene Wigner at Coral Gables.

mentum cutoffs. These, in turn, lead to failure of Lorentz invariance or probability conservation. But Dirac argued that a partial theory, a theory of a single type of interaction, need not be Lorentz invariant—that that restriction can logically be imposed only upon the complete theory. The important thing in a cutoff theory is that the quantities of interest should not be sensitively dependent on the value of the cutoff, and he suggested in this connection an approach based on the no-particle state rather than the vacuum state (the state of lowest energy). These two states are completely different from each other in quantum field theory. I will always remember Dirac's answer to a question (I have forgotten the question): A theory that has some mathematical beauty is more likely to be correct than an ugly one that gives a detailed fit to some experiments.

Relativistic interactions. It is appropriate now to refer to Eugene P. Wigner's talk on the relativistic interactions of classical particles. Many readers will be surprised to learn that this is an unsolved problem even for two particles. Others will recall the classical work of John Wheeler and Richard P. Feynman; but they treated electromagnetic interactions, the particles radiate, and so there are no conservation laws. It was shown earlier that Poincaré invariance (that is, Lorentz plus translation invariance) implies that *no* interaction is possible in the

canonical Hamiltonian formulation of the problem. Wigner and his collaborator, H. Van Dam, succeed in retaining conservation laws, Poincaré invariance, and constant rest masses, at the expense of restricting the interaction to the case where the two particles are outside each other's light cones; the force on one particle is expressed as an integral over the appropriate portion of the other particle's world line. Applying reasonable simplifying conditions, an interaction is obtained that is a central force in four-space, is symmetric in the particle coordinates, and is in fact a relativistic generalization of the $1/r^2$ law of force. The theory is characterized by the presence of *interaction* energy, momentum and angular momentum. Wigner extended these ideas to propose a simple two-particle generalization of the Dirac equation with interaction, which has the puzzling property that interaction may be present in one Lorentz frame but can apparently be caused to vanish in another frame.

The CP-violating weak interaction was discussed by Murray Gell-Mann (Cal Tech), Richard J. Oakes (Northwestern University) and Christian Fronsda (UCLA). Gell-Mann summarized and criticized the various classes of explanations suggested to explain the Fitch-Cronin effect ($K_{\text{long}} \rightarrow 2\pi$), emphasizing that the small neutron electric dipole moment (which is zero to a high accuracy) excludes many theories. He then considered the possibility of new particles playing a role in CP-violation and reviewed the rather inconclusive experimental evidence concerning them. Fronsda (with Richard E. Norton) dealt with a theory of Nishijima, who proposed that the usual hadronic weak interaction is a second-order effect (as in intermediate-boson theory), the first-order interaction being pure CP-violating; the Fitch-Cronin effect would then be of third-order, hence CP-violating. Fronsda suggested how this theory could be extended to cover all weak interactions.

Regarding CP-conserving weak interactions, Gino Segre (University of Pennsylvania) discussed models of the hadronic current based on current algebra, while R. R. Gatto (CERN and Padua) and Nicola Cabibbo (Rome) both addressed them-

selves to the calculation of the Cabibbo angle, a small parameter ($\approx m_\pi/m_K$) that occurs as the coefficient of the strangeness-changing part of the hadronic current. The work of Gatto and his collaborators, as well as that of Cabibbo and Maiani, is based on the fact that, although the weak coupling constant is very small, nevertheless the successive terms of the perturbation series are infinite, aside from the lowest-order term. In electrodynamics, where the same difficulty is present, it was possible to lump the infinities into infinite mass and charge renormalizations, all other quantities being finite. But as the divergences in weak interactions are much worse, the theory is apparently not renormalizable. In certain models of the hadronic weak current the Cabibbo angle appears in the coefficients of the leading (that is, the worst) divergent terms, and Gatto and others observed that these coefficients could be made to vanish by a suitable choice of the Cabibbo angle. This choice, in fact, is in close agreement with the experimental value. He has now extended this model to other models and to higher order terms in the perturbation series, with the hope of eventually realizing a renormalizable theory. Cabibbo's aim is similar, but slightly more ambitious, in that he looks for a self-consistent solution for the cancellation of the leading weak divergences in the presence of strong and electromagnetic renormalizations and mass shifts. This solution requires the introduction of a parameter, which is, however, experimentally accessible in principle—for example, by electromagnetic decays of the eta-meson (including $\eta \rightarrow 3\pi$). Presently available measurements do not appear to agree with the theory.

Strong interactions. In the field of strong interactions proper, Gabriele Veneziano (MIT) discussed a remarkably simple representation for the scattering amplitude that he proposed about a year ago. It exhibits "duality," that is, Regge behavior that is symmetrical in the energy and the momentum-transfer channels. Although it is a narrow-resonance approximation, incapable of giving resonance widths and lacking unitarity, it has been successful in giving a mass spectrum and in explaining otherwise unexplained experimental results. (PHYSICS TODAY, March, page 59.) The last point was stressed at

the conference in a review by H. R. Rubinstein (New York University). Veneziano outlined a possible bootstrap program in which unitarity would be included in the scheme in successive steps. Richard Eden (University of Cambridge) offered a more conventional approach in discussing the behavior of Regge trajectories, based on the idea of self-consistency in strong interaction dynamics. Vernon Barger (University of Wisconsin) discussed the interpretation of backward peaks in scattering cross sections in terms of Regge-pole phenomenology. L. Soloviev (Serpukhov) discussed nonforward high-energy scattering by means of dispersion sum rules.

Other approaches to mass spectra were used by Loughlainn O'Raifeartaigh (Dublin Institute for Advanced Study), who is still attempting to carry through the Dashen-Gell-Mann program of saturating the current algebra with single-particle states, and by V. P. Shelest (Ukraine Institute for Theoretical Physics) in terms of a phenomenological quasi-potential method.

Marvin L. Goldberger (Princeton) derived an integral equation for elastic scattering, based on applying unitarity to a multiperipheral Regge model. This equation (collaborators: Chew, Low, Tam and Wang) can be handled in a bootstrap manner, requiring that the deduced Regge behavior be consistent with the Regge behavior that is assumed in writing the equation. Laurie M. Brown (Northwestern University) discussed the interaction of a pseudoscalar and two vector mesons in the framework of chiral symmetry. This work (with Herman Munczek) gives theoretical justification to the well known Gell-Mann-Sharp-Wagner form of the interaction.

On the fundamental side, Kurt Symanzik (DESY) discussed recent quantum field theories, pointing out the mathematical advantages to be gained by the formal use of a complex time variable. By analytically continuing the Wightman functions to $z = -i$, for example, one is able to use a Euclidean, rather than a Lorentzian, metric so that singularities occur only for coinciding points (not on light cones) and Feynman path integrals become Wiener integrals, for which there exists a good mathematical theory. I. T. Todorov (Institute for Advanced Study, Princeton)

presented work (with C. Itzykson) on the algebraic formulation of the relativistic two-body problem.

Gravitation. The remainder of the conference consisted of talks on gravitation by John Wheeler (Princeton), Joseph Weber (Maryland), David Finkelstein (Yeshiva), and Peter Freund (Chicago). These reports were interesting and are, perhaps, deserving of extensive summary, but their relevance is to cosmology and not to the small times and short distances involved in high-energy physics.

Exact Statistical Mechanics at Irvine

A very informal symposium on exact results in statistical mechanics was held at the University of California, Irvine on 8-9 November. The idea for such a symposium, with the purpose of an unhampered discussion of progress and problems in this rapidly evolving field, was generated in correspondence between Alexei Maradudin (chairman of the physics department at Irvine), Meinhard ("Hardy") Mayer (who holds a joint appointment in physics and mathematics at Irvine) and David Ruelle (of the Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, a visiting professor of mathematics and physics at Irvine during the fall quarter).

The symposium brought together a small number of active workers in the field of "exact statistical mechanics," who, characteristically for this field, can be found on the faculties of departments of chemistry, mathematics or physics (sometimes with joint positions in any combination of these). Also characteristic for the field is that, unlike most other areas of theoretical physics, mathematical sophistication and rigorous analysis are not luxuries, to be superimposed on top of results that one can also derive by means of the usual handwaving approach to mathematical physics. On the contrary, sophistication and rigor are real necessities for attaining any kind of progress in the field, as became clear only during the last decades. One might even claim that this area of physics demonstrates clearly that the mathematical training of our future theoretical physicists is at least 30 years out of date, and that unless something is done about it, the new generation of theorists will have to spend a good deal of their postdoctoral time learning 20th-century mathematics, in or-

sics. At least this is the case at present, and it is not expected to change until we have accelerators of about 10^{38} eV. Assuming the present logarithmic rate of growth of accelerator energies, one predicts that this will occur in about two centuries. Such predictions, of course, are usually wrong so it is better to say we simply do not know when gravitation will begin to play a role in high-energy physics. It could even be next year! After all, weak interactions, which in comparison to strong inter-

actions hardly even exist, have been important tools in the elucidation of strong interactions—and the masses of hadrons and leptons are the masses of gravitating objects. Let us simply say: We do not know.

* * *

The conference was organized by Behram Kursunoglu, at the Center for Theoretical Studies, University of Miami, Coral Gables, Florida. The proceedings will be published by Gordon and Breach.

LAURIE M. BROWN
Northwestern University

der to tackle the physics of the 21st century.

Exact statistical mechanics is rather difficult to delineate and explain to the nonspecialist. As Joseph Mayer of the University of California, San Diego justly remarked in his opening talk at the symposium, it suffices to switch off all interactions to obtain the only "realistic" exact system: the ideal gas. Roughly speaking, however, one may divide the field (at least as it was represented at this meeting) into the following four areas:

- Proofs of the existence of "thermodynamic limits." By this we mean proofs of the existence of extensive thermodynamic functions in the limit as the particle number and volume go to infinity, with the density remaining constant; it became clear some time ago that this limit is necessary for the existence of phase transitions. For finite systems the functions are "too analytic," that is, in many cases, they are polynomials.

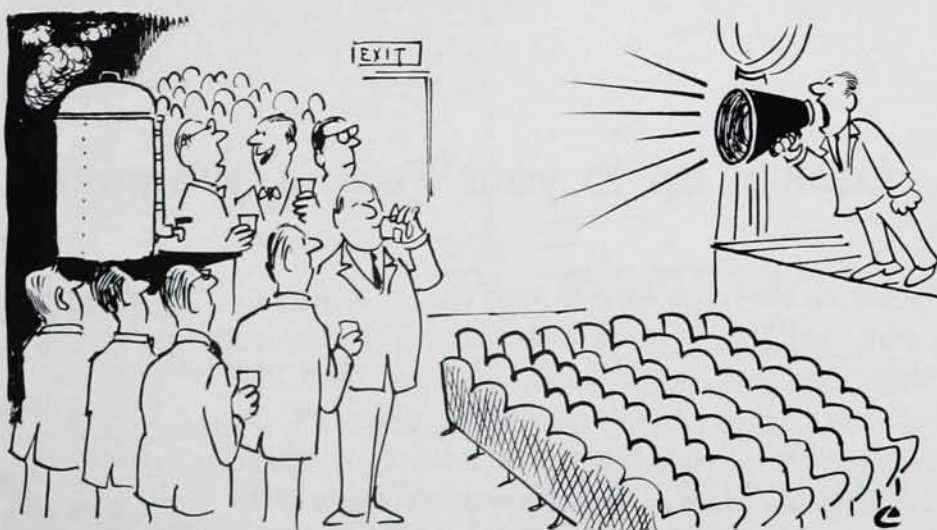
- Analyticity properties of partition functions in temperature and activity. These properties are also important for phase transitions.

- Exactly soluble models. The best known of these are the various modifications of the Ising model (first solved by Lars Onsager, last year's Nobel Laureate in chemistry), lattice gases with model potentials and hard-sphere gases.

- The algebraic approach. This approach replaces the limiting process $V, N \rightarrow \infty$ by a direct formulation of statistical mechanics for infinite systems, where the observables form C^* algebras.

The reader who wishes to get a more exact idea of the first three topics (or their status before our symposium) is referred to the excellent review by Joel Lebowitz,¹ and for the fourth topic and a detailed discussion of most of the others to the forthcoming book by David Ruelle.²

Because our informal symposium came shortly after the "big" confer-



"... and often the speakers were asked to talk louder so that they could be heard near the coffee urn at the back of the room..."