Unified Theories of ELEMENTARY PARTICLES

Participants at a topical conference are hopeful that quantum field theory may elucidate the symmetry and interactions of the smallest bits of matter

by Sidney A. Bludman

THEORISTS AT A RECENT SEMINAR on unified theories of elementary particles were brought together by continued interest in more or less realistic application of quantum field theory to elementary-particle physics. Thus they do not share the fears of Freeman J. Dyson (expressed in last June's PHYSICS TODAY)—about the relevance of field theory to strong-interaction physics nor his fear that field theorists are to become an isolated band of specialists like specialists in general relativity.

Within this conviction, however, working field theorists can be separated into "conservatives" (who accept the conventional conceptual framework that has been successful in quantum electrodynamics and undertake the difficult task of finding calculational techniques appropriate to strong interactions) and "radicals" (who are willing to tamper with conventional conceptions to obtain a new theory in which simpler calculational techniques may be applicable).

Participants in the seminar, held last July in Munich, realized the physicists' dream of a topical conference attended almost exclusively by a small group of active contributors. Thirty post-PhD theorists and about 14 advanced students attended; the 24 who presented lectures were concerned mainly with such subjects as model field theories, dynamical symmetries, fundamental fields and particles, the possibility of calculating fundamental constants, and consequences of the vacuum being asymetric.

Model field theories

A member of seminar participants addressed themselves to the exact treatment of model field theories. Kurt Symanzik (New York University) spoke on quantum field theories in Euclidean space, which exist if the corresponding Minkowski space field theories do but which he is able to analyze in detail for a specially chosen model. Kenneth Wilson (Cornell) treated more specific models in which more specific question can be answered: these models are nonrelativistic but retain important features of relativistic theories. John R. Klauder (Bell Telephone Laboratories) solved rotationally-invariant models to show that the translation generators need not be expressible in terms of the basic field operators. This showed that the representations of the ring of field operators that we use need not be irreducible.

Also concerned with the application of dynamical computation schemes, this time to experimental data, were talks by James Hamilton (Nordita) on peripheralism and nucleon isobars, and by E. Leader (Berkeley) summarizing the present phenomenological status of Regge pole theory. C. R. Hagen (Rochester) showed that magnetic monopoles cannot exist in a canonical quantum electrodynamics with the usual degrees of freedom.

Kinematics and dynamics

A most rapidly developing subject in elementary-particle theory, which has been successful in correlating a number of empirical results, is the group-theoretical structure of strong interactions. Various aspects of this subject were discussed in Munich by Julian Schwinger (Harvard), E. C. G.

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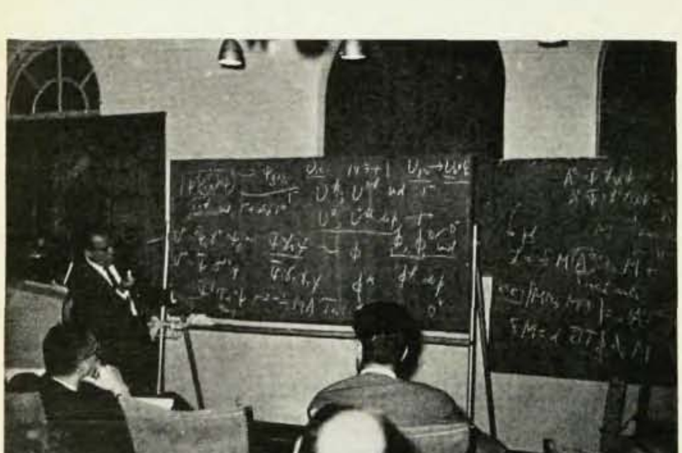
Sudarshan (Syracuse), J. Wess (Vienna), Bruno Zumino (New York University), and Meinhard E. Mayer (Indiana). Different theories, whose relation to one another is not now clear, differ in how dynamical notions are combined with invariance principles to explain the approximate symmetries observed. As long as the higher symmetries considered are symmetries of the field equations, one is close to a unified field theory that constitutes, in the sense of Einstein's program, a geometrization of dynamics in a manifold larger than ordinary space-time. What represents a really quantum-mechanical departure from the classical approach to symmetry is considerations of groups that are *not* symmetries of the field equations or of theories built on an asymmetric vacuum.

Especially in the eloquent presentation of Schwinger but also in the work of Umezawa, Sudarshan and others, fields are employed on two distinct levels. Fundamental fields are assumed to obey symmetric dynamics. Other phenomenological fields, which produce the observed particles, are associated with these fundamental fields by means of a dynamical assumption relating the two fields at very short distances or high energies. Schwinger claims that the phenomenological Lagrangian he obtains is practically independent of the details he assumes in the first place for his fundamental fields. The phenomenological Lagrangian leads to the same successful numerical predictions that several other theories do. This means that by means of present phenomenology alone we are not likely to choose between rival theories or to fix on any fundamental dynamical structure.

It is precisely on this point that a working difference between the extreme S-matrix and field-theoretical points of view will emerge. Bootstrap dynamics assumes that the particles we now see in high-energy physics represent an ultimate level of matter beyond which we are not to penetrate and that a complete dynamical theory can be based on these observed elements. Field theory assumes fundamental localized fields as a substructure lying beneath the particle phenomenology. These fundamental fields, if they are anything more than useful theoretical constructs, are a level of realty with conceptual and physical elements different from those of particles (elementary and composite) and hopefully still to be revealed at higher ergies.



JULIAN SCHWINGER
addresses the seminar

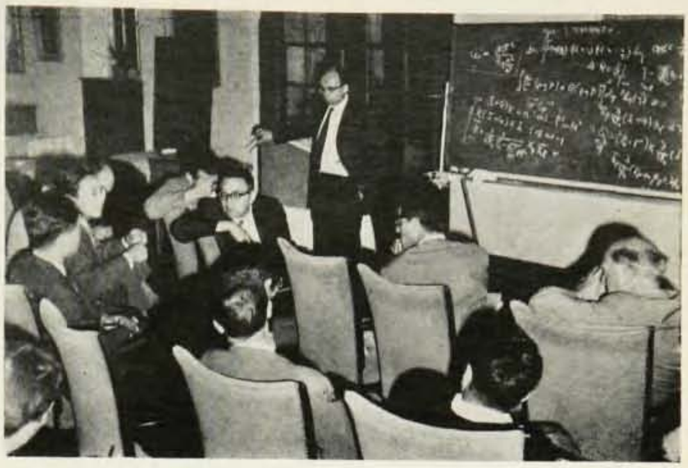
Fundamental and phenomenological fields

The multiplicity of levels of description, referred to above in speaking of fundamental and phenomenological fields, is encountered even in classical field theories, such as turbulence theory. (Quantum field theory is, of course, distinguished by the additional requirement of a particle interpretation. This necessity imposes distinctive and important analytic properties on Green functions and S-matrix elements.) The nonlinearities present in all but the most trivial field theories lead to different "fine-grained" and "coarse-grained" levels of description whose relation to one another is characterized by dimensionless parameters. These scaling parameters can often be very small or very large. It is not unreasonable, therefore, to hope that a unified theory relating different levels of description—or scales of distance or energy—might require certain definite values for coupling constants or mass ratios. In this respect the hopes of quantum field theorists are more ambitious nowadays than they were 15 years ago.

Kazuhiko Nishijima (Illinois) described a dynamical calculation in which the strong interactions defined the weak interactions but the existence of weak interactions imposed definite restrictions on the strong interactions. In this sense weak and strong interactions are partially unified.

Values of fundamental constants

One series of papers at Munich was concerned with the values of renormalization constants. D. Lurié (Dublin) spoke on the equivalence between composite particles and elementary particles whose wave function renormalization Z vanishes. He emphasized the essential role played so far by the cutoff: the interaction tends towards zero as the



A GROUP OF STUMPED PHYSICISTS. Left to right: K. Nishijima, H. Umezawa, M. E. Mayer (head bowed), K. Symanzik (hand to forehead), S. A. Bludman, D. Lurié (standing), H. P. Dürr, Werner Heisenberg. Four men in foreground with backs to camera are not identified.

cutoff tends towards infinity. C. R. Hagen (Rochester) showed that, in many theories, the bare mass must diverge as Z tends to zero, and emphasized the conceptual difficulties involved in assuming that *all* wave-function-renormalization constants vanish. The vanishing of all Z's is supposed to be the field theoretical expression of the bootstrap mechanism. Raymond S. Willey (University of Washington) spoke on the program he has with K. Johnson and M. Baker for obtaining a finite quantum electrodynamics; it now appears as if this objective cannot be realized unless a very special eigenvalue equation is satisfied by the bare electric charge.

Asim O. Barut (Univ. of Colorado at Boulder) was willing to assay the calculation of many coupling constants and masses. The most persistent program of this kind, that of the Heisenberg school, is unconventional enough to work with a degenerate vacuum, an indefinite metric and a noncanonical scheme for quantization. Werner Heisenberg and H. P. Dürr (Max Planck Institute, Munich) described the current status of this program, while H. Stumpf and H. Mitter (Max Planck Institute, Munich) described the computational problems encountered in this nonlinear field theory when, to eliminate light-cone singularities, a noncanonical quantization scheme is used. The Tamm-Dancoff method, as applied to an anharmonic oscillator, is now rather sophisticated and is being extended to field theory. The interpretation of strange particles as "spurion compounds," the concept of the photon as a Goldstone particle associated with dynamical breakdown of isospin symmetry, the appearance of lepton and baryon poles in Green functions of the same field, all led to vigorous and prolonged discussion. Some participants argued that the introduction of a zero-momentum spurion was bound to lead to difficulties with causality and that instead of insisting that strange particles be spurions somehow attached to ordinary particles, Heisenberg's basic symmetry ought now to be enlarged from SU (2) to SU (3). On these matters no definite agreement was reached.

F. Bopp (Munich) spoke at the Munich seminar on a new antiparticle concept. Such a question is interesting in connection with the possibility that, in the PC violation observed in K_2 decay, we see a clash between different C operations defined by different interactions.

The asymetric vacuum

Motivated by known examples of condensed states of matter, Heisenberg and Yoichiro Nambu have made the attractive assumption that observed broken symmetries hide a symmetry of the Lagrangian that is broken only because of an asymmetry of the dynamically stable physical vacuum. A definite consequence of this kind of symmetry breakdown, discussed by S. A. Bludman (University of Pennsylvania), H. Umezawa (Naples) and G. Guralnik (Imperial College), is that massless spinless particles carrying definite quantum numbers must emerge. This comes about formally because, using the commutators of certain formal charge operators and the field operators or using canonical communication relations, one shows that certain current-density operators create such massless spinless states out of the vacuum. Bludman and Guralnik each presented examples emphasizing that, although in particular dynamical calculations (nonrelativistic or cutoff-dependent) such massless particles emerge, this formal application of symmetry considerations does not generally guarantee that these massless particles need be physically observable.

Sudarshan gave a comprehensive and masterful summary of the Munich conference. The author is indebted to him for a copy of this summary, on which this report is based.