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Introductory Remarks

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Introductory remarks

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The title of this meeting, which refers to gauge theories, could equivalently have specified renormalizable quantum field theories. The first quantum field theory arose from the quantization by Dirac, Heisenberg and Pauli of Maxwell's classical theory of electromagnetism. This immediately revealed the basic problem that although the smallness of the fine-structure constant appeared to give an excellent basis for a power-series expansion, corrections to lowest-order calculations gave meaningless infinite results. Quantum electrodynamics (QED) is, of course, an Abelian gauge theory, and the first major triumph of fundamental physics after World War II was the removal of the infinities from the theory by the technique of renormalization developed by Schwinger, Feynman and Dyson, stimulated by the measurement of the Lamb shift and the anomalous magnetic moment of the electron. In the intervening years, especially through the beautiful experiments at Cern on the anomalous magnetic moment of the muon, the agreement between this theory and experiment has been pushed to the extreme technical limits of both measurement and calculation.

Subnuclear physics, as we know it today, was just starting to develop at the time of the formulation of QED to which I have referred, and the early predictions of the existence and properties of pions made by Yukawa, Kemmer and others were all cast in the mould of quantum field theory. However, early experimental work after the War quickly established that the coupling between pions and nucleons was strong. This appeared to make the only method of calculation (the perturbation expansion) quite useless, and for twenty years quantum field theory fell into disuse, not to say disrepute, for the description of subnuclear phenomena. Theorists struggled desperately to find a satisfactory framework for the dynamics of strong interactions. This led to the use of leading-pole approximations, dispersion relations, Regge pole analysis, and such ingenious devices as the Mandelstam representation and the Veneziano model. At best these approaches are largely phenomenological and much of this work has now been forgotten.

By far the most successful progress during this period was made through the application of the theory of Lie groups, exploiting the direct connection between invariance with respect to a group and conservation laws, and the physical realization of the irreducible representations of a group through mass multiplets. The first major advance came in 1957 with the unambiguous observation of parity violation in β decay. This was provoked by the so-called τ–θ puzzle (the two-pion and three-pion decay modes of kaons) and was quickly explained in terms of chiral invariance and two-component neutrinos, leading to the notion of weak interactions mediated by vector bosons. The second turning point came in 1964 with the discovery of Ω^- whose improbable properties had been predicted two years earlier on the basis of group theoretic arguments. In modern language, this established that hadrons are constructed from three types of fractionally charged quarks, carrying three different 'flavours' – electric charge, baryon number and hypercharge (or strangeness).

Field theory made its come-back onto the centre of subnuclear physics in the late 1960s, by a combination of the essential features of QED and these later successes, through the gauging of quantized fields invariant with respect to larger (non-Abelian) groups. This in itself was easy and had been done many years earlier. The renaissance of field theory depended on three further developments within this context, which were each essential to make such a theory directly relevant to experiment. The first of these was the Higgs mechanism which makes it possible simultaneously to break the symmetry, to give masses to all particles, including the intermediate vector bosons, thereby making the interactions of finite range and exorcizing massless Goldstone ghost particles. Secondly, through the renormalization group, it was shown that non-Abelian gauge theories with strong coupling at low energy have an effective coupling at high energies that is weak (asymptotic freedom), making perturbation theory again relevant. Finally, it has been established that such theories are renormalizable. The present volume is concerned with this renaissance – its achievements to date and the possible lines of future development.

The most successful aspect of this development is the electroweak theory of QED and weak interactions, proposed independently by Salam and by Weinberg in 1968, which combines the electrodynamic and weak properties of leptons in a single non-Abelian gauge theory. As demonstrated by Glashow, the extension of the theory to include hadrons requires a fourth type of quark, carrying a fourth 'flavour', charm. Evidence for charmed particles has accumulated since 1974 and a great variety of weak interaction phenomena have been explained in terms of a single parameter, the Weinberg angle. Papers in this volume describe the current status of this parameterization and of the preparations at Cern to find the intermediate vector bosons implied by the theory, through the proton–antiproton collider.

With regard to the strong interactions it is now generally believed that the four-flavoured quarks each come in three 'colours' and that the strong forces arise through the gauging of the three-dimensional unitary symmetry associated with colour. This non-Abelian theory is known as quantumchromodynamics (QCD) in analogy with QED. This is less well established than the electroweak theory and there are papers on its theoretical and experimental status.

Moving to much more speculative ground, grand unified theories are also considered which aim at combining the strong and electroweak interactions in a still larger group, leading to proton instability. Finally, after excursions into the implications of these ideas in cosmology and the theory of monopoles, there is a discussion of the possibilities of including gravity in the total picture.

Both experimentally and theoretically the subject is in a very exciting phase, which is reflected in the papers contained in this volume.