TRENDS IN PHYSICS
Istanbul, 7-11 September 1981

High Energy and Particle Physics: Where Do We Stand?

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It is undeniable that the past ten years have produced an impressive list of important results in the field of High Energy and Particle Physics.

From the pioneering Stanford Experiments (1967) on the deep structure of the proton to the recent confirmations of the unifying theory of electromagnetic and weak interactions (the electroweak theory of Glashow, Salam and Weinberg), our knowledge of this fascinating area of scientific endeavour has registered considerable advances.

Let me briefly review some of the most striking and unchallenged achievements of Particle Physics in the past decade.

(i) Quarks

Practically nobody denies that the notion of quarks plays a central role in the description of the physics of the so-called strong interaction (or hadronic physics). The conviction that quarks are here to stay is largely the result of the discovery of new quark types in the J/ψ and Υ mesons, in the charmed particles and most recently in the "beautiful" mesons.

Particle spectroscopy, with its several hundred states, can be completely described in terms of the dynamics of bound quark-antiquark and three-quark states. No compelling evidence has so far been produced in favour of the existence of any states that cannot be described in such a simple fashion. The intricate and seemingly wild particle zoo has found in quarks a very effective ordering principle.

But what confers on the quark idea, the tremendous appeal that it possesses in present-day high energy physics is not only its success in accounting for particle spectra, but also its deep relevance to those cataclysmic interactions that were first studied at the Stanford Linear Accelerator Center. These high energy processes, that are called "deep inelastic scatterings", are the modern analogue of the celebrated Rutherford experiments that gave the first direct evidence for the atomic nucleus.

Beams of very high energy electrons, muons and neutrinos (the leptons), are projected into a nuclear target, and only the leptons emerging with large transfers of energy and momentum are observed. We know that in such interactions something totally shattering happens to the target: tens of high energy particles (mostly pions) are ejected from it in a seemingly chaotic fashion. Nevertheless, when we look at the outgoing leptons only, everything happens as if the incoming particles were scattered on minuscule (point-like) objects moving almost freely inside the extended nucleons. And if we try and determine their electromagnetic and weak charges, we find them identical with those that we had to postulate to explain the particle spectra.

Low and high energy particle phenomena find thus a most remarkable unification.

(ii) Colour

As soon as one tries to develop a simple particle theory based on the quark idea, the initial enthusiasm, inevitably, begins to cool owing to a number of bothersome facts: the baryon wave function should be spatially antisymmetric as required by the Pauli principle, and not symmetric as observed experimentally; the e^+e^- annihilation cross section experimentally turns out to be about three times larger than expected; similar troubles afflict the decay $\pi^0 \to 2\gamma$, and so on.

Do we have to go through some epicyclic strategy to fix things up? No, the solution indeed is very simple; it turns out to be *colour*. We need only assume that quarks, these point-like Dirac particles, come in three different colours (red, white and blue, for instance), and all our previous headaches disappear. We can then understand those facts that were irreducible to a simple (colourless) explanation.

More than that, we have thereby discovered a *new*, real symmetry of particle physics, the unitary group SU(3) of colour. Note that this SU(3) is exact, as opposed to the celebrated SU(3) of the "eightfold way", which was only approximate and whose physical relevance has been largely de-emphasized in the past few years.

(iii) Gauge-symmetries

The discovery ('t Hooft 1972) that a quantum field theory with a gauge symmetry group (and with gauge-vector mesons) is renormalizable even when the symmetry is broken by the vacuum state (spontaneous breaking), has given an enormous impulse to the study of such theories and to their applications in the world of high energy physics. Today we have strong confidence that the interactions among particles (leaving out gravitation which is also incidentally a gauge interaction) can all be described by gauge (Yang-Mills) field theories (either exact or spontaneously broken), where the gauge-symmetry group contains at least:

$$SU(3)_{colour} \times [SU(2) \times U(1)]_{electroweak}$$

Such is the "standard group", a very simple symmetry structure which appears to govern the multitude of bizarre and fascinating phenomena of the high energy world. It is, I believe, the triumph of high energy physics of the '70's to have handed over to this decade such an impressive and beautiful legacy.

But Now

Should we then consider (as Jolly, the teacher of Max Planck, at the end of the last century) that physics has come to an end, and that we finally possess the keys to explain all high energy physics phenomena?

Without considering the new energy domains that the machines of the '80's (the colliders, Isabelle, LEP, etc.) will open up, leading almost certainly to the discovery of entirely new phenomena, the answer, even remaining within the known world, must be definitely negative.

It is my conviction that much more than technical break-throughs are needed to transform our *ideas* about quarks and gauge-symmetries into a *real theory* of particle physics.

As the previous statement is certainly controversial (not many people appear in fact to agree with it) I shall try to explain the reasons for my skepticism vis à vis the great optimism which seems to pervade the high energy physics community.

The Problems

Let me enumerate a few of the difficulties and paradoxes that have been with us these past years, and which so far have resisted any satisfactory explanation.

(α) *Quark Confinement*

Quarks are great, they simplify a lot of things, but who has ever seen a real, isolated quark? While our theories treat quarks and leptons almost identically, their physical manifestations seem radically different. Why? The conventional answer is that, unlike leptons, quarks are confined, i.e. they cannot be separated from the colour-neutral states that they form (the quark-antiquark and the three-quark states that populate the hadronic world). Here we have a very strange notion: a "constituent" which is fundamentally inseparable from its "compound". The long road that from macroscopic objects, passing through molecules, atoms and nuclei, brought us to protons, neutrons and electrons, seems to stop with quarks! How is that possible? Nobody knows, even though some recent calculations with Quantum Chromodynamics (QCD) on a lattice give some encouraging indications. But the calculations involved are so terribly complicated, that one wonders how the beautiful simplicity of the quark-model of hadrons could arise from such a contrived dynamical scheme.

(β) *Gluons*

In the popular theoretical scheme of today (the QCD paradigm), in addition to quarks one should also have eight coloured (perhaps confined) vector mesons, the gluons. These new dynamical degrees of freedom are then expected to generate a very rich spectrum of colourless states, much in the same way as quarks are known to produce the great variety of hadronic particles, But up to now, no firm evidence has been produced for the existence of such states, and perhaps naively (but probably truthfully) we might conclude that gluons are unlikely to have the same dynamics as quarks. And, if this conclusion is correct, we must admit that we are still missing some really fundamental notion.

Many other difficulties afflict those who try to account *quantitatively* for the observations in high energy physics; it is my feeling that all can be traced to α and β above. What then can we conclude? To me it seems necessary to admit that whilst we have met with remarkable success in isolating many profound and important aspects of particle physics, like quarks, colour and the "standard group", we are still unable to grasp the origin of the bizarre and tantalizing phenomena of quark confinement.

It is in the successful effort to understand this, that we may expect far reaching progress in the future.

Against this background, the Symposium led by **P.A.M. Dirac, A. Salam and V. Weisskopf** which will take place in Istanbul on the Wednesday morning (9 Sept.) promises to be exceptionally rewarding. Remembering also Dirac's distrustful attitude towards renormalization processes (*EN* **8** (1977) 10) one can be confident that the mood will not be one of complacency. (Ed.)

Quantum Electronics

Changes in Emphasis

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Although research in quantum electronics devoted to atoms and molecules is still very active, it has shown no spectacular breakthroughs of late, whereas it seems that interest in solids is expanding. This can be attributed to several causes. First, the methods of quantum electronics and non-linear spectroscopy are now highly developed and solid state physicists are using them on a daily basis; second, as simple systems are well understood, most effort is directed toward the more complex ones, which might prove also to be richer. Finally one can point to the influence of device applications. A number of problems encountered in modern components for microelectronics and microoptonics are related to the intrinsic limitations in the response of solids to an electromagnetic perturbation. As examples one can quote those related to: ballistic carriers dynamics, ultra-fast relaxation of energy and phase, intrinsic or defect-related saturated absorption and dispersion ... etc. Investigations of these phenomena require new tools, some of which belong to the field of quantum electronics. Research tendencies that can be singled out are indicated in the Table. Special mention must also be made of fibre optics, integrated optics and related areas which, because of their huge development potential, command an intense research effort.

Two topics have attracted a lot of interest recently, both because they give rise to new concepts in quantum electronics and because of their possible applications. These are phase conjugation and optical bistability, where intense experimental work on gases, liquids and solids as well as theroretical studies are making headway.

Laser Developments

Turning now to recent achievements, in the domain of new lasers and new coherent sources, significant progress has been made with tunable near-infrared lasers. Two types are very promising: the colour centre laser (F_2^+) in alkali-halides, which now covers the entire range 0.8 µm - 2 µm, and the transition-metal-doped lasers using MgF_2 or MgO as matrix, and covering the 1 µm -2 µm range. Both types can sustain CW-action and operate at liquid nitrogen temperature. Recent work on NaF crystals however indicates that operation at room temperature may be possible. Note that F-centre lasers can be mode-locked and soliton propagation in an optical fibre has been observed at 1.55 µm using such a mode-locked laser.

An intense effort is being made to push coherent sources towards shorter wavelengths and laser action in the near UV from a YLF:Ce solid state laser has recently been observed. In gases, charge transfer lasers are being investigated (both in Europe: Hull University and MPI-Garching, and in the USA), and significant gain at the hydrogen Lyman-α line has been reported recently by a group at Cornell University. In another approach, the output frequencies of known lasers can be shifted toward the UV by frequency mixing in metal vapours or rare gases. Very short wavelength sources can be obtained in this way; for instance, third harmonic generaton of dye laser output can generate tunable radiation in the 1050 Å - 1470 Å range (Bielefeld University Germany) and that of KrF lasers between 823 Å and 833 Å.

On the other hand, work in the medium infrared (10 µm - 50 µm) seems to be less intense than a few years ago, with one exception — that of the free-electron laser. It was believed that in the Compton regime, only 1% of the kinetic energy of the electrons could be converted into radiation, but new concepts are being developed aimed at increasing the energy conversion and experiments are under way to verify their applicability.

Spectroscopic investigations on atoms and molecules form now well defined fields with their own specialized meetings and journals. The development of new methods for ultra-high resolution still sustains interest and new approaches such as utilizing the picosecond Raman gain or the inverse Raman effect (which is purely coherent) are being considered. The odd properties of Rydberg atoms can lead to interesting studies, not only for fundamental physics.

GENERAL TENDENCIES IN THE RESEARCH INTEREST

Volume	→	Surface
Crystalline	→	Disordered, Amorphous
Bulk semiconductors	→	Organics Low dimensionality
Statics	→	Dynamics Transient phenomena