24: New Directions in Particle Theory*

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Abstract. A personal selection of theoretical topics, and *not* a summary, is presented.

1 Particle theory 1967-1997

Particle theory, the subject of this talk, has evolved in an incredible way during the thirty or so years of my own scientific life. It has grown in complexity, diversity, and mathematical sophistication, much beyond what I could ever have expected. Progress has been enormous, as exemplified by the overwhelming success of the Standard Model. Areas of particle theory have a growing (excessive?) role in interpreting, suggesting (biasing?) particle-physics experiments. Other areas are daring beyond imagination, look somewhat (too?) pretentious, and, to some of us, somewhat (too?) remote from the real world.

A corollary of what precedes is that the field is hard to follow in its entirety. The biased sample of subjects I will discuss below should give an idea of what I mean. Fortunately, the organizers have limited to 45' the length of my talk (further squeezed by a marriage ...) and to 10 pages its write-up. In order to meet these space-time constraints I will apply three theoretical "cuts": familiarity, novelty, interdisciplinarity.

Can we see a common denominator in the trends characterizing modern particle theory? I claim that there is at least one: *the idea and the use of effective theories*. Let me explain.

In spite of its astonishing successes, most theorists no longer regard Quantum Field Theory (QFT), our present tool to check particle data against theory, as an internally consistent, final framework, mostly because of its ultraviolet (UV) divergences. Although we have learned how to live with renormalization, infinities are conceptually highly unsatisfactory and, from a more practical viewpoint, limit predictivity. All this without mentioning the fact that we do not know how to quantize General Relativity, the classical theory of gravitational phenomena. My own attitude on this is summarized as:

**The final theory must be finite,
but a finite theory is not necessarily the final one.**

* Dedicated to the memory of Vladimir Gribov, who inspired much of my early research, and whose unsurpassed passion for physics is still so alive in my memory.

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As shown by S. Weinberg in his recent books on QFT [1], the familiar renormalizable quantum field theories emerge anyway as the only possible *low-energy effective theories* that correctly incorporate the constraints of special relativity and quantum mechanics. Gauge theories are needed to describe spin 1 particles, general-covariant theories for including spin up to 2. The relevant questions in particle theory then become:

- Which is the effective theory that describes a particular class of HEP phenomena?
- Which are the symmetries that determine its dynamics?
- Which is the structure (degeneracy, symmetry, etc.) of its ground state?
- Which are its relevant/irrelevant degrees of freedom?
- Can we integrate out the latter and derive the effective dynamics of the former?
- Can we solve that effective dynamics and make contact with the data?

My presentation will illustrate what precedes through specific examples taken from gauge theories of non-gravitational phenomena (Section 2), from theories of gravity/cosmology (Section 3), and from the most recent attempts to a Grand-Synthesis (Section 4).

2 Gauge theories of non-gravitational phenomena

A renormalizable chiral gauge theory, known as the Standard Model (SM), appears to describe well all non-gravitational phenomena. Nonetheless, the SM is still facing difficult, unsolved theoretical problems, such as the large-distance behaviour of QCD, or the nature of the EW phase transition at finite temperature. The way the theoretical effort is being directed these days is shown in Fig. 1, in which the vertical axis denotes the amount of supersymmetry in the gauge theory under study. Two arrows order points on that axis. The “relevance” arrow goes upwards, from $N = 4$ to $N = 0$, the non-supersymmetric case, while the arrow of “tractability” goes in the opposite direction: formal theorists love supersymmetry because it makes theoretical analysis much easier. Unfortunately, even if there are indications that Nature too likes SUSY, this must be largely broken, and the relevance to the real world of understanding SUSY dynamics is still to be proved. My presentation in this section will follow the direction of increasing (decreasing) tractability (relevance).

2.1 $N = 0$

I picked up five subjects, according to the criteria I explained and will briefly comment on them in turn.