Stringing a theory of the Universe

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November 2002

Fundamental physics today is comprised of two Standard Models (SM), one for the theory of Elementary Particles and the other for Cosmology. Both models have been tested to progressively greater accuracy, bringing theory and experiment closer at every step. The cosmology forefront is much in the news as space based telescopes have opened up new frontiers of observation. It has been shown that the tiny ripples in the microwave radiation that fills all space, obey precisely the model required to explain the formation of galaxies. In Particle Physics only the so-called Higgs particle needs to be discovered, everything else is modeled accurately to parts in a million. Nevertheless, one needs to be cautioned against any sense of finality in the knowledge of physics. Towards the end of the nineteenth century, with the consolidation of Newtonian mechanics, the end of physics appeared to have been reached. The advent of Special Relativity and Quantum Mechanics all but blew away that complacence. One should therefore take stock of what is appealing and elegant about our present theories, as also what may hold the key to their further development.

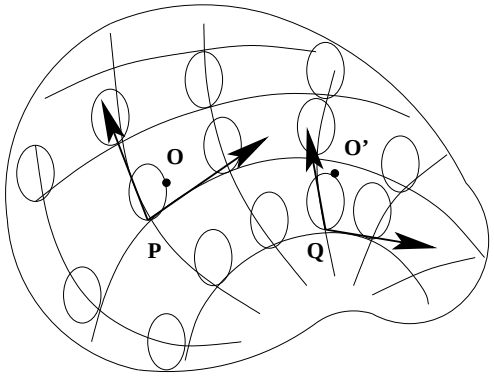

Figure 1: This shows a curved surface with a curvilinear coordinate system. Local reference axes at grid points P and at Q have different scalings. The circles shown at each grid point do not belong to the curved surface itself, but represent an auxiliary internal space. For the internal space the origin can be independently chosen at different points, *e.g.,* O at P and O' at Q.

Fundamental Forces: Unity or Diversity?

Let us note two outstanding puzzles. According to Big Bang hypothesis, the Universe was compressed to stupendous densities at the early epochs of the Universe. Under such conditions Gravity is expected to obey the principles of Quantum Mechanics. But despite several ingenious attempts, we do not yet have a consistent theory of Quantum Gravity. Secondly, there is a curiosity with the nuclear forces. According to the well-known Glashow-Salam-Weinberg theory, Electromagnetic force is a descendent of a more basic *Electroweak* force combining both the Electromagnetic and the Weak nuclear force, while the Strong force is independent . These three force laws, which constitute the Standard Model, have an identical, almost repetitive structure. These apparently different force laws have the same underlying principle (like inverse square law for both Gravity and Electricity). What is more curious, these laws can be understood by a geometric principle which seems identical in spirit to that obeyed by Gravity, although different in specific form.

To understand this similarity of the underlying principle, remember that Special Relativity stipulates a team of observers spread across space utilising identical rods and clocks. But the principle of General Relativity states that Gravity is correctly obtained by demanding that its equations are invariant even if the members of the same team use differently scaled rods and clocks. This is referred to as *gauge* (*i.e.,* scale) *invariance*.

The Electroweak and Strong forces too obey such

gauge invariance. In short, all the four forces of nature obey separate gauge invariances. This requires deeper understanding. Further, the invariance of the gravitational force is tied to space-time frames, while that of the nuclear forces is tied to a hypothetical *internal space* (see Fig. 1).

Towards extra dimensions

It turns out that the seeming puzzle can be explained if one assumes that the hypothetical internal space is actually just like the real space, only that its physical size is microscopic. Indeed, it was Kaluza and Klein who first showed during 1920's and 30's that the electric charge inherent to matter was a result of the curvature of this extra dimension, just as gravity is a consequence of curvature of the real space-time continuum. However, for a long time this idea could not be confirmed. It was in the early 1980's, that these ideas were revived with the advent of the String Theory of matter. This theory postulates that the fundamental entities behind the façade of common matter are strings, which obey both the principles of Relativity as well as Quantum Mechanics. The theory also introduced another appealing idea of *Supersymmetry* a concept difficult to explain in the short space here. But what is important is that for this idea of supersymmetry to be true, the String Theory had to be formulated in a space-time continuum with 10 dimensions! It has been shown that both General Relativity as well as Gauge theory are special cases of this physics of Superstring. The elegance of String Theory resides in the fact that all the forces of nature can be explained purely from geometric considerations without assigning separate charges to separate forces. It also ensures a consistent Quantum behaviour of Gravity. Now this String Theory suggests novel kind of geometries known as *brane* worlds (from membrane) and we could be confined to such a brane. Extra dimensions beyond our brane would be possible to probe with high energy accelerators. There could be several branes similar to the one on which we live; and perhaps the Big Bang separated such worlds out, leaving little information in our present world which exists at far lower energies compared to that at the beginning. Of course, the theory of strings seems to have only found a mathematical paradise. For, we do not actually live in 10 dimensions. So how do we explain this mismatch? There are several known examples in which a universal theory remains hidden. For instance, the friction and elastic forces are manifestations of Electromagnetism, which requires only one universal number, the value of the electron's charge. But each substance requires different values of friction and elastic coefficients, because the underlying universal force is hidden. Perhaps the dimensionality mystery will be similarly tackled.

Current research at IIT Bombay focuses on unification of forces using early Cosmology as the testing ground as also the mathematics of String Theory. We have studied proposals that will unify the nuclear forces into a more elegant theory, and also identified mechanisms within them that can explain one of the outstanding cosmic mysteries, the prevalence of matter and the absence of anti-matter, the so called baryon-asymmetry of the Universe. Further work is proposed to derive such unified theories from brane compactification of String Theory. Future prospects in this field are exciting, as cosmological data are only now becoming easily available.

References

[1] General reference for many topics covered here is S. Weinberg, "*Dreams of a Final Theory*" Vintage Books, (1993)

[2] Some of the topics covered here are available as popular articles from the author's website `http://khwarizmi.phy.iitb.ac.in`