

## Five great 'Unsolved' problems in Theoretical Physics

by Manjil Saikia - Monday, August 27, 2012

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Theoretical Physics, considered one of the most thrilling, exciting and pain staking branches in all of sciences, deals with explaining the mysteries of the universe in the beautiful complexities of mathematics as it has been the language of physicists from time immemorial. The brilliant minds deeply immersed in this field and spending their sleepless nights in search of truth form a different class of scientists, known as theoretical physicists.

In this short piece, an attempt has been made to highlight some of the most important and interestingly *unsolved* problems in theoretical physics till date which has made some of the finest minds of science across the globe go restless especially from the turn of the last century.

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Just tracing back history a little, we encounter the first revolution in physics by Sir Issac Newton in this magnificent book *Philosophiae Naturalis Principia Mathematica* in 1687. Then began the next revolution by Max Plank in 1900 with the advent of a new theory of atomic world viz. *The Quantum Theory*. Not even a few years had been passed after the discovery of Quantum theory, when there came into limelight the little known clerk at the Swiss patent office, Albert Einstein, to steal the show making him more than famous in the scientific arena. Einstein, working just by himself, staying apart from the complexities of the world, gave some of the most beautiful theories on fundamental principles of the universe which he named as *Special Theory of Relativity*, *General Theory of Relativity*, *Photoelectric Effect* etc. It is basically on the strong foundations of these supremely elegant theories that most of modern physics rests upon. It also needs special mention here that whenever the topic of fundamental problems of theoretical physics had been raised *unification* is the word that has always made the grey-haired ones scratch their heads and rethink again on everything. The first genius to establish the concept of unification was James Clerk Maxwell in his beautiful equations unifying electricity and magnetism more specifically known as *Electromagnetic Theory*. With it ignited the era of unification and has been prevailing in the whole of physics since then. Such as in the case of Einstein's special theory of relativity where he combined space and time in one single thread, then again unifying gravity with STR, leading to the general theory of relativity. Some more important additions to this unification trend were made in the past century finally coming to an ultimate predicted solution that would unify all of nature under one single theory and more precisely by one single equation known as the *Theory of everything*.

Physics has survived a long time without that unified theory. The reason is that as far as experiment is concerned, we have been able to divide the world into two realms. In the atomic realm, where quantum physics reigns, we can usually ignore gravity. We can treat space and time as much as Newton did- as an unchanging background. The other realm is that of gravitation and cosmology in which the quantum picture doesn't come into mind.

But solution to the above problems must be there and in order to see the ultimate solution physicists must

solve some of the important problems in that direction. The first problem in this arena is:

**Problem 1:** *Combine General relativity and Quantum Theory into a single theory that can claim to be the complete theory of nature. This is called the problem of Quantum gravity.*

General theory of relativity and quantum theory have both proved to be very much successful to a great extent in their own realms; one in explaining the origin and mechanism of the universe as a whole and the other the complex atomic world. But both have to deal with the inherent problem of *infinities* which might be a way of nature to punish the imprudent theorists who like to play with her. In GTR infinities arise when we try to penetrate inside a black hole and the same occurs in quantum mechanics when we try to describe fields such as electromagnetic fields using quantum theory. The problem is that the electric and magnetic fields have values at every point in space which means there are infinite numbers of variables fluctuating uncontrollably even in a finite volume. This makes clumsy mathematical equations which are nearly impossible to handle in order to predict the strength of the force at a particular point. In this regard there has been a hope from the last few decades that if we somehow combine gravity with quantum mechanics then the problem of the fluctuations and infinities will end and we will have a finite theory known as quantum gravity.

**Problem 2:** *Resolve the problems in the foundations of quantum mechanics, either by making sense of the theory as it stands or by inventing a new theory that does make sense.*

There are several different ways one might do this:

1. Provide a sensible language for the theory, one that resolves all puzzles like the ones just mentioned and incorporates the division of the world into system and observer as the feature of the theory
2. Find a new interpretation of the theory- a new way of reading the equations- that is realist, so that measurement and observation play an important role in the description of fundamental reality.
3. Invent a new theory one that gives a deeper understanding of nature than quantum mechanics does.

**Problem 3:** *Determine whether or not the various particles and forces can be unified in a theory that explains them all as manifestations of a single, fundamental entity.*

Over the past century our physical description of the universe has simplified quite a bit. The particle picture of the world consisting of mainly quarks and leptons has gained much popularity. In this regard the Standard Model of particle physics has been the most successful both theoretically and experimentally. But the problem lies in the explanation of the constants of the theory. It seems puzzling that there are about twenty free constants in the model which are freely specifiable. The results of these equations are independent of the values of the constants taken, and that is a tremendous embarrassment to the theory.

**Problem 4:** *Explain how the values of the free constants in the standard model of particle physics are chosen in nature.*

The explanation behind the fourth problem is an extension of the third problem. It mainly deals with

finding perfect physical reasoning behind the value of the free constants in the standard model as it is very essential for a complete physical theory.

**Problem 5:** *Explain dark matter and dark energy. Or, if they don't exist, determine how and why gravity is modified on large scales. More generally, explain why the constants of the standard model of cosmology, including dark energy, have the values they do.*

The fifth great problem is similar to the previous problem. Just as in particle physics there is the Standard model of elementary particles, in cosmology its counterpart is the Standard model of Cosmology and it too has about fifteen freely specifiable constants which denotes among other things, the density of different kinds of matter, energy and the expansion rate. No one knows why these constants have the values they do just as in particle physics. So solving it has been a thing that has been keeping physicists up at night.

\* This article has been inspired by a book which I recently read by Prof. Lee Smolin who is a pioneering theoretical physicist and founder of the Perimeter Institute of Theoretical Physics.

[This article has been written by our Consulting Editor Madhurrya P. Talukdar]

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