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Heterotic string model with gauge symmetry E8xE8'

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1 Introduction

The Standard Model of particle physics is the theory describing three of the four known fundamental forces (the electromagnetic, weak, and strong interactions, and not including the gravitational force) in the universe, as well as classifying all known elementary particles. String theory is a candidate for theory of everything that describes all fundamental forces and forms of matter.

In this theory particles are presented by as one-dimensional object called strings. String theory describes how strings propagate through space and interact with each other. On distance scales larger than the string scale, a string will look just like an ordinary particle, with its mass, charge, and other properties determined by the vibrational state of the string. In this way, all of the different elementary particles may be viewed as vibrating strings.

Superstring theory includes supersymmetry which allows to involve into consideration also fermion strings. There are five versions of superstring theories.

The type I string has one supersymmetry in the ten-dimensional spacetime (16 supercharges). This theory is special in the spacetime that it is based on unoriented open and closed strings, while the rest of theories are based on oriented closed strings.

The type II string theories have two supersymmetries in the ten-dimensional space-time (32 supercharges). There are actually two kinds of type II strings called type IIA and type IIB. The difference between these theories is mainly that the IIA theory is non-chiral (parity conserving) while the IIB theory is chiral (parity violating).

The heterotic string theories are based on a peculiar hybrid of a type I superstring and a bosonic string. There are two kinds of heterotic strings differing in their ten-dimensional gauge groups: the heterotic $E_8 \times E_8$ string and the heterotic SO(32) string. (The name heterotic SO(32) is slightly inaccurate since among the SO(32) Lie groups, string theory singles out a quotient Spin(32)/Z2 that is not equivalent to SO(32).)

2 Compactification and symmetry breaking

Initially, symmetry is supposed between ordinary world(E8) and mirror world(E8'). 26 dimensional strings are reduced to 10-dimensional gravity with the $E_8 \times E_8'$ gauge group by compactification of 16 internal dimensions on the torus.

In order to make contact between the string theories and real world one must understand how six of the spatial dimensions compactify to a small leaving four four flat dimensions, how the gauge group is broken down to a group of Standart Model. Gauge symmetry is broken by compactification into Calabi-Yau manifolds or orbifolds.

Calabi-Yau manifolds are the Kahler manifolds which admit a Ricci flat metric(so that they have SU(3) holonomy). Compactification on Calabi–Yau n-folds are important because they leave some of the original supersymmetry unbroken(if the holonomy is the full SU(3)). These Calabi-Yau compactifications, produce for each manifold K, a consistent string vacuum, for which the gauge group is no larger than $E_6 \times E_8'$, and N $= 1$ supersymmetry is preserved. In general Calabi-Yau manifolds have many free parameters (moduli) which determine their size and shape.

This leads to the existence of a huge number of false vacuums, this problem is known as the landscape of string theory.

Orbifold T_6/G is the quotient space of T_6 by a finite isometry group G which acts with fixed points. We compactify on tori divided by the action of a discrete group. This allow us to break gauge group and arrive at different low-energy predictions(Orbifolds are probably special limits of Calabi Yau spaces).

The mechanism of gauge symmetry breaking as a result of compactification on Calabi – Yau manifolds or orbifolds leads to the prediction of homotopically stable solutions with a mass $m_\alpha = r_c/\alpha'$, where r_c – radius of compactification, α' – string tension.

The homotopically stable particles are "sterile" with respect to the charges of strong, weak, and electromagnetic interactions and participate only in the gravitational interaction. Therefore the possibilities of verifying the existence of these particles are related exclusively to their cosmological manifestations.

After compactification E8 is broken to E6 and E8' remains unbroken. Therefore symmetry between "ordinary" and "mirror" world is broken, and it leads to existence of "shadow" world which interacts with ordinary matter only by gravity.

3 Generations of fermions

The Eulerian characteristic of the topology of compactified 6 dimensions determines the number of generations of quarks and leptons.

To calculate the number of generations predicted by the theory, we must first calculate the number of massless particles. The 10-dimensional Klein-Gordon operator:

$\Box_{10}\psi = (\Box_4 + \Box_6)\psi = 0$

In general,$\Box_6$ will have eigenvalues denoted by m^2, that is, $\Box_6\psi_m = m^2\psi_m$ so that wave equation becomes

$(\Box_4 + m^2)\psi_m = 0$

We are interested in the massless sector in four dimensions, so we want to keep only the zero eigenvalues of the $\Box_6$ operator. Thus,

$\Box_4\psi = \Box_6\psi$

It means that the four-dimensional fermions are massless. And it also means that ψ is a harmonic form in six dimensions. Therefore the number of massless modes in four dimensions will be related to the number of harmonic forms that we can write for the six dimensions manifold. Thus, topological arguments alone should give the number of generations. It is expected that the number of generations is a topological number because of the Dirac index theorem. We know that the solutions of the Dirac equation can, in general, have zero modes:

$i\not{D}\psi = 0$

In fact, the index of this operator is equal 10 the difference between the positive and negative chiralilies of the zero modes:

$Index(\not{D}) = n_+ - n_-$

But the Dirac index is also equal to the generation number, because we will be considering only fermions of one specific chirality. Thus, the precise relation between the generation number and the Dirac index, or the Euler number, is

Generation number $= \frac{1}{2}|\chi(M)|$

For example, one will consider the discrete symmetry group $Z_5 \times Z_5$ which has 25 generators. Thus, the Euler number of this new manifold is

$\chi(M) = \frac{-200}{25} = -8$

which predicts four generations.

4 Inflation

There are two different versions of string inflation. In the first version, modular inflation, the inflaton field is associated with one of the moduli, the scalar fields which are already present in the KKLT construction. In the second version, the inflaton is related to the distance between branes moving in the compactified space.

5 Baryogenesis. Affleck – Dine – Linde mechanism

Baryon asymmetry can be explained by the processes with the B- and CP-violation.

Affleck – Dyne – Linde mechanism is considered in the model which is consistent supersymmetry. New hypothetical scalar fields(SUSY-partners of ordinary particles) carries the baryon(lepton) number. Through interactions with the inflaton field CP-violating and B-violating effects can be introduced. As the scalar particles decay to fermions, the net baryon number the scalars carry can be converted into an ordinary baryon excess. The Affleck – Dine – Linde mechanism is an example of non-thermal baryogenesis.

6 Dark matter

After symmetry breaking between ordinary and mirror world appears "shadow" world which consist 248 fields of matter and of interactions which are connected with ordinary particles only by gravity. They may be candidates for the dark matter.

Contribution to the dark matter can give also 4th generation of heavy neutrino and neutralino which appears in the supersymmetry theories.

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