Introduction to Supersymmetry

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1 Abstract

Particle Physics is the study of matter at the smallest scales that can be accessed by experiment. Currently energy scales are as high as $100GeV$ which corresponds to distances of $10^{-16}cm$ (recall that the atomic scale is about $10^{-9}cm$ and the nucleus is about $10^{-13}cm$). Our understanding of Nature up to this scale is excellent[1]. Indeed it must be one of the most successful and accurate scientific theories and goes by the least impressive name "The Standard Model of Elementary Particle Physics". The mathematical framework for such a theory is a relativistic quantum field theory and in particular a quantum gauge theory.

There are two essential ingredients into relativistic quantum field theories: Special relativity and quantum mechanics. The success of special relativity and quantum mechanics are particularly astounding. In some sense what our understanding of particle physics has taught us is that reality is ultimately ruled by quantum mechanics and the Lorentz group is the most fundamental structure we know about spacetime.

Quantum mechanics remains largely untouched in modern theoretical physics. However mathematically there is something deeper than the Lorentz Lie-algebra. This is the super-Lorentz algebra or simply supersymmetry. It is possible to construct interacting relativistic quantum field theories whose spacetime symmetry group is larger than the Lorentz group. These theories are called supersymmetric and exhibit a novel kind of symmetry where Fermions and Bosons are related to each other.

Supersymmetric theories turn out to be very interesting. Since they have more and deeper symmetries they are generally more tractable to solve quantum mechanically. Indeed almost all theoretical progress in understanding gauge theories such as those that arise in the Standard Model have come through studying their supersymmetric cousins. Supersymmetry has also grown-up hand in hand with String Theory but it is logically independent. However the successes of String Theory have also been brought using supersymmetry and hence supersymmetry has, along with String Theory, become a central theme in modern theoretical particle physics.

Beyond the abstract mathematical and theoretical beauty of supersymmetry there are phenomenological reasons studying supersymmetric extensions of the

[1]This ignores important issues that arise in large and complex systems such as those that are studied in condensed matter physics.

Standard Model. There is currently a great deal of interest focused on the LHC (Large Hadron Collider) in CERN. The great hope is that new physics, beyond that predicted by the Standard Model, will be observed. One of the main ideas, in fact probably the most popular, is that supersymmetry will be observed.

2 Outline

In these three lectures we will aim to introduce supersymmetry in gauge theories. We will not have time to cover as much as we'd like. In particular we will not construct supersymmetric versions of QCD or the standard model. We will restrict our attention to the fundamentals of supersymmetry and construct supersymmetric versions of pure glue: QCD with no quarks. The idea here is to present the basics which can then be followed up by further theoretical or phenomenological study, according to taste. Roughly speaking the three lectures will be on the following:

- Lorentz Algebra, Clifford Algebra's and Spinors
- Supersymmetry and its consequences
- Super-Yang-Mills.

There is a considerable literature on Supersymmetry. In the bibliography I list more extensive versions of my lecture notes [1,2] from courses given at King's College London upon which this course is based. I also list three classic books [3,4,5] but by now there are many others such as [6].

References

[1] N. Lambert, *Supersymmetry*, Lecture notes from King's College London:
www.mth.kcl.ac.uk/∼lambert/SUSY.pdf

[2] N. Lambert, *Supersymmetry and Gauge Theory*, Lecture notes from King's College London:
www.mth.kcl.ac.uk/∼lambert/SUSYGaugeTheory.pdf

[3] P. Freund, *Introduction to Supersymmetry*, Cambridge University Press, 1988.

[4] J. Wess and J. Bagger, *Supersymmetry and Supergravity*, Princeton University Press, 1992.

[5] P. West, *Introduction to Supersymmetry*, Word Scientific, Singapure, 1987.

[6] S. Weinberg, *The Quantum Theory of Fields, Vols III*, Cambridge University Press, 1995.