PURDUE UNIVERSITY

LECTURE NOTES IN PHYSICS

GUTS, SUSY AND SUSYGUTS

by

T. E. Clark

Physics Department
Purdue University
West Lafayette, Indiana 47907

1983

PURDUE UNIVERSITY

LECTURE NOTES IN PHYSICS

GUTS, SUSY AND SUSYGUTS

by

T.E. Clark

Physics Department
Purdue University
West Lafayette, IN 47907

1983

Preface

These are the lecture notes for an introductory course in grand unified theories and supersymmetry given at Purdue University during the Spring semester in 1982 and 1983. The purpose of the course was to acquaint the students with the use of symmetries in describing elementary particle interactions. My aim was to present this within the framework of specific examples such as the SU(2) x U(1) Glashow Weinberg Salam model. The effort was spent in constructing classically invariant actions given the symmetry transformations of the fields and in determining how the standard model elementary particles fit into these schemes. When highly technical subjects, such as the renormalization group equation, were discussed it was attempted to be done in a fairly self-contained manner. The students were assumed to have only a cultural knowledge of such things as loop calculations in a non-abelian gauge theory, ghosts, renormalization etc. The highly technical machinery necessary to consistently discuss symmetries in a quantum field theory was not introduced or presumed known. Typically upon enrolling in this course our students have had a one semester introduction to perturbative quantum field theory.

Chapter 1 briefly reviews the ingredients of the standard model with more detail being given to the subjects of the spontaneous breakdown of SU(2) x U(1) symmetry in section 1.1.2 and the renormalization group equation and effective coupling constants in section 1.2.2. A practical guide to group theory is given while discussing the SU(5) grand unified theory of Georgi and Glashow in Chapter 2. The recovery of the low energy standard model is discussed along with the running of the various coupling constants and an estimate of the proton lifetime. Chapter 3 begins with a long review of the representations of the

Lorentz group before introducing the supersymmetry algebra in section 3.1. In order to make them more familiar, the superspace tools developed in that section are immediately applied to the simple Wess-Zumino model in 3.2. Finally gauge invariance in supersymmetric theories is discussed in 3.3 with super QED analyzed in section 3.4. The spontaneous breaking of gauge symmetry as well as supersymmetry is discussed in Chapter 4.0. Sections 4.1 and 4.2 introduce the supersymmetric extension of the SU(5) grand unified theory. The changes in the renormalization group equation β function due to supersymmetry are given in section 4.3 in order to calculate $\sin^2\theta_w$, M_x, *and* m_b/m_τ. *In section 4.4 the proton lifetime is estimated in the super SU(5) model.*

In attempting to present a limited range of material in detail I, needless to say, have had to omit many important topics from these notes. It is hoped that this omission is overlooked in view of the belief that it is better for the student to learn a little about a few things than nothing about a lot. In general the short list of references should provide any further information desired. *I would like to thank my family for their patience while these notes were being written. And finally, I would like to thank Coleen Flanagan, Nancy Schnepp, and Carol Neff for their heroic acts of deciphering and typing my hand written notes.*

Thomas E. Clark

May 1983
West Lafayette, Indiana

Table of Contents

GUTS, SUSY AND SUSYGUTS

Table of Contents

Page

CH. 1) The Standard Model..... 8

1.0. Introduction..... 8

1.1. The Glashow-Weinberg-Salam (GWS) Model of Electroweak Interactions..... 10

1.1.1. Particle representations and the symmetric SU(2)xU(1) electroweak Lagrangian..... 10

1.1.2. Spontaneous symmetry breaking, particle masses, coupling constants, mixing angle, etc..... 28

1.2. Quantum Chromodynamics [QCD]..... 44

1.2.1. Particle representations and the symmetric SU(3) color Lagrangian..... 49

1.2.2. Asymptotic freedom and confinement..... 55

1.3. The Standard Model: SU(3) x SU(2) x U(1) family structure..... 69

CH. 2) Grand Unified Theories (GUTS): The Georgi-Glashow SU(5) Model 73

2.0. Introduction..... 73

2.1. The particle representations and the symmetric SU(5) Lagrangian... 74

2.2. Proton decay, unification mass, $\sin^2\theta_w$..... 117

2.3. Spontaneous symmetry breaking and fermion masses..... 133

CH. 3) Supersymmetry [SUSY] and Superspace..... 150

3.0. Introduction..... 150

3.1. Supersymmetry and superfields, superspace techniques, the covariant derivative, supersymmetric actions, and all that..... 151

GENERAL REFERENCES

1) Electroweak interactions:

a) E. Abers and B.W. Lee: Physics Reports 9 (1973) 1.

b) J.C. Taylor: Gauge Theories of Weak Interactions, Cambridge University Press (1976).

2) QCD:

a) W.H. Marciano and H. Pagels: Physics Reports 36 (1978) 137.

b) D. Politzer: Physics Reports 14 (1974) 129.

3) GUTS:

a) P. Langacher: Physics Reports 72 (1981) 185.

b) R. Slansky: Physics Reports 79 (1981) 1.

4) SUSY:

a) P. Fayet and S. Ferrara: Physics Reports 32 (1977).

b) J. Wess and J.A. Bagger: Princeton University Reprint (1981).

5) Unified Theories of All Types:

a) J. Ellis: Phenomenology of Unified Gauge Theories, Les Houches Summer School August 1981, LAPP-TH-48, CERN Preprint TH-3174-CERN.