FSI3350 Grand Unified Theories 7.5 credits

Storförenande teorier

This is a translation of the Swedish, legally binding, course syllabus.

If the course is discontinued, students may request to be examined during the following two academic years

Establishment

Course syllabus for FSI3350 valid from Spring 2009

Grading scale

Education cycle

Third cycle

Specific prerequisites

Quantum field theory. Standard model of particle physics.

Language of instruction

The language of instruction is specified in the course offering information in the course catalogue.

Intended learning outcomes

After completed course, the PhD student should be able to:

- having the knowledge about the structure of the embedding of the SM gauge group and the relevant degrees of freedom into a unified scheme.
- matching of the Standard Model parameters onto the 'microscopic' parameters of the underlying framework.
- having the knowledge about the origin of the 'generic' predictions of the unified scenarios - the Weinberg angle, the proton instability, the preference of a TeV-scale supersymmetry.
- emphasizing the differences between the supersymmetric and non-supersymmetric model building and the corresponding experimental constraints.

Course contents

Disposition

I. Standard Model of particle interactions & hints on physics beyond SM
☐ Standard model of particle physics
☐ open problems in SM
• hypercharge quantization in the SM & the "miracle" of anomaly cancellation
• the flavour problem of the SM (the Weinberg angle, Yukawa couplings, CKM mixing)
• the gauge hierarchy problem
• neutrino masses & mixing

II. Hints on physics beyond the (renormalizable) SM
- hints on new physics from neutrinos
• Majorana neutrinos, seesaw mechanism(s), d=5 Weinberg operator
• anomalies of U(1) of baryon and lepton number in SM & emergence of B-L
☐ new physics due to d=6 operators - baryon number non-conservation
• B violation necessary for baryogenesis
• d=6 induced proton decay rate and the scale of the underlying physics
• L non-conservation as a lower bound on the B-L breakdown scale
☐ hints on new physics from SU(2)xSU(3) running
• the concept of a running coupling
• running gauge couplings in Yang-Mills theories with fermions and scalars at one loop
☐ potential benefits from having a unified gauge structure (Weinberg angle, Yukawa unification...)

III. Intermezzo 1: Elementary intro into Lie groups & representations
☐ Lie groups and Lie algebras
☐ simple, semisimple Lie algebras, compactness
☐ subgroups, subalgebras, Cartan subalgebra, weights & roots
☐ classification of simple Lie algebras, Dynkin diagrams
☐ elements of representation theory
• real x complex representations, reducible x irreducible representations
• fundamental x antifundamental representations, adjoint representation
• index, symmetry features
☐ examples - basic SU(N) representations, Young tableaux, SO(n) representations, spinors
☐ decompositions or irreps with respect to subgroups, Clebsch-Gordan coefficients

IV. Embedding the SU(3)xSU(2)xU(1) of the SM into a (semi-)simple gauge group G
☐ SM Cartans & need to look for rank 4 or more
☐ need for complex representations
☐ single simple rank 4 option - emergence of SU(5)
☐ normalization issues & 'canonical' vs. 'physical' normalization of U(1) charges in GUTs
☐ quantization of the SM (hyper)charge
☐ Higgs sector, singlets with respect to a subgroup, Higgs mechanism

V. Dynamical consequences
☐ d=6 proton decay (general considerations)
☐ gauge coupling unification, decoupling under M_G & GUT-scale threshold corrections
☐ hints on the minimal model(s) structure

VI. Minimal SU(5) model
☐ structure
☐ non-trivial predictions
• GUT-scale Weinberg angle
• third family Yukawa convergence
☐ gauge running in minimal SU(5)
• a hint for supersymmetry

VII. Intermezzo 2: Supersymmetry & Supersymmetric GUTs
☐ Supersymmetry basics
☐ Minimal Supersymmetric Standard Model
☐ SUSY flavour and CP issues, proton decay & R-parity, lepton flavour violation in SUSY
☐ SUSY gauge running
☐ tension between proton decay & SUSY CP and flavour vs. unification & hierarchy requirements

VIII. Minimal SUSY SU(5) model
☐ structure
☐ proton decay in minimal SUSY SU(5) model
☐ troubles of minimal SUSY SU(5) (proton decay, neutrino sector, D-T finetunning)

IX. LR symmetry & Pati-Salam
☐ U(1)B-L [x SU(2)R] as a gauge symmetry
☐ the neutrino mass scale origin
☐ Pati-Salam symmetry and lepton number as a fourth colour
☐ alleviating proton decay in SUSY LR models

X. SO(10) models
☐ spinors of SO(10)
☐ SO(10) in SU(5) and Pati-Salam language
☐ SUSYx non-SUSY setting
☐ renormalizable x non-renormalizable seesaw
☐ proton decay in SUSY SO(10)
• d=4 proton decay
• d=5 proton decay
• comparison to SUSY SU(5)

XI. Minimal renormalizable SUSY SO(10)
☐ particle contents
☐ R-parity as a gauge symmetry

☐ type-II seesaw and naturally large lepton mixing
☐ absolute neutrino mass scale issue

XII. Open problems & directions
☐ doublet-triplet splitting
☐ SUSY proton decay
☐ perturbativity & proximity of the Planck scale
☐ intermediate scales, gravitino problem in SUSY GUTs
☐ SUSY SO(10) or non-SUSY SO(10)
☐ split SUSY

XIII. Exotics (time permitting)
☐ classical non-perturbative solutions & spontaneously broken gauge theories
• Nielsen-Olessen vortex in 2+1 dimensions, topological charges
• t'Hooft-Polyakov monopole in 3+1 dimensions
☐ monopoles in GUTs
☐ baryon decay catalysis
☐ monopoles & inflation

Course literature

- **P.Langacker, Phys.Repts. 72 (1981)**
- **R.Slansky, Phys.Repts. 79 (1981)**
- **D.Bailin, A.Love, SUSY gauge field theories and string theory, ISBN 0750-302674**
- **G.G.Ross, Grand Unified Theories, 1984, ISBN 0805-369678**
- **R.N.Mohapatra, Unification & Supersymmetry, 1986/92, ISBN 0378-955348**

Examination

Based on recommendation from KTH’s coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

Other requirements for final grade

A set of homework exercises.

Ethical approach

- All members of a group are responsible for the group's work.
- In any assessment, every student shall honestly disclose any help received and sources used.

- In an oral assessment, every student shall be able to present and answer questions about the entire assignment and solution.