July 16, 2016

Short Description of QFT-III course at IPM

Lecturer: **M.M. Sheikh-Jabbari**

Quantum Field Theory (QFT) has become the main framework and computational tool in almost all areas of theoretical physics, from condensed or soft matter to particle physics and cosmology. Being so widely at use, a huge effort has gone into developing the framework itself. QFT has now a thick literature which may not be covered in a one-year course. The QFT-III course is in fact to cover a part of this vast literature, beyond the standard ones.

In QFT-I and II we have covered basics of relativistic field theories, the notion of fermion and boson and spin statistics and CPT theorems. We have developed canonical and path integral quantization methods and pertubative treatment of interactions and computing S-matrix. We discussed unitarity of the S-matrix, how to relate the n-point functions to the S-matrix, the LSZ formula. We then discussed. Loop computations and regularizations, IR and UV divergences, systematics of renormalized perturbation theory and counter-terms. We discussed the Wilsonian effective field theory description which clarified the meaning of divergences and led to Wilsonian Renormalization Group (RG) flow and Callan-Symanzic equation. We discussed the modern QFT approach where one may perturb the theory around its RG fixed point by any observable operator with a given coupling, rendering the β and γ functions, which determine the RG flow of the theory in its parameter space, to essentially the same notions. We also discussed a bit how to formulate critical phenomena and phase transitions in the language of QFT and RG flows. We discussed non-Abelian gauge theories and their renormalizability and β-function and the notions of asymptotic freedom and dynamical generation of scale.

In the QFT-III course, having learned the basics of perturbative analysis of QFT and RG flows, we try to cover more advanced topics, in particular the following.

1 Anomaly in QFT's: 6 sessions

- Chiral gauge theories and scale invariant theories;

- Introducing notion of anomaly in QFT and chiral and trace anomalies;

- Computation of anomaly, path integral and Feynman diagrams, establishing that it is not regularization dependent;

- Fermionic zero modes and one-loop exactness of the anomaly;

- 't Hooft anomaly matching and anomaly cancellation;

- Anomaly chains, chiral (self-dual) forms and ....

2 Non-perturbative effects in QFT: 8 sessions

- Solitonic and BPS states, solitonic vacua;

- Topological vs. Noether charges,

  - Kink solutions, codimension 1 objects;
  - Vortex solutions, codimension 2 objects;
  - Monopoles, codimension 3 objects;

     – Instantons codimension 4 objects.

- Perturbation theory around soliton;

- Instanton/solitonic contributions to partition function.

3   Conformal Field Theoriess: **10 sessions**

- Confromal algebra, conformal symmetry in two and higher dimensions;

- Unitary representations of the conformal algebra;

- Conformal Field Theories (CFT), a general introduction;

- Conformal symmetry and n-point functions;

- OPE and cluster expansion and its usage in CFT analysis;

- Scale vs. Conformal invariance;

- CFT's in $d = 2$;

- Brief mention of CFT's in $d = 4$;

4   Supersymetric Field Theories: **6 sessions**

- SUSY algebras in 4d and other dimensions and their representations;

- SUSY QFT's, WZ model and notion of superpotential;

- Non-renormalization theorems;

- SUSY gauge theories and a brief description of their dualities;

- Super Conformal Field Theories in 4d;

- Super Conformal Field Theories in $d = 3, 6$.

Important Notes for the Students

- This is an advanced PhD level course and I assume background knowledge of QFT-I & II.

- During the lectures I will provide several questions and problems and registered students are supposed to solve and return them to me. The final grade will be based on them.

- This course is equivalent to *four units* and there is the possibility of formally registering for the course as a "guest student" for non-IPM students. For the latter please arrange the formal details with department office, Ms Pileroudi, niloufar@theory.ipm.ac.ir.

- The lectures will be **10-12am, Sunday and Tuesday**, *in Farmanieh Bldg* and they will **start on 4th of Mehr (25 Sept. 2016)**.