Proposed Title: Classical Field Theory: A First Course.

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About the author:

Suresh Govindarajan is an Associate Professor in the Physics Department at the Indian Institute of Technology (IIT) Madras. He has more than a decade of experience teaching undergraduate and graduate level courses. His research interests lie in the field of Theoretical High Energy Physics, mainly in superstring theory.

Topic: This book is a textbook for a first course in relativistic classical field theory. The necessary mathematical background is also provided to make the book self-contained. The material should be accessible to advanced undergraduates and beginning graduate students in Physics as well as to theoretically inclined students in the natural sciences as well as engineering. In the Indian context, advanced B.Sc. and M.Sc. students will find the material accessible. The book is based on a course that has been offered by the author at IIT Madras.

Approach: Some basic knowledge of classical mechanics (Lagrangian and Hamiltonian mechanics) and electromagnetism (Maxwell's equations) is expected. However, this is reviewed in the beginning to aid the reader. A basic knowledge of linear algebra will be useful as well.

With this background, the book systematically develops continuum field theories, placing emphasis on symmetries and their implications. Examples involving scalar fields, abelian and non-abelian vector fields, and general relativity are discussed. Several exercises are provided, which help the student to become familiar with the concepts. These exercises also complement the text.

Fermionic(Grassmann) fields and supersymmetry have been excluded to simplify the presentation and help the student focus on the most basic concepts. The book thus aims at whetting the curiosity of the student rather than providing an overly pedagogical introduction to the subject. It is anticipated that this will let the student *discover* the subject rather than *learn* the subject.

Scope: This book would be eminently suitable in a post-graduate physics programme, and also for advanced undergraduate (honours) programmes. The course may be followed up with a course on Quantum Field Theory. It can also be used by students for a self-study course, provided they work through the exercises as well.

Proposed Contents: *Mathematical sections are indicated in italics*

1. **Review of Classical Mechanics:** Hamiltonians and Lagrangians. *Legendre transforms and their properties.* Euler–Lagrange equations. Principle of least action. *Functional calculus.* What is classical field theory?

2. **Vectors and Tensors:** Group theory from invariances of classical equations. Newton's equations and the Galilean group. Maxwell's equations. Special Relativity and the Lorentz group. Vectors and tensors of the rotation and Lorentz groups. *Basics of group theory: definition, discrete groups and matrix groups.*

3. **Basics of CFT:** Systems with infinite degrees of freedom. Locality in space and time. Lagrangian densities for real and complex scalar fields. Euler-Lagrange (EL) equations. *Functional calculus revisited.* Hamiltonian density. The energy-momentum tensor.

4. **Solutions to the EL equations:** Finite-energy time-independent solutions – classical vacua. Kinks in the Sine–Gordon and ϕ^4 theories. Green functions as singular solutions. Boundary conditions.

5. **Symmetries and Conservation Laws:** Discrete and continuous symmetries. Noether's theorem: the energy–momentum tensor, the generalised angular momentum and the electromagnetic current. *Lie groups and Lie algebras. Representations of groups. Young diagrams.*

6. **The massless vector field:** The Lagrangian density. Gauge invariance and the electromagnetic field strength. Maxwell's equations. Lorentz invariants of the field strength. The symmetrised energy-momentum tensor. The generalised angular momentum and the spin of the photon.

7. **Secret Symmetry:** Global symmetries. Spontaneous breakdown of symmetry. Goldstone's theorem. *Coset spaces in group theory.* Phonons in solids as Goldstone bosons.

8. **Solitons:** Solitons as finite-energy solutions. Derrick's theorem. Getting around Derrick's theorem. Local symmetries and gauge fields. Abelian vortices. The Dirac monopole as a singular solution of Maxwell's equations. Dirac quantisation.

9. **Local Symmetries:** Abelian gauge fields. Covariant derivatives and minimal coupling. The abelian Higgs model. Vortex solutions (in type II superconductors). Topological conservation laws. *Introduction to topology – fundamental groups of spheres and tori.* Higgs mechanism.

10. **Non-abelian gauge theories:** Covariant derivatives; The Yang–Mills field strength; Coupling matter to non-abelian gauge fields; Higgs

mechanism – $SU(2) \to U(1)$ and $SO(3) \to U(1)$; Weinberg's theorem. The 't Hooft-Polyakov monopole as a non-singular solution. Julia–Zee dyons; the Bogomolnyi–Prasad–Sommerfield(BPS) limit. Dirac quantisation for dyons. The theta term and the Witten effect.

11. **The Standard Model of Particle Physics:** Basic forces in nature. Symmetry breaking in the electroweak sector. Quantum Chromodynamics and the quark model.

12. **Instantons:** Instantons as finite action solutions to the EL equations. The 't Hooft solution. The ADHM construction for instantons. Nahm and Bogomolnyi equations.

13. **General Relativity:** Equivalence Principle. Locally inertial frames. Vectors and tensors revisited. *Curved space and Riemannian geometry.* Parallel transport and curvature. Geodesic motion. Einstein's field equations. Schwarzschild, Kerr and Friedmann-Robertson-Walker solutions.

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