Part II: Introduction to Particle Physics and Gauge Field Theories

This part of the book contains material put together specifically keeping in mind the needs of those whose background is basically in general relativity and cosmology. It seeks to present, in a compact form, the theoretical framework and methods of calculation, and a description of the factual situation in elementary particle physics.

R. P. Saxena (Chapter 9) introduces the basic principles of relativistic Lagrangian field theory, first in the classical context and later in the quantized form. He discusses various free fields, their quantization, Lorentz invariance and the important discrete symmetries. Going on to interacting quantum fields, the invariant perturbation theory and Feynman graphs are succinctly discussed. Renormalizability and renormalization methods are covered, with emphasis on the method of dimensional regularization.

The chapter by J. Pasupathy (Chapter 10) gives a description of the phenomenology of particle physics, more or less in a historical sequence. The various interactions, their strengths and symmetries, associated selection rules, and details of the particle spectrum are discussed, with frequent presentation of orders of magnitude of physical quantities. Isotopic spin, strangeness, baryon and lepton numbers, and the discrete symmetries C, P, T and their combinations are explained. The presentation includes γ_5 invariance of the $V-A$ form of weak interactions; the quark-gluon picture for strong interactions based on $SU(3)_c$; and the gauge principle for electrodynamics and for non-Abelian theory. The Glashow–Weinberg–Salam model is briefly sketched.

The next chapter, by G. Rajasekaran (Chapter 11), carefully builds up, step by step, the standard gauge model of particle physics based on the group $SU(3)_c \times SU(2) \times U(1)$. It is expressly written for those without prior exposure to these ideas. Spontaneous symmetry breaking via the Nambu–Goldstone mode, and then via the Higgs mode for gauge theories, are presented via examples, first for the Abelian U(1) and then for the non-Abelian SU(2) case. The physically interesting $SU(2) \times U(1)$ model is then taken up. The emergence of massive vector bosons is demonstrated. After this preparation, the 'standard model' of the late 60's prior to the gauge theory revolution, based on the $V-A$ current-current weak interactions, minimal electromagnetism, and an unspecified strong interaction, all in quark–lepton language, is set up. It is then compared to the standard gauge model of $SU_c(3) \times SU(2) \times U(1)$. The compelling reasons for QCD as the theory of strong interactions are spelt out. An introduction to renormalization group methods as the main calculational tool for QCD,

B. R. Iyer et al. (eds.), Gravitation, Gauge Theories and the Early Universe, 133–134.

asymptotic freedom, infrared problems, and physically motivated reasons for going beyond the standard model are presented.

In Chapter 12, K. C. Wali begins more or less at the point reached by the previous chapter and gives a pedagogical introduction to Grand Unified Theories (GUT). After discussing the general features to be expected in any such theory, as well as the motivations for them, a detailed presentation of SU(5) theory is given. The group structures, particle multiplets, gauge and Higgs bosons are well explained. The two stages of spontaneous symmetry breaking via the Higgs model, are calculated individually and in combination. Fermion mass matrices and relations between quark and lepton masses are derived. Predictions of SU(5) theory, calculated using renormalization group methods, are derived. The chapter ends with discussions that bring together particle physics and cosmology, including the baryon asymmetry problem, phase transitions in the very early universe, and singularities like domain walls, vortex lines, and monopoles.

All in all, the material included should give a good idea of the current scene in particle physics and particle theory, and the ways in which it merges with cosmology in the understanding of the early universe.

Two brief mathematical supplements complete this part: on topology and homotopy by B. R. Sitaram (Chapter 13), and on compact Lie groups and their representations, by N. Mukunda (Chapter 14). These chapters are not intended to be exhaustive, but just to indicate the main ideas in these areas.