Chapter 5

Quantum Numbers: The Identity of Elementary Particles

5.1 Introduction

Every elementary particle possesses a unique set of quantum numbers. These numbers specify how a particle transforms under the symmetries of the Standard Model and determine which interactions it can experience.

5.2 What Is a Quantum Number?

A quantum number is a measurable property associated with a conserved quantity or a symmetry. Examples include electric charge, spin, weak isospin, hypercharge, color charge, baryon number, and lepton number.

5.3 Spin

Spin is the intrinsic angular momentum of a particle. Fermions have half-integer spin and obey the Pauli exclusion principle, while bosons have integer spin and mediate the fundamental forces.

5.4 Electric Charge

Electric charge determines how strongly a particle interacts with the electromagnetic field. After electroweak symmetry breaking, electric charge is related to weak isospin and hypercharge by $Q = T3 + Y/2$.

5.5 Weak Isospin and Hypercharge

Weak isospin (T and T3) describes a particle's transformation under SU(2)L. Hypercharge (Y) is associated with U(1)Y. Together they define the particle's electromagnetic charge after symmetry breaking.

5.6 Color Charge

Quarks carry one of three color charges—red, green, or blue—and interact through the strong force. Gluons exchange color and bind quarks into hadrons.

5.7 Baryon and Lepton Numbers

Baryon number distinguishes baryons from other particles. Lepton number classifies leptons. These quantum numbers are conserved in ordinary particle interactions, although some theories predict violations under extreme conditions.

5.8 Flavor Quantum Numbers

Historically, strangeness, charm, bottomness, and topness were introduced to describe the properties of hadrons containing heavier quarks. Today they are understood as consequences of quark flavor.

5.9 Chirality and Helicity

Chirality describes how a field transforms under the Lorentz group, whereas helicity is the projection of spin along the direction of motion. The weak interaction couples only to left-handed fermions and right-handed antifermions.

5.10 Quantum Numbers and Symmetry

Quantum numbers are not arbitrary labels. They arise because particles belong to specific mathematical representations of the Standard Model gauge group. Symmetry determines identity, and identity determines interaction.

Chapter Summary

Quantum numbers provide the identity card of every elementary particle. They determine which forces act on a particle, how it transforms under symmetry groups, and how it interacts with other particles. Understanding quantum numbers is essential for understanding the structure of the Standard Model.