Chapter 7

Gauge Bosons: Carriers of the Fundamental Forces

7.1 Introduction

Gauge bosons are the force-carrying particles of the Standard Model. They arise naturally from local gauge symmetry and mediate the electromagnetic, weak, and strong interactions.

7.2 What Is a Gauge Boson?

A gauge boson is an elementary particle with integer spin that transmits a fundamental force between matter particles. Except for the Higgs boson, all known force carriers are gauge bosons with spin 1.

7.3 The Photon

The photon is the gauge boson of the electromagnetic interaction. It is massless, electrically neutral, travels at the speed of light in vacuum, and couples to electric charge.

7.4 The Weak Bosons

The weak interaction is mediated by the W+, W–, and Z bosons. Because of the Higgs mechanism these particles are massive, giving the weak force its short range. The charged W bosons change quark and lepton flavor in weak decays.

7.5 The Gluons

Quantum Chromodynamics predicts eight gluons, each carrying combinations of color and anticolor. Unlike photons, gluons interact with one another because they themselves carry color charge.

7.6 Why Eight Gluons?

The gauge group SU(3) has eight independent generators. Each generator corresponds to one gauge field, leading naturally to eight gluons rather than nine.

7.7 Gauge Bosons and Feynman Diagrams

In quantum field theory, particle interactions are represented by Feynman diagrams. Gauge bosons appear as exchanged particles that transfer momentum, energy, and quantum numbers between interacting particles.

7.8 Electroweak Mixing

Before electroweak symmetry breaking there are four electroweak gauge fields. After the Higgs field acquires a vacuum expectation value, these fields mix to produce the photon and the massive W and Z bosons.

7.9 Comparison of Gauge Bosons

Photons are massless and mediate long-range electromagnetism. Gluons are massless but confined within hadrons because of color confinement. W and Z bosons are massive and therefore mediate only short-range weak interactions.

7.10 Beyond the Standard Model

Many theories predict additional gauge bosons, including heavy Z′ and W′ bosons associated with larger gauge symmetries. Their discovery would provide evidence for physics beyond the Standard Model.

Summary Table

Photon: Electromagnetism, U(1), massless.
W+, W−: Weak interaction, charged, massive.
Z0: Weak neutral current, massive.
Eight Gluons: Strong interaction, SU(3), massless, carry color charge.

Chapter Summary

Gauge bosons are a direct consequence of local gauge symmetry. The photon, gluons, and W and Z bosons transmit the fundamental forces of the Standard Model. Their properties are determined by the gauge groups U(1), SU(2), and SU(3), making them central to our understanding of particle interactions.