Chapter 8

The Origin of Electric Charge

8.1 Introduction

Electric charge is one of the most familiar properties in physics, yet its origin is subtle. In the Standard Model, electric charge is not an independent quantity but emerges from the electroweak gauge symmetry after spontaneous symmetry breaking.

8.2 The Electroweak Gauge Group

Before symmetry breaking, the electroweak interaction is described by SU(2)L × U(1)Y. Particles possess weak isospin and weak hypercharge rather than ordinary electric charge as a separate gauge symmetry.

8.3 Weak Isospin

Weak isospin is associated with SU(2)L. Left-handed fermions are grouped into doublets with third-component quantum numbers T3 = +1/2 and T3 = -1/2.

8.4 Weak Hypercharge

Weak hypercharge is the quantum number associated with U(1)Y. Every Standard Model particle is assigned a hypercharge chosen so the theory is gauge invariant and free of anomalies.

8.5 The Gell-Mann–Nishijima Relation

After electroweak symmetry breaking, electric charge is determined by the relation Q = T3 + Y/2. This single equation correctly predicts the charges of leptons and quarks.

8.6 The Higgs Mechanism

The Higgs field acquires a nonzero vacuum expectation value, breaking SU(2)L × U(1)Y into the surviving electromagnetic symmetry U(1)EM. The W and Z bosons become massive while the photon remains massless.

8.7 Why the Photon Is Massless

The photon corresponds to the unbroken generator of U(1)EM. Because the electromagnetic symmetry remains exact, the photon acquires no mass.

8.8 Charge Quantization

The observed charges of quarks and leptons occur in precise fractional and integer units. Grand Unified Theories such as SU(5) and SO(10) provide deeper explanations by embedding hypercharge into a larger symmetry group.

8.9 Open Questions

The Standard Model explains how electric charge arises but does not explain why the hypercharge assignments have their observed values. This remains one of the motivations for Grand Unified Theories and other extensions of the Standard Model.

8.10 Looking Ahead

The study of electric charge illustrates a central theme of modern physics: many observable properties of particles are consequences of deeper symmetry principles.

Key Equations

Electroweak gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Electric charge: $\mathbf{Q = T_3 + Y/2}$

Chapter Summary

Electric charge emerges from the electroweak symmetry rather than existing as an independent fundamental property. Weak isospin, weak hypercharge, and the Higgs mechanism combine to produce the familiar electromagnetic interaction and the massless photon. The deeper origin of hypercharge remains an active area of theoretical research.