

VID. Symmetries in Particle Physics

I. Space-Time Symmetries

These describe the geometry of spacetime itself.

Translation Symmetry

- Space translations
- Time translations

Conservation laws:

- Momentum
- Energy

Rotational Symmetry

SO(3)

Conservation law:

- Angular momentum

Lorentz Symmetry

SO(3,1)

Includes

- rotations
- boosts

Special Relativity is based on Lorentz symmetry.

Poincaré Symmetry

ISO(3,1)

Contains

- Lorentz symmetry
- translations

This is the fundamental spacetime symmetry of quantum field theory.

General Coordinate Symmetry

(Diffeomorphism invariance)

The symmetry of General Relativity.

II. Gauge Symmetries

These generate the fundamental forces.

U(1)

Electromagnetism

Gauge boson:

- Photon

SU(2)_L

Weak interaction

Gauge bosons:

- W⁺
- W⁻
- Z

SU(3)_C

Strong interaction (Color)

Gauge bosons:

- 8 gluons

Standard Model Gauge Symmetry

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

This is the fundamental symmetry of the Standard Model.

III. Internal Symmetries

Not related to spacetime.

Examples:

Isospin

SU(2)

Treats proton and neutron similarly.

Weak Isospin

SU(2)_L

Acts only on left-handed fermions.

Hypercharge

U(1)_Y

Combined with weak isospin to give electric charge:

$$Q = T_3 + \frac{Y}{2}$$

Flavor Symmetry

Approximately

SU(2)

SU(3)

SU(4)

SU(5)

Relates different quark flavors.

Color Symmetry

SU(3)

The symmetry of Quantum Chromodynamics.

IV. Discrete Symmetries

These are extremely important.

C

Charge Conjugation

Matter ↔ antimatter

P

Parity

Mirror reflection

T

Time Reversal

Reverse time direction.

CP

Charge + Parity

Almost conserved.

Broken weakly.

CPT

The combined symmetry

Charge

Parity

Time

Every known quantum field theory obeys CPT symmetry.

V. Global Symmetries

Approximately conserved.

Examples:

Baryon Number

Lepton Number

Electron Number

Muon Number
Tau Number
Strangeness
Charm
Bottomness
Topness
Some are exact.
Some are approximate.

VI. Chiral Symmetries

Very important in QCD.
Left-handed
Right-handed
Examples
 $SU(2)_L \times SU(2)_R$
 $SU(3)_L \times SU(3)_R$
Broken spontaneously.

VII. Supersymmetry

SUSY
Relates
Fermions \leftrightarrow bosons
Generators:
Q
Although elegant, supersymmetry has not yet been experimentally confirmed.

VIII. Grand Unified Symmetries

Attempt to unify the Standard Model.
Examples
 $SU(5)$
 $SO(10)$
E6
E7
E8
These naturally explain charge quantization.

IX. Noether Symmetries

According to Emmy Noether, every continuous symmetry corresponds to a conserved quantity:

Symmetry	Conserved Quantity
Time translation	Energy
Space translation	Momentum
Rotation	Angular momentum
$U(1)$	Electric charge
$SU(3)$ color	Color charge
Gauge symmetry	Gauge charges

X. Broken Symmetries

Many important symmetries are broken rather than exact.

Examples:

- Electroweak symmetry breaking
- Chiral symmetry breaking
- CP violation
- Spontaneous symmetry breaking
- Explicit symmetry breaking
- Anomalous symmetry breaking