Isospin: A Quantum Number for Strong Interactions

Isospin (I) is a quantum number in particle and nuclear physics that describes the symmetry between particles with similar masses but different electric charges, particularly under the strong nuclear force. It is **not** actual spin but shares analogous mathematical properties.

Why "Isospin"?

- **Etymology**: The term combines "**iso**" (Greek for "equal") and "**spin**" (due to mathematical similarities to quantum spin).
    - Proposed by Eugene Wigner (1937) as "isotopic spin" or "isobaric spin" [^1][^4].
- **Core Idea**: Particles like protons and neutrons are nearly identical in mass and strong-force interactions but differ in charge. Isospin treats them as two states of a single particle, the **nucleon**, with different projections of isospin [^1][^5].

Key Properties

1. **Isospin Quantum Number (I)**
    - Defines the size of a multiplet (group of related particles).
    - For nucleons (proton/neutron): $ I = \frac{1}{2} $.
    - For pions ($ \pi^+, \pi^0, \pi^- $): $ I = 1 $ [^1][^3].
2. **Third Component ($ I_3 $)**
    - Projects the charge state within a multiplet:
        - Proton: $ I_3 = +\frac{1}{2} $
        - Neutron: $ I_3 = -\frac{1}{2} $
        - $ \pi^+ $: $ I_3 = +1 $, $ \pi^0 $: $ I_3 = 0 $, $ \pi^- $: $ I_3 = -1 $ [^1][^6].
3. **Quark Formulation**
    - For quarks:
        - Up quark ($ u $): $ I_3 = +\frac{1}{2} $
        - Down quark ($ d $): $ I_3 = -\frac{1}{2} $
    - Hadron $ I_3 $ is the sum of its quark components:
    $$I_3 = \frac{1}{2}(n_u - n_d)$$
    where $ n_u $ = number of up quarks, $ n_d $ = number of down quarks [^1][^2].

Physical Significance

- **Symmetry of Strong Force**: The strong interaction is invariant under isospin rotations, meaning protons and neutrons interact identically under this force [^1][^5].
- **Conservation Law**:
  - Total isospin I and I_3 are conserved in strong interactions.
  - Violated in weak interactions (e.g., beta decay) [^3][^5].
- **Practical Use**: Simplifies classification of hadrons and predicts reaction outcomes (e.g., stability of deuteron) [^7][^5].

Example: Nucleon and Delta Families

Particle	Quarks	I	I_3	Charge
Proton	uud	$\frac{1}{2}$	$+\frac{1}{2}$	+1
Neutron	udd	$\frac{1}{2}$	$-\frac{1}{2}$	0
Δ^{++}	uuu	$\frac{3}{2}$	$+\frac{3}{2}$	+2
Δ^{-}	ddd	$\frac{3}{2}$	$-\frac{3}{2}$	-1

> **Note**: Isospin is a *flavor symmetry* of the strong force, distinct from spin (which relates to angular momentum). It emerges because up and down quarks have nearly identical masses and strong interactions [^2][^5].

Summary

- **Isospin** is a quantum number quantifying symmetry between particles like protons/neutrons.
- **Called "spin"** due to mathematical parallels, but unrelated to angular momentum.
- Governs strong-force interactions and simplifies particle classification [^1][^3].

⁂