Weak interaction

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(Redirected from Weak force)

The **weak interaction** (often called the **weak force** or sometimes the **weak nuclear force**[1]) is one of the four fundamental interactions of nature. In the Standard Model of particle physics, it is due to the exchange of the heavy W and Z bosons. Its most familiar effect is beta decay (of neutrons in atomic nuclei) and the associated radioactivity. The word "weak" derives from the fact that the field strength is some 10^{13} times less than that of the strong force.

Contents

Properties

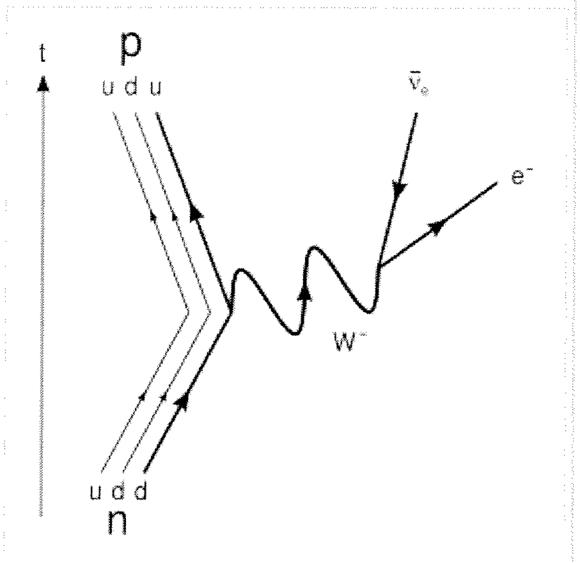
The weak interaction affects all left-handed leptons and quarks. It is the only force affecting neutrinos (except for gravitation, which is negligible on laboratory scales). The weak interaction is unique in a number of respects:

1. It is the only interaction capable of changing flavour.
2. It is the only interaction which violates parity symmetry **P** (because it only acts on left-handed particles). It is also the only one which violates **CP** (CP Symmetry).
3. It is mediated by *heavy* gauge bosons. This unusual feature is explained in the Standard Model by the Higgs mechanism.

Due to the large mass of the weak interaction's carrier particles (about 90 GeV/c^2), their mean life is limited to about 3×10^{-27} seconds by the uncertainty principle. Even at the speed of light this effectively limits the range of the weak interaction to 10^{-18} meters, about 1000 times smaller than the diameter of an atomic nucleus.

Since the weak interaction is both very weak and very short range, its most noticeable effect is due to its other unique feature: flavour changing. Consider a neutron (quark content: *UDD*, or one up quark and two down quarks). Although the neutron is heavier than its sister nucleon, the proton (quark content *UUD*), it cannot decay into a proton without changing the flavour of one of its down quarks. Neither the strong interaction nor electromagnetism allow flavour changing, so this must proceed by **weak decay**. In this process, a down quark in the neutron changes into an up quark by emitting a W boson, which then breaks up into a high-energy electron and an electron antineutrino. Since high-energy electrons are beta radiation, this is called a beta decay.

Due to the weakness of the weak interaction, weak decays are much slower than strong or electromagnetic decays. For example, an electromagnetically decaying neutral pion has a life of about 10^{-16} seconds; a weakly decaying charged pion lives about 10^{-8} seconds, a hundred million times longer. A free neutron lives about 15 minutes, making it the unstable subatomic particle with the longest known mean life.



The Feynman diagram for beta decay of a neutron into a proton, electron, and electron antineutrino via an intermediate heavy W^- boson

Interaction types

There are three basic types of weak interaction vertices (up to charge conjugation and crossing symmetry). Two of them involve charged bosons, intermediate vector bosons, they are called "charged current interactions." The third type is called "neutral current interaction."

- A charged lepton (such as an electron or a muon) can emit or absorb a W boson and convert into a corresponding neutrino.
- A down-type quark (with charge -1/3) can emit or absorb a W boson and convert into a superposition of up-type quarks. Conversely, an up-type quark can convert into a superposition of down-type quarks. The exact content of this superposition is given by CKM matrix.
- Either a lepton or a quark can emit or absorb a Z boson.

Two charged-current interactions together are responsible for the beta decay phenomenon. The neutral current interaction was first observed in neutrino scattering experiments in 1974 and in collider experiments in 1983.

Violation of symmetry

The laws of nature were long thought to remain the same under mirror reflection, the reversal of all spatial axes. The results of an experiment viewed via a mirror were expected to be identical to the results of a mirror-reflected copy of the experimental apparatus. This so-called law of parity conservation was known to be respected by classical gravitation and electromagnetism; it was assumed to be a universal law. However, in the mid-1950's Chen Ning Yang and Tsung-Dao Lee suggested that the weak interaction might violate this law. Chien Shiung Wu and collaborators in 1957 discovered that the weak interaction in fact maximally violates parity, earning Yang and Lee the 1957 Nobel Prize in Physics.

Although the weak interaction used to be described by Fermi's theory of a contact four-fermion interaction, the discovery of parity violation and renormalization theory suggested a new approach was needed. In 1957, Robert Marshak and George Sudarshan and, somewhat later, Richard Feynman and Murray Gell-Mann proposed a **V−A** (vector minus axial vector or left-handed) Lagrangian for weak interactions. In this theory, the weak interaction acts only on left-handed particles (and right-handed antiparticles). Since the mirror reflection of a left-handed particle is right-handed, this explains the maximal violation of parity.

However, this theory allowed a compound symmetry **CP** to be conserved. **CP** combines parity **P** (switching left to right) with charge conjugation **C** (switching particles with antiparticles). Physicists were again surprised when in 1964, James Cronin and Val Fitch provided clear evidence in kaon decays that CP symmetry could be broken too, winning them the 1980 Nobel Prize in Physics. Unlike parity violation, CP violation is a very small effect.

Electroweak Theory

The Standard Model of particle physics describes the electromagnetic interaction and the weak interaction as two different aspects of a single electroweak interaction, the theory of which was developed around 1968 by Sheldon Glashow, Abdus Salam and Steven Weinberg (see W and Z bosons). They were awarded the 1979 Nobel Prize in Physics for their work.

According to the electroweak theory, at very high energies, the universe has four identical massless gauge bosons similar to the photon and a scalar Higgs field. However, at low energies, the symmetry of the Higgs field is spontaneously broken by the Higgs mechanism. This symmetry breaking produces three massless Goldstone bosons which are "eaten" by three of the photon-like fields, giving them mass. These three fields become the W and Z bosons of the weak interaction, while the fourth field remains massless and is the photon of electromagnetism.

Although this theory has made a number of impressive predictions, including a prediction of the mass of the Z boson before its discovery, the Higgs boson itself has never been observed. Producing Higgs bosons will be a major goal of the Large Hadron Collider being built at CERN.

References

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- Gordon L. Kane (1987). *Modern Elementary Particle Physics*. Perseus Books. ISBN 0-201-11749-5.

See also

- Formulation of the standard model
- Electroweak interaction
- Weakless Universe — the postulate that weak interactions are not anthropically necessary

External links

- Citation for 1957 Nobel Prize
- Citation for 1979 Nobel Prize
- Citation for 1980 Nobel Prize

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