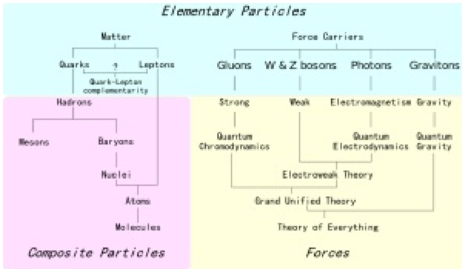
Standard Model of particle physics

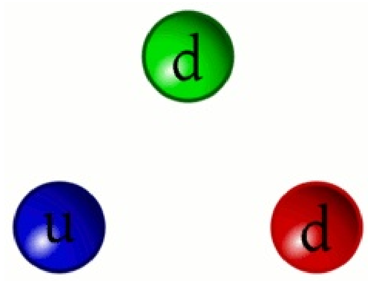
Standard Model



Elementary Particle (split)

According to the **quantum field theory** developed in the 1970s (the *Standard Model*), all matter in the universe consists of six kinds of quarks and six kinds of leptons, between through which various *interactions* may occur; these interactions are mediated by the so-called *exchange* (or *intermediate* or *mediating*) *particles* of the respective field.

Fermions and Bosons



According to the value of spin, we divide the particles into *fermions* (seminumerical spin, their behavior can be described by *Fermi-Dirac statistics* and they behave according to the *Pauli exclusion principle*, which says that they cannot exist two fermions with completely identical energy characteristics) and *bosons* (integer spin, described by *Einstein-Bose statistics*). According to this division, *quarks and leptons* (i.e., the basic building blocks of the material form of matter) belong to *fermions*, while the *intermediate particles* of physical fields belong to *bosons*; here are a few examples:

- **fermions** (seminumerical spin):
  - leptons - e.g. electrons, positrons, neutrino,
  - quarks - they consist of heavier particles, e.g. nucleons,
  - some composite particles, e.g. baryons,
- **bosons** (integer spin):
  - intermediate particles - photons, gluons etc.,
  - some composite particles, e.g. mesons.

Basic physical interactions

Traditionally, physics considers four basic types of interactions:

- **Electromagnetic Force**
- **Gravity'**
- **Weak Interaction**
- **Strong Interaction**

These interactions give rise to the following fields:

Kind of field	Field resource	Reach	Quantum
Electromagnetic field	electric charge	unrestricted	photon
Gravitational field	mass	unrestricted	graviton (hypothetical particle)
Strong nuclear field	color	10^{-15} m	gluons
Weak nuclear field	scent	10^{-18} m	intermediate bosons (W^+, W^-, Z^0)

The Standard Model is based on discoveries from the 1960s, which show that it is possible to combine the electromagnetic force and the weak interaction into one so-called electroweak interaction.

Gravity

From the Greek gravis – heavy, it is a general property of all bodies.

Gravitational interaction, unlike other interactions, **acts without exception on all particles**. Gravitational interaction is always ``attractive *and has an **infinite range**, i.e. its effects cannot be interrupted. Thus, it is the decisive force between very distant objects. However, it is also true that of all the interactions, the gravitational interaction is the **weakest** one. Gravitational interactions acting between two bodies are thus **always mutual**, which also follows from the third **Newton's** law. Therefore, we can say that gravity is a **general property of all material objects***. **However, we cannot always observe the mutual force action of two bodies, only the** motional effect of the force of a many times more massive body on the other **is manifested, even though the mutual** attractive force of these bodies is the same**.**

Gravitation is associated with many topics, from the structure of galaxies, the formation of black holes, the big bang, to practically obvious phenomena such as falling objects, the impossibility of carrying some heavy bodies, etc.

Newton's Law of Gravitation - is the oldest physical theory describing gravitational interactions, it is part of classical physics, therefore it is mainly used to describe the gravitational interactions of weak gravitational fields and particles with **low speeds compared to the speed of light** .

General Relativity - describes gravity as a **curvature of space-time** caused by the properties of space and time. It postulates the existence of ``gravitational waves *(propagating changes in the gravitational field) that travel at the speed of light. It is used for strong fields and for speeds approaching the speed of light. In the future, a **theory of quantum gravity** is being considered, which should be the successor of the general theory of relativity and should connect quantum physics, electrodynamics, nuclear and particle physics with gravity (theory of space and time). The hypothetical particle of the theory of quantum gravity is the **graviton**.*

Electromagnetic force

It is the best-studied force interaction that is commonly encountered in, for example, televisions, computers, radios, light transmission, or even in ourselves in the form of nerve impulses. It is **responsible for the shape and volume of bodies**, as it takes care of **the cohesion of atoms, their size, the structure of substances and the formation of chemical bonds**. We can observe its action as a manifestation of resistance or frictional forces.

The electromagnetic force is **long-range** and its strength decreases **quadratically** with distance. It only works **on charged particles**. It can be either repulsive or attractive. If one particle has a positive charge and the other a negative one, there will be an **attractive force**, if both particles have the same charge, there will be a **repulsive force** between them. But the particles can also have a neutral electric charge, then the electromagnetic **force will not act** between them.

We often think of the electromagnetic force as if it were composed of two fields - electric and magnetic. However, there is a close relationship between these fields, they cannot be examined completely separately, and that is why, for example, with electromagnetic waves we speak of **electric and magnetic components that are mutually perpendicular**.

The intermediate particles of the electromagnetic force are **photonss'**. Although the electromagnetic force acts between charged particles, photons themselves **carry no charge**.

Electromagnetic interaction has its theory in both classical and quantum physics:

In classical physics, electromagnetic interactions are described, for example:

- Coulomb's law (forces between two charges),
- Gauss's law of electrostatics (flow of electric field intensity),
- Lorentz force (a charge moving in an electric and magnetic field),
- Ampere's Law (electric current creates a magnetic field),
- Biot-Savart law (electromagnetic induction),
- Maxwell's equations (electromagnetic waves).

Electromagnetic forces in the quantum world are described by quantum electrodynamics. The most important knowledge stemming from this (especially for biophysics) is the finding that the vast majority of observed phenomena (e.g. chemical bonds, interaction of radiation with matter, etc.) are **the result of mutual interactions between photonss and electronss** . **These *photon-electron interactions* are well represented by Feynman diagrams.**

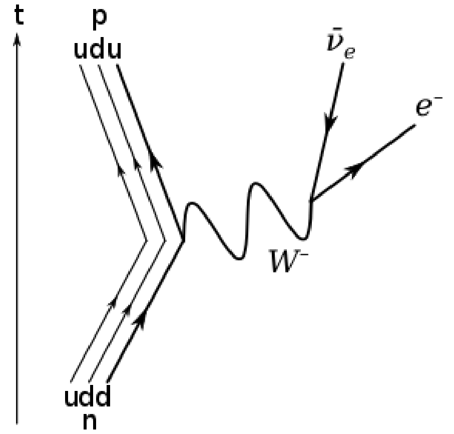
Weak interaction

Weak interactions involve leptons and hadrons, manifesting in neutronu or mionu decays. They have a **very short range** 10^{-17} m and their intermediate particles are **bosons W^+, W^-, Z^0**.

At low energies (up to 20 GeV) they are quite weak, so they are referred to as weak interactions. At higher energies, they are about as strong as electromagnetic interactions.

It participates in β decay of a neutron, when a protonu, electronu and an electron antineutrino are formed with the participation of the W- boson.

The weak interaction together with the electromagnetic force is described by **electroweak theory.**



β neutron decay

Strong interaction

It acts between quarkss that make up **hadrons**. Its charge is referred to as **colored charge*. It has*** *only a small range'*, on the order of 10^{-15} m, and is the **strongest of the fundamental interactions**. Mediating particles of this interaction are **gluons**.

It binds nucleons together (the **residual strong interaction**) and is responsible for the very fast decay of hadrons.

Quantum chromodynamics (QCD) describes the behavior of particles in strong interactions.

Intermediate particle

- **gluon**
- **photon**
- **bosony** W^+, W^- and Z^0
- **graviton**

Fundamental particles of matter

Elementary particles

Terminological problem: The concept of "elementary (fundamental) particles" as the simplest building blocks of matter is **dependent on the state of knowledge** at a given time. Gradually, this term was used for hadrons (protons, neutrons...), leptons and quarks (within the so-called *Standard Model*) and with continued knowledge this term may move to other particles, as they will seem "elementary" to us . Therefore, it is better to avoid the concept of "elementary particles".

Leptons and Quarks

1. **Leptons** (do not interact with the strong nuclear force; electrons and electron neutrinos, muons and muon neutrinos, tauons and tauon neutrinos).
2. **Quarks** (fragrance: up, down, charm, strangeness, bottom, top; color: red, green, blue; charge -1/3 or +2/3).

Fundamental particles have **spin ±1/2** and for each there is an antiparticle (same mass, opposite spin, opposite magnetic moment, charge and color).

Quarks can be composed into **hadrons** (conditions: integer charge and white color), **mesons'** (a quark and an antiquark; integer spin) and **baryons** (3 quarks, non-integer spin; proton and neutron).

Compound Particles

Hadrons

- **mesons'**
- **baryons:**
  - nucleons
  - hyperons

Alpha particle

In particle physics, ^4He nuclei are considered alpha particles. The particle consists of 2 neutrons and 2 protons, the total charge of this particle is +2e, we denote it α or He^{2+}. An alpha particle has a non-zero rest mass, so it moves at a speed **always less than the speed of light**. We refer to the stream of α particles as **alpha radiation**, it arises during **alpha decay.**

Antiparticle

An **antiparticle** is essentially the "opposite" of a particle. An antiparticle and its corresponding particle have the same mass, spin, and mean lifetime, but differ from each other in electric charge, magnetic moment, baryon and lepton number, isospin, and strangeness. Antiparticles obey the same laws of physics as particles.

For more information see Antiparticles.

Quasiparticles

Quasiparticles are a concept primarily of condensed matter physics. It is not a particle in the true sense of the word, it is an excitation spreading through a given environment, which is convenient to consider as a particle for the needs of further analysis. Quasiparticles can be used to analyze some complex physical phenomena.

For more information see Quasiparticles.

Links

Related Articles

- Atom
- Atomic nucleus
- Compton scattering
- Hadrons
- Fundamental Particles of Matter

External sources

- Elementary particles
- Lecture recording: Prof. RNDr. Petr Kulhánek, CSc., FEL CTU, Astrophysics 03 (https://avc-cvut.cz/avc.php?id=1869) (Excellent lecture! – approx. 500 MB)
- Systematic overview of elementary particles (https://www.aldebaran.cz/astrofyzika/interakce/particles.html) on the Aldebaran.cz server

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