2 Quarks and Leptons

2.1 The Particle Zoo

Cosmic rays are high-energy particles from space. When they enter the Earth's atmosphere, they create new short-lived particles and antiparticles as well as photons. Including

- The **muon** μ - negatively charged, 200 times the rest mass of the electron.
- The **pion** π - can be charged or neutral, greater rest mass than the muon but less than proton.
- The **kaon** K - can be charged or neutral, greater rest mass than the pion but less than proton.

Strange Particles

Kaon are created in twos through the **strong interaction**. However, their decay through the weak interaction took longer and included **pions** as the product. Kaons are called **strange particles** due to this property.

Exotic particles can be created using **accelerators** where protons collide head-on. Their properties can then be measured.

- A **kaon** decay into **pions**, or $\mu + \bar{\nu}$, or $\bar{\mu} + \nu$.
- **Charged pions** can decay into $\mu + \bar{\nu}$ or $\bar{\mu} + \nu$.
- $\pi^{\mathbf{0}}$ meson decays into high-energy **photons**.

Decays always obey conservation rules.

2.2 Particle Sorting

Particles can be divided into two groups according to whether they interact through the **strong interaction**.

- **Hadrons** can interact through all four fundamental interactions, including the **strong interaction**.
  - The proton is the only stable hadron.
  - Hadrons tend to decay through the weak interaction.
- **Leptons** interact only through the **weak**, gravitational and electromagnetic interaction.

The hadrons can be divided into two groups

- **Baryons** are protons and all other hadrons that decay into protons.
- **Mesons** are hadrons that do not include protons in their decay products.

Baryons and mesons are composed of smaller **quarks** and **antiquarks**.

2.3 Leptons at Work

Leptons and antileptons can interact to product hadrons, an **electron-positron annihilation event** can produce a quark and antiquark.

Neutrinos

- Travels near the speed of light.
- Billions passing through the Earth each second with almost no interaction.
- Produced in **beta and muon decays**.

Neutrinos and antineutrinos produced in beta decays are different from that in muon decays. ν_μ and ν_e are two types of neutrinos.

Lepton Rules

- Change into other leptons through the **weak interaction**.
- Produced or annihilated in **particle-antiparticle interactions**.
- They appear to be **fundamental** - don't break down into non-leptons.

Interaction between **a lepton (neutrino or antineutrino) and a hadron** changes it into or from a corresponding charged lepton.

The **lepton number** is $+1$ for any lepton, -1 for antilepton, 0 for non-lepton. Lepton number is conserved.

$$\nu_e + n \to p + e^-$$

In **muon decay**, the muon changes into a muon neutrino.

$$\mu^- \to e^- + \bar{\nu_e} + \nu_\mu$$

2.4 Quarks and Antiquarks

Strange particles all decay through the weak interaction.

- **Kaon** K decays into pions only.
- **Sigma** Σ
  - Have different rest masses greater than the proton's rest mass.
  - Decays into **protons and pions**.
- Strange particles are created in twos.

Strangeness is conserved in strong interaction, and changes by 0, $+1$ or -1 in weak interactions.

The Quark Model

	u	d	s
charge Q	$+2/3$	$-1/3$	$-1/3$
strangeness S	0	0	-1
baryon number B	$1/3$	$1/3$	$1/3$

Mesons is a quark-antiquark combination.

- π^0 is any quark-corresponding antiquark combination.
- There are **two uncharged kaons**, K^0 and $\bar{K^0}$.
- The antiparticle of any meson is another meson.

Baryons and antibaryons are hadrons made of three quarks or antiquarks.

- Proton: uud
- Neutron: udd
- Antiproton: $\bar{u}\bar{u}\bar{d}$
- A Σ particle is a baryon containing a strange quark.

In β^- decay, a neutron in a neutron-rich nucleus changes into a proton - a down quark changes into an up quark.

$$d \to u + e^- + \bar{\nu_e}$$

2.5 Conservation Rules

- **Energy and charge** are conserved in all changes in science.
- **Lepton number** is conserved in any change.
- **Strangeness** is conserved in any strong interaction.
- **Baryon number** is conserved in any change.

The **baryon number** is $+1$ for any baryon, -1 for antibaryon, 0 for mesons and leptons.