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Teachers' Resource Book on 
Fundamental Particles and Interactions 

Helen R. Quinn, Jonathan Dorfan, R. Michael Barnett, Robert N. Cahn, 
Gerson Goldhaber, and Gordon J. Aubrecht II 

January 1989
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January 31, 1989

TEACHERS’ RESOURCE BOOK ON
FUNDAMENTAL PARTICLES AND INTERACTIONS*

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AND MEMBERS OF THE FUNDAMENTAL PARTICLES
AND INTERACTIONS CHART COMMITTEE

To accompany the FPICC Wall Chart

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Foundation under agreement no. PHY83-18358.
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Funding

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This is a Preliminary Version of the Resource Book for use in field testing.

January 1989
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Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

**FERMIONS**

<table>
<thead>
<tr>
<th>Leptons</th>
<th>spin = 1/2</th>
<th>(Antileptons)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric charge</strong></td>
<td><strong>Flavor</strong></td>
<td><strong>Mass GeV/c^2</strong></td>
</tr>
<tr>
<td>0</td>
<td>e electron</td>
<td>$&lt; 2 \times 10^{-5}$</td>
</tr>
<tr>
<td>-1</td>
<td>$\mu$ muon</td>
<td>$&lt; 2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

**Quarks** | spin = 1/2 | (Antiquarks) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric charge</strong></td>
<td><strong>Flavor</strong></td>
<td><strong>Approx. mass GeV/c^2</strong></td>
</tr>
<tr>
<td>2/3</td>
<td>u up</td>
<td>$4 \times 10^{-3}$</td>
</tr>
<tr>
<td>1/3</td>
<td>d down</td>
<td>$7 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

Spin is the intrinsic angular momentum of particles. It must be included to conserve angular momentum in particular reactions. Spin is given in units of h, which is the quanta unit of angular momentum. For particles with half-integer spin, allowed and forbidden angular momenta are h/2 and h, respectively. For particles with integer spin, allowed and forbidden angular momenta are h and 2h, respectively. These properties are fundamental to the structure of matter. Particles with integer spin are called bosons.

Electric charges are given in units of the proton's charge. In SI units the charge of the proton is 1.602176634 x 10^-19 Coulombs.

The energy units of particle physics is the electron volt (eV), the energy gained by one electron in changing a potential difference of one volt.

**BOSONS**

<table>
<thead>
<tr>
<th>BOSONS</th>
<th>force carriers</th>
<th>spin = 0, 1/2, ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unity</td>
<td>Unified Electroweak</td>
<td>spin = 1</td>
</tr>
<tr>
<td></td>
<td>$\gamma$ photon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$W^-$</td>
<td>$Z^0$</td>
</tr>
<tr>
<td></td>
<td>Electric charge</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Strong or color charge</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Isospin</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Electric charge</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mass GeV/c^2</td>
<td>81</td>
</tr>
</tbody>
</table>

**Structure within the Atom**

**Quark Size** $< 10^{-14}$ m

**Electron Size** $< 10^{-15}$ m

**Nucleus Size** $< 10^{-14}$ m

**Atom Size** $< 10^{-10}$ m

**ToF the INTERACTIONS**

- **Gravitational**
- **Electroweak**
- **Electromagnetic**
- **Fundamental**
- **Residual**

**Sample Fermionic Hadrons**

<table>
<thead>
<tr>
<th>Baryons euq and Antibaryons</th>
<th>Quark content</th>
<th>Electric charge</th>
<th>Mass GeV/c^2</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>udd</td>
<td>1</td>
<td>0.938</td>
<td>3/2</td>
</tr>
<tr>
<td>$\bar{p}$</td>
<td>udd</td>
<td>-1</td>
<td>0.938</td>
<td>1/2</td>
</tr>
<tr>
<td>n</td>
<td>udd</td>
<td>0</td>
<td>0.940</td>
<td>1/2</td>
</tr>
<tr>
<td>$\Lambda$</td>
<td>udds</td>
<td>0</td>
<td>1.166</td>
<td>1/2</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>udds</td>
<td>-1</td>
<td>1.672</td>
<td>3/2</td>
</tr>
</tbody>
</table>

**Matter and Antimatter**

Every particle type has a corresponding antiparticle type, except for the photon and the graviton. Antimatter has identical mass and spin but opposite charge. The electro-neutral condition is not sufficient for compatibility in matter made of matter and antimatter. This property of matter is consistent with the corresponding antiquark (e.g., $u$ = $\bar{d}$) as their own antiparticles.

**Bosons**

- **Mesons**
- **Gluons**
- **Higgs bosons**

**Sample Bosonic Hadrons**

<table>
<thead>
<tr>
<th>Bosons</th>
<th>Quark content</th>
<th>Electric charge</th>
<th>Mass GeV/c^2</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+$</td>
<td>uud</td>
<td>+1</td>
<td>0.140</td>
<td></td>
</tr>
<tr>
<td>$K^+$</td>
<td>uud</td>
<td>-</td>
<td>0.494</td>
<td></td>
</tr>
<tr>
<td>$\rho^+$</td>
<td>uud</td>
<td>+1</td>
<td>0.770</td>
<td></td>
</tr>
<tr>
<td>$D^+$</td>
<td>uud</td>
<td>+1</td>
<td>1.869</td>
<td></td>
</tr>
<tr>
<td>$\eta_c$</td>
<td>uud</td>
<td>0</td>
<td>2.980</td>
<td></td>
</tr>
</tbody>
</table>

**Matter and Antimatter**

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**Bosons**

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- **Gluons**
- **Higgs bosons**

**Sample Bosonic Hadrons**

<table>
<thead>
<tr>
<th>Bosons</th>
<th>Quark content</th>
<th>Electric charge</th>
<th>Mass GeV/c^2</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+$</td>
<td>uud</td>
<td>+1</td>
<td>0.140</td>
<td></td>
</tr>
<tr>
<td>$K^+$</td>
<td>uud</td>
<td>-</td>
<td>0.494</td>
<td></td>
</tr>
<tr>
<td>$\rho^+$</td>
<td>uud</td>
<td>+1</td>
<td>0.770</td>
<td></td>
</tr>
<tr>
<td>$D^+$</td>
<td>uud</td>
<td>+1</td>
<td>1.869</td>
<td></td>
</tr>
<tr>
<td>$\eta_c$</td>
<td>uud</td>
<td>0</td>
<td>2.980</td>
<td></td>
</tr>
</tbody>
</table>

**Figures**

These diagrams are as simple a set of junctions of physical processes. They are not exact and have their own scale units. Each should only reveal the scale of processes in the given field and not the same process as it appears in the larger field of the same process.

**Notes**

- The standard model of the Fermat-Planck-Nordtvedt Theory of Quantum Mechanics and Electrodynamics, published in 1972, is the most comprehensive model of particle interactions. It is an extension of the standard model and includes new fundamental forces that are not described by the standard model.
- The standard model is a powerful tool for understanding the fundamental forces and particles that make up the universe. It is used to make predictions about the behavior of particles and to test theories of particle interactions.

**References**

- Standard Model of the Fermat-Planck-Nordtvedt Theory of Quantum Mechanics and Electrodynamics, 1972
- The Standard Model of Particle Physics, 2013
Preliminaries

1. Introduction
The Standard Model of particle physics is an excellent approximation to nature. The Standard Model is the best theoretical framework we have to explain the fundamental forces and particles of the universe. It is based on the principles of quantum mechanics and special relativity, and it predicts the existence of three forces: the strong, weak, and electromagnetic forces. The model also describes the behavior of elementary particles, such as quarks and leptons, and it provides a framework for understanding the behavior of the universe at the smallest scales.

The Standard Model is built around the idea of a standard model of particle physics, which includes the basic building blocks of matter and energy. These building blocks are categorized into two types: fermions and bosons. Fermions make up matter and include quarks and leptons, while bosons mediate the forces and include the gauge bosons of the strong, weak, and electromagnetic forces.

The Standard Model is based on the idea of supersymmetry, which proposes that every known particle has a supersymmetric partner. Supersymmetry is a theoretical framework that attempts to unify the forces of nature and explain the existence of dark matter.

The Standard Model is not perfect, however. It is based on a series of assumptions and approximations, and there are still many open questions about the nature of the universe. Further advances in particle physics research may lead to a better understanding of the fundamental forces and particles of nature.
Chapter 9 presents a brief summary of some crucial experiments.
The Standard Model is a step further. The words "color" and "gauge" are not new. Consider "force" and "symmetry". The Standard Model's predictions come with well-defined meanings. The name color is chosen to convey the idea that particles come with properties. In the Standard Model, the particles experience an interaction if and only if they carry a charge associated with that interaction. This is the Standard Model's particle perspective on interactions.

In this book, the particle physics component is based on the Standard Model. Occasionailly, claims have been made that a need for a "hidden force" exists. These claims have been made in the past as part of the Standard Model. Clearly, if the Standard Model is correct, strong interactions described by the Standard Model include strong, electromagnetic, and gravitational forces. The Standard Model includes strong, electromagnetic, and gravitational forces. The Standard Model is our guide to the structure of the Standard Model.
Chapter 2

**2.3. PARTICLE TYPES**

Spin - Bosons and Particles.

The first major distinction in particle types is the separation of all particles into two classes - Bosons and Particles. Any particle with zero spin is called a Boson. Any particle with a spin is called a Particle. Any particle with a spin is an odd number of half units of elementary spin. Bosons do not. Particles carry an intrinsic angular momentum.

Enrico Fermi and S. N. Bose. The name for these two classes is Fermions and Bosons. The name comes from the French physicists: Le Grand, Fermions and Bosons.

**2.3.1. BOSONS**

Bosons are particles with zero spin. They are the carriers of the forces in nature.

**2.3.2. PARTICLES**

Particles are distinguished from Bosons by their spin. Particles are the carriers of angular momentum.

**2.3.3. FERMIONS**

Fermions are particles with a spin that is an odd number of half units of elementary spin. The name comes from the French physicist, Paul Dirac.
The antiparticle of a quark has the same color and spin as the quark.

The color charges of the quark and antiquark must be combined to a color-neutral pair, which are called mesons. Mesons can have any integer spin, and thus they are bosons.

Hadrons consist of a quark and an antiquark (for example, $\pi^+$, which is an $u$ quark and an $\bar{d}$ antiquark). Such objects are called hadrons.

Bosons

<table>
<thead>
<tr>
<th>Boson</th>
<th>Parton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon</td>
<td>$Z$</td>
</tr>
<tr>
<td>$\pi^+$</td>
<td>$\pi^-$</td>
</tr>
</tbody>
</table>

The following table summarizes the various particle types.

<table>
<thead>
<tr>
<th>Particle Name</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon</td>
<td>$\alpha_b$</td>
</tr>
</tbody>
</table>

This table includes the various particle types.

The same object and the corresponding antiparticle, such as $u = \bar{d}$, the parton and the antiparton, are color-neutral. For every quark made of three quarks, there is an antiquark made of three antiquarks, and the color charges of the quarks and antiquarks cancel in pairs. This is called the principle of color neutrality.

The fundamental bosons are the carriers of the fundamental interactions. The photon is the carrier of the electromagnetic field, the graviton (which is yet to be discovered) is the carrier of gravity, and the gluon is the carrier of the strong nuclear force. The $\omega$ and $\phi$ bosons are hypothetical particles that are not yet experimentally observed.

There are two classes of bosons: particles and antiparticles. Every particle has an antiparticle, and vice versa. This is known as the principle of conservation of charge. For example, the electron and the positron, which are antiparticles of each other, have the same mass and charge but opposite spins.

The quantum of the electromagnetic field, the photon, has zero electric charge.

The quark model of the strong interactions is called QCD. All of these particles have spin 1/2, 2, 3/2, ...

The range of the strong interactions is called the strong interaction region. The $W$ and $Z$ bosons play the same role for weak interactions. The photon is the quantum of the electromagnetic field, and the gluon is the carrier of the strong nuclear force. The $\omega$ and $\phi$ bosons are hypothetical particles that are not yet experimentally observed.

There are two classes of bosons: particles and antiparticles. Every particle has an antiparticle, and vice versa. This is known as the principle of conservation of charge. For example, the electron and the positron, which are antiparticles of each other, have the same mass and charge but opposite spins.
The problem of scales could be the problem that the atom is a quantum mechanical atom, not a picture. One cannot draw a sensible picture of the atom. Apart from the problems of scales, there is the problem that the atom is a quantum mechanical atom, not a picture. One cannot draw a sensible picture of the atom.

6.1. Layout of the Chart

This chapter briefly explains all the tables and figures that appear on the chart.
<table>
<thead>
<tr>
<th>Flavor</th>
<th>Mass (GeV)</th>
<th>Charge</th>
<th>Spin</th>
<th>Flavor</th>
<th>Mass (GeV)</th>
<th>Charge</th>
<th>Spin</th>
<th>Flavor</th>
<th>Mass (GeV)</th>
<th>Charge</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom</td>
<td>0.15</td>
<td>-1/3</td>
<td>1/2</td>
<td>Strange</td>
<td>7 x 10^{-3}</td>
<td>-1/3</td>
<td>1/2</td>
<td>Down</td>
<td>2/3</td>
<td>0</td>
<td>1/2</td>
</tr>
<tr>
<td>Top</td>
<td>1.5</td>
<td>2/3</td>
<td>1/2</td>
<td>Charm</td>
<td>4 x 10^{-3}</td>
<td>1/2</td>
<td>1/2</td>
<td>Top</td>
<td>1.5</td>
<td>2/3</td>
<td>1/2</td>
</tr>
<tr>
<td>t</td>
<td>3</td>
<td>2/3</td>
<td>1/2</td>
<td>t</td>
<td>3</td>
<td>2/3</td>
<td>1/2</td>
<td>t</td>
<td>3</td>
<td>2/3</td>
<td>1/2</td>
</tr>
</tbody>
</table>

**QURKKS (Quarkplus)**

<table>
<thead>
<tr>
<th>Flavor</th>
<th>Mass (GeV)</th>
<th>Charge</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>0.10</td>
<td>-1</td>
<td>1/2</td>
</tr>
<tr>
<td>Neutrino</td>
<td>&gt; 3.5 x 10^{-2}</td>
<td>0</td>
<td>1/2</td>
</tr>
</tbody>
</table>

**LEPTONS (Leptonplus)**

<table>
<thead>
<tr>
<th>Flavor</th>
<th>Mass (GeV)</th>
<th>Charge</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>0.51</td>
<td>0</td>
<td>1/2</td>
</tr>
<tr>
<td>Neutrino</td>
<td>&gt; 2.5 x 10^{-8}</td>
<td>0</td>
<td>1/2</td>
</tr>
</tbody>
</table>
Quarks have no-zero color charge and hence the equations they are combined two at a time have not been observed (as of January 1999).

In 1974, a sixth quark (Q) was observed by the Texas-Arkansas-Louisiana group, under the name \textit{c} quark. In 1976, A sixth quark (\textit{d}) was observed by the Brookhaven National Laboratory. These two quarks, along with the other quarks, form the proton and neutron. The quarks are the building blocks of the proton and neutron, which are the fundamental particles of matter.

The quark model was first proposed by Murray Gell-Mann and George Zweig in 1964. In this model, quarks are considered to be fundamental particles that combine to form hadrons.

### Quark Combinations

<table>
<thead>
<tr>
<th>Quark Combination</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q) + (-Q)</td>
<td>0</td>
</tr>
<tr>
<td>0 + 0 + 0</td>
<td>0</td>
</tr>
<tr>
<td>0 + (Q) + (-Q)</td>
<td>1</td>
</tr>
<tr>
<td>0 + 0 + (Q)</td>
<td>1</td>
</tr>
</tbody>
</table>

Table showing the possible combinations of quarks to form protons and neutrons. These combinations are based on the rules of quantum mechanics and the principles of particle physics.

### Further Research

Quark detection has been an active area of research in particle physics. The discovery of new quarks and the understanding of their properties are crucial for the development of our understanding of the fundamental forces of nature.

The muon, discovered in 1937, was the first particle of the second generation. It is a particle with a mass approximately 206.6 times that of the electron. The muon plays a significant role in particle physics and is a key player in our understanding of the fundamental forces of nature.
<table>
<thead>
<tr>
<th>Boson</th>
<th>Mass GeV/c²</th>
<th>Electric charge</th>
<th>Strong or Color</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z⁰</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>W⁺, W⁻</td>
<td>81</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Photon</td>
<td>81</td>
<td>-1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Bosons**

Spin = 0, 1, 2...

Force carriers
but rather from the stronger interaction components. We can use the mass difference
between most of the mass of protons and neutrons does not come from quark masses.
what is meant by gapped mass? This is especially true for the higher electron
cannot be isolated. It is very difficult to determine the mass of even to define fully.
For quarks, the color quanta are termed "proton-antiproton mass." Because a quark

the page, which type of theory is correct

does not yet know which type of theory is correct.

theoretical model known as Grand Unified Theories. In some of these theories

be very tiny, less than 10⁻³⁵⁴ eV. Experimentsally this mass is known to

to the exact conservation of electric charge. Experimentally this mass is known to

the number of quarks in a hadron is not even a

The quarks are the quarks in that they cannot be isolated, and hence their

forms of the W and Z bosons are determined experimentally. The mass of

the mass of the W and Z bosons are determined experimentally. For the photon

between any fermion and any antifermion. Between fermions bound together by

that are the quarks which are produced in experimentals.

be observed. It is more likely that this is not the case, but if it is, the mass since it has not

For the top quark we can only give a lower limit on the mass since it has not

This gives an accurate estimate of heavy quark masses.

is plotted on the upper right of the chart shows the fundamental bosons of

Table 32. BOSON TABLES

a chapter of quark physics. The proton-smash experiment involves transitions

above the quark charge - 1/3 of a Dirac charge. W-bosons do not have charge - 1/3 of a

By combining a W-boson and a Z-boson, one obtains a Z-boson, the electrically charged vectrenon. Since W-bosons are electrically charged, the electrically

they interact. Just as the photon is the quantum of the electromagnetic field

it is a fundamental fact that the standard model cannot be altered without changing the

the standard model. These are known as "lepton flavors." This is an important

are also labelled "factors". This is an important

the quark number of the corresponding hadron is also conserved. Each of these particles is the quantum of the corresponding

consistent. When the physicists use the word mass it always

The labels show mass for the charged leptons; these masses are experimentally

it is understood that the horizontal axis represents the quark number. The

between the gapped masses. We can see from the funnel-antifunnel diagram above the

gaps. There is no gap on a quark which has a gap between the quark and the quark, is used somewhat differently for quarks than for leptons. For leptons,

are color charged. Each quark flavor has come with any of the possible color charges. The

With the funnel-antifunnel they have very small masses.
### Baryons $bb$ and Antibaryons $ar{b}ar{b}$

<table>
<thead>
<tr>
<th>Spin</th>
<th>Charge</th>
<th>Mass [GeV/c²]</th>
<th>Electric Charge</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Pion</td>
<td>π⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Proton</td>
<td>p⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>K-meson</td>
<td>K⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Meson-π</td>
<td>π⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Meson-proton</td>
<td>p⁺</td>
</tr>
</tbody>
</table>

### Mesons $b$ and Antimesons $\bar{b}$

<table>
<thead>
<tr>
<th>Spin</th>
<th>Charge</th>
<th>Mass [GeV/c²]</th>
<th>Electric Charge</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Pion</td>
<td>π⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Proton</td>
<td>p⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>K-meson</td>
<td>K⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Meson-π</td>
<td>π⁺</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>0.001</td>
<td>1+</td>
<td>Meson-proton</td>
<td>p⁺</td>
</tr>
</tbody>
</table>
The quark and antiquark make a possible meson.

The combination is an integer, mesons are bosons. Any combination of flavors for the quark with an antiquark such hadrons are called mesons. Since the total spin of the quarks is odd, the quark cannot combine to form a color-neutral combination of quarks.

There are three quarks and three antiquarks, each of which has the three possible color charges and putting them together. The quark of each of the three possible color charges and putting them together. The neutral, the three of SU(3), one can make a color-neutral object by taking one neutral. Any combination of these quarks makes a baryon. Baryons are color triplets. The two labels include simple fermionic hadrons and simple bosonic.

3.2. HADRON TABLES
<table>
<thead>
<tr>
<th>20</th>
<th>Not applicable</th>
<th>Not applicable</th>
<th>I</th>
<th>10^{-7}</th>
<th>10^{-9}</th>
<th>( r \approx 3 \times 10^{-17} ) m</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>I</td>
<td>10^{-4}</td>
<td>10^{-11}</td>
<td>( r \approx 10^{-18} ) m</td>
</tr>
</tbody>
</table>
| 25 | Not applicable | Not applicable | I | 8.0     | 10^{-11} | Strong

<table>
<thead>
<tr>
<th>Mesons</th>
<th>Quarks, Gluons</th>
<th>( \gamma )</th>
<th>( M + M' \approx 2 ) GeV</th>
<th>Interaction (not yet observed, G-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Residual Force)</td>
<td>(Gluons, Quarks)</td>
<td>( \gamma )</td>
<td>( M + M' \approx 2 ) GeV</td>
<td>Interaction (not yet observed, G-1)</td>
</tr>
<tr>
<td>Color Neutral</td>
<td>Color Charge</td>
<td>Electric Charge</td>
<td>Flavor</td>
<td>Mass-Baryon Property</td>
</tr>
<tr>
<td>Particles</td>
<td>Particles with Charge</td>
<td>Particles with Charge</td>
<td>Lapron</td>
<td>Particles</td>
</tr>
<tr>
<td>Particles</td>
<td>Particles</td>
<td>Particles</td>
<td>Particles</td>
<td>Particles</td>
</tr>
<tr>
<td>Note:</td>
<td>See note</td>
<td>See note</td>
<td>See note</td>
<td>See note</td>
</tr>
<tr>
<td>Residual</td>
<td>Fundamental</td>
<td>Interaction</td>
<td>Weak Interaction</td>
<td>Gravitational Interaction</td>
</tr>
<tr>
<td>Fundamental</td>
<td>Electroweak Interaction</td>
<td>Electroweak Interaction</td>
<td>Electroweak Interaction</td>
<td>Electroweak Interaction</td>
</tr>
</tbody>
</table>

Propertes of the fundamental Interactions
exchanger. The exchange between two particles is a special case of exchange interactions, but it is not necessarily a simple two-particle process. The exchange interaction between two particles can be explained in terms of the exchange of a magnetic moment between them. The exchange interaction is a fundamental force, and it is responsible for the formation of magnetic domains in a ferromagnetic material. The exchange interaction also plays a role in the formation of domain walls, which are responsible for the magnetic properties of a ferromagnetic material.

The exchange interaction is a two-particle process, and it is mediated by the exchange of a magnetic moment between the two particles. The exchange interaction is a short-range interaction, and it is effective only over a short distance. The strength of the exchange interaction depends on the distance between the two particles, and it decreases rapidly with increasing distance. The exchange interaction can be described by the exchange interaction constant, which is a measure of the strength of the interaction. The exchange interaction constant is a fundamental constant in the theory of exchange interactions, and it is used to describe the strength of the interaction between two particles.

The exchange interaction is a fundamental force, and it is responsible for the formation of magnetic domains in a ferromagnetic material. The exchange interaction also plays a role in the formation of domain walls, which are responsible for the magnetic properties of a ferromagnetic material. The exchange interaction is a two-particle process, and it is mediated by the exchange of a magnetic moment between the two particles. The exchange interaction is a short-range interaction, and it is effective only over a short distance. The strength of the exchange interaction depends on the distance between the two particles, and it decreases rapidly with increasing distance. The exchange interaction can be described by the exchange interaction constant, which is a measure of the strength of the interaction. The exchange interaction constant is a fundamental constant in the theory of exchange interactions, and it is used to describe the strength of the interaction between two particles.

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neutron β-decay

Time lapse pictures showing the sequence of events in $\beta^-$ decay:

- **Frame 1**: Initial state with a neutron.
- **Frame 2**: Neutron becomes a proton and an electron.
- **Frame 3**: Proton and electron are emitted, leaving a neutron in the nucleus.
- **Frame 4**: Final state with a proton and a neutron in the nucleus.
the W-boson in this example, are called "virtual" particles, unobservable particles that appear in the intermediate stage of such a process, such as the production of a Higgs boson. Once the Higgs boson is not in its ground state, it may decay to other particles, such as a tau pair or a muon pair. The decay of the Higgs boson is a crucial test of the Standard Model and is a key process in the search for new physics.

The Standard Model also predicts the existence of a neutral current, which is a weakinteraction process involving the exchange of a neutral boson, such as the Z-boson. The decay of the Z-boson can also be used to test the Standard Model and to search for new physics.

The Standard Model also predicts the existence of a charged current, which is a weakinteraction process involving the exchange of a charged boson, such as the W-boson. The decay of the W-boson can also be used to test the Standard Model and to search for new physics.
Resulting in production of D mesons.

Time lapse sequence for electron-positron annihilation:

\[ \text{FRAME 1} \]

\[ \text{FRAME 2} \]

\[ \text{FRAME 3} \]

\[ \text{FRAME 4} \]

\[ \text{FRAME 5} \]

\[ \text{FRAME 6} \]

\[ \text{FRAME 7} \]

\[ \text{FRAME 8} \]

\[ \text{FRAME 9} \]
In the diamond's particularly simple case it shows, where only one additional collision combines to form color-neutral hadrons. These are observed to emerge from the strong interaction between their color-charge states. They are produced, not only at the boundary of the original electron and positron, but also at the opposite boundary. Somewhere in between lie the virtual photons, which are colorless, and the virtual quark-antiquark pairs. These two particles combine to form the observed final state of the collision.
resulting in production of a pion and two K mesons.

Time lapse sequence for the quarks in an \( \nu\) meson to annihilate

\[-\nu + Y_0 + \bar{\nu} \rightarrow \gamma \]
A projectile strikes a target, is deflected, and is observed in a detector.

**Fig. 4-1.** A projectile strikes a target, is deflected, and is observed in a detector.

**Target**

**Projectile**

**Detector**

Study particles and interactions get information from such collisions, but this is in fact the primary way that they escape, the probe and their interactions. If we are investigating this process, we learn about the actinic an ion. By observing the outcome of this process, we learn about the intermediate processes to use one particle to probe another and show us another picture that was not observed in the previous case. In this chapter, we shall describe some of the key experiments that lead to the next chapter we will describe the equipment that is used to study particles in the high-energy world that is the quantum nature of particles.

### 4. Introduction to Experimental High Energy Physics

#### 4. Accelerators and Detectors

Decay of 

\[ \text{Decay of } \]
especially each containing into 6 - 12 protons. If the initial nuclei have high
velocity, each containing a KE of 50 MeV, an energy which is sufficient to
overcome the yield of the 200 GeV, which is spread upon the other 151 protons.

For example, the second figure on the right, which is spread upon the other strip
in the core of the center, shows a large number of particles forming a ring.

The possible decay products of all these reactions are then measured by a
systematic series of detectors, and the possible decay products of some of these
are shown in the right-hand figure, which is spread upon the other strip.

Since the detection and position beam coincides with the beam of particles
initially directed at the target, the experimental arrangement is repeatedly unchanged.

These outcomes when the experiment is repeated many times.

Colliding Beam Experiments

The protons are the same size of objects that can be resolved in the target.

The protons in the track of the target are resolved, the protons in the track of
the target are not. The protons in the track of the target are not. The protons in
the track of the target are not. The protons in the track of the target are not.

The protons in the track of the target are not. The protons in the track of the
target are not. The protons in the track of the target are not. The protons in
the track of the target are not.
We see therefore that to discover nature's secrets, telescopes are inadequate to probe deeper into those

positions of particles produced at the collision point.

The direction of particles produced at the collision point.

positions of particles produced at the collision point.

positions of particles produced at the collision point.

positions of particles produced at the collision point.

positions of particles produced at the collision point.
When a charged particle is accelerated, its radiative properties are important for its electric interaction. These two types of interactions are the most important for momentum. When these properties are considered, we can derive the correct formula for momentum.

In this example, the correct formula for momentum is

$$\frac{1}{\alpha} = \frac{1}{\omega}$$

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$$\frac{1}{\alpha} = \frac{1}{\omega}$$

When a charged particle is accelerated, its radiative properties are important for its electric interaction. These two types of interactions are the most important for momentum. When these properties are considered, we can derive the correct formula for momentum.

In this example, the correct formula for momentum is

$$\frac{1}{\alpha} = \frac{1}{\omega}$$
The Cockcroft-Walton accelerator is a precursor of many accelerators in which a high energy acceleration can start with such a beam.

In this way, the Cockcroft-Walton accelerator is used today for the production of many accelerators, and in these accelerators are still used today for the production of many accelerators.

The Cockcroft-Walton accelerator is only a way of how in a high fraction of the beam the particles and the beam are directed in the beam. This beam is only a fraction of the beam. This beam is only a fraction of the beam.

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The Cockcroft-Walton accelerator is only a way of how in a high fraction of the beam the particles and the beam are directed in the beam. This beam is only a fraction of the beam.
Electron Linac
In the gap shown, the particle is called the target. The target is the nucleus of the nucleus. The nucleus is the target nucleus. The target nucleus is the target of the target nucleus. The target nucleus is the target of the target nucleus.

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The deflection of the beam is caused by two effects: the electric field and the magnetic field. The electric field causes the beam to deflect in a circle, while the magnetic field causes the beam to deflect in a rectangular pattern. This combination of forces results in a circular trajectory that is modified by the magnetic field.
Newton's Law of Motion: 7

Collision of the Beam: 

Collision of the beam is caused by the movement of the particles in such a way that the beam expands and the collision particles move apart. This is followed by the beam being made from the non-collision of the particles that hit a fixed target of the beam. The beam is made from two beams of momentum which are compared with each other. The result of the beam is made from a CM frame which is compared with a CM frame.

In a CM frame, the beam is accepted and then aimed at a fixed target. In a CM frame, the beam is made from a CM frame which is compared with a CM frame.

Collision Phenomena: 

Will be some 80 bl in diameter.

(SEC) will use superconducting magnets to guide the beam around its path, which occurs when the beam is made from a CM frame. The beam is made from a CM frame which is compared with a CM frame.

In a CM frame, the beam is accepted and then aimed at a fixed target. In a CM frame, the beam is made from a CM frame which is compared with a CM frame.

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The known particle types are: 1. If we know the particle mass we can use a momentum measurement to calculate the energy of the particle using:

\[ E^2 - m^2 = p^2 c^2 \]

The chapter is closed and contains no further content about cloud chambers.

Cloud Chambers and Bubble Chambers

on the modern detectors

When particles leave the detector, they ionize the gas and produce electron-positron pairs. These ionization tracks can be detected by a cloud chamber or bubble chamber. The ionization energy is then measured and the particle's momentum and energy are determined. The cloud chamber is a more sensitive detector, but bubble chambers are more versatile and can be used to detect particles that are not charged. Both types of detectors are used in nuclear physics experiments to study the properties of elementary particles.
Particle Detection and Identification Through Energy Loss Rate

Switzerland, Netherlands, Italy, Belgium, and Spain.

China, the Soviet Union, the U.S., East and West Germany, France, Hungary, and the United Kingdom have collaboration with the CERN (European Center for Nuclear Research) and others. The detectors used in the experiment at the Super Proton Synchrotron are described below in more detail because of their importance to the field of physics.

Beck's equation, which is part of the General Theory of Relativity, was used to describe the behavior of charged particles. The method of particle detection in this experiment is based on the General Theory of Relativity.

Modern Detectors

Today, the development of modern detectors for particle detection is still ongoing. As new technologies become available, we are able to measure particles with greater accuracy.

The ABCD model of a charged particle detector is used in the experiment. This model is based on the General Theory of Relativity.

The experiment results are analyzed using the General Theory of Relativity. The results are then used to improve the design of future detectors.
Electromagnetic showers indicate electrons or photons.

When relativistic charged particles traverse a medium, they lose energy and interact with the medium, exciting the atomic electrons of the nuclei. The energy loss of these excited electrons is measured by detecting their ionization. This ionization can then be used to determine the total energy loss of the charged particle.

The ionization loss per unit length is given by the stopping power of the medium. This stopping power is a function of the momentum and the atomic number of the medium.

We will begin the discussion of detector components by considering the detection of electrons. The electron's energy loss per unit length is given by the stopping power of the medium.
EXPERIMENTALLY, particles produced in the collision have track-like paths. Their width is equal to the product of the momentum of the charged particle and the energy of the collision. The charged particles have enough energy to survive the initial reaction, and the magnetic field provides the necessary momentum to accelerate them. As they pass through the wire of the magnetic spectrometer, they deflect in a direction proportional to the magnetic field and their own momentum. The deflection is measured, and the momentum of the particle is calculated from the coordinates of the deflected particle. This method is used in a spectrometer of this type.

To distinguish between the charged particles, a charged particle detector is placed in the middle of the spectrometer. It is sensitive to charged particles and can detect their presence. The detector is placed in the middle of the spectrometer, and the particles are deflected by a magnetic field. The momentum of the charged particles is proportional to the deflection, and the momenta of the charged particles are measured using a magnetic spectrometer. The deflection is proportional to the magnetic field and the momentum of the charged particles. The magnetic spectrometer is used to measure the momenta of the charged particles.

Consider now placing a charged particle detector in the middle of the spectrometer, and the charged particles are deflected by a magnetic field. The momentum of the charged particle is proportional to the deflection, and the momenta of the charged particles are measured using a magnetic spectrometer. The deflection is proportional to the magnetic field and the momentum of the charged particles. The magnetic spectrometer is used to measure the momenta of the charged particles.

Charged Particle Tracking - Magnetic Spectrometer

called a "spectrometer" because particles are deflected by a magnetic field in a spectrometer, and the deflection is proportional to the momentum of the particle. The magnetic spectrometer is used to measure the momenta of the charged particles.
Most charged particle tracking devices used today are based on the principle of proportional counters. These detectors can be used to detect any charged particles. A proportional counter is a device that can detect the presence of charged particles. The device works by creating a spark in the gas between two electrodes, which is then followed by a proportional signal. This signal is then amplified and can be used to detect the presence of charged particles. The device is sensitive to a wide range of energies and can be used to detect particles with energies ranging from a few keV to several MeV. The sensitivity of the device can be varied by changing the gas pressure and the size of the electrodes. Proportional counters are widely used in nuclear physics experiments and in the detection of charged particles in the natural environment.
drifting ions. These signals can also be read out to provide additional localization information. In Fig. 4-8, devices A and A' could be made up of many layers of planar multiwire proportional chambers, with anode wires oriented alternately in the horizontal and vertical direction. Charged particles which traverse such a stack will leave a pattern of signals in the wires closest to the particle paths. Computer software can then be used to reconstruct the trajectories of the particles passing through the device.

Charged Particle Tracking – Drift Chambers

Multiwire proportional chambers will have a spatial resolution determined by the inter-wire spacing, namely about 1 mm. For many applications this is not good enough. In addition, they require an enormous number of instrumented anode wires to cover a large area. A refinement called a drift chamber, in which we measure the time taken for the ionization to travel from the point of origination to the wire, allows the inter-wire spacing to be increased to about 10 cm while still permitting spatial resolution of about 100 microns (1 micron = 10^-6 meters). To measure this time we must measure the arrival time of the beam (the moment of the collision) very precisely. Another requirement (due to the long drift distances) is that the drift field be quite uniform. To achieve this, field-shaping wires are needed, in addition to anode and cathode sense wires. A typical design of the set of wires forming the basic unit or "cell" of a drift chamber is shown in fig. 4-10(b).

Fig. 4-10 shows the design of a cylindrical drift chamber, which is the typical shape for a collider detector. Stacks of planar drift chambers are typical in fixed-target detectors; to reconstruct the direction of tracks alternate layers are arranged to have their wire directions measure horizontal and vertical track coordinates.

Other Neutral Particles

We have now discussed the main elements of a detector illustrating how they might be combined for a fixed target experiment to measure the position and momenta of charged particles and photons. Neutrinos produced in the collisions are not detected, though their production may sometimes be inferred because of the energy and momentum that they carry off. Neutrinos undergo only weak interactions and hence no practical method for efficient detection exists in a general detector. However, large, specialized detectors have been built which can detect the effects of the collisions of neutrinos with the immense mass of material in the detector.

Neutral, stable hadrons like neutrons require further instrumentation. Neutrons are detected in hadronic calorimeters. These are very much like electromagnetic calorimeters except that the material used is usually steel and the thickness of the sandwich slices is governed, not by the physics of an electromagnetic cascade, but by the multiple nuclear interactions by which the neutron loses its energy. Considerably more material is required to absorb hadrons than photons – hence hadron calorimeters are more massive. They are usually placed immediately behind the electromagnetic calorimeter, like device D in fig. 4-8. Of course all hadrons, charged hadrons too, are absorbed by such calorimeters. For charged hadrons they add a complimentary energy measurement to that obtained from the magnetic spectrometer. In many situations, particularly at higher energies, the calorimetric energy measurement is more precise than that obtained from the magnetic spectrometer. However the charged particle directions are measured considerably better by the spectrometer.
Fig. 4-10. - a) The inner part of the Mark II drift chamber during construction. The many wires can be seen, as well as the precision-drilled end-plate which serves to hold them in place. (Photo by Joe Faust).
Fig. 4.10. (c) The paths taken by the electrons as they drift towards the sense wires in the sense wire. Electrons liberated along the particle trajectory follow these drift paths. The field lines and the sense wires for a single "cell" chamber used in the MARK II detector. A sloping region shows the position of a quadrant of the end plate of the large cylindrical drift chamber.
Figure 4-11. An example of a typical colliding beam detector. The image shows a schematic of a detector used in high-energy physics experiments, particularly in particle physics. The components are described in the text. Mark II does not have electron calorimeters and therefore particles like electrons are not detected. The detector consists of silicon detectors, lead slabs, and electromagnetic calorimeters. The silicon detectors are sensitive to charged particles and measure their position and energy. The lead slabs serve as absorbers for hadrons. The entire system is designed to measure the momentum of the primary particles and thus determine their path through the detector.
A critical role in understanding the nature of nuclear reactions.

DALEK D. DECORR (PhD) has found that when a charged particle is deflected in a magnetic field, the direction of deflection is given by the formula:

\[ \theta = \frac{eB}{m} \times \frac{1}{v} \]

where \( \theta \) is the angle of deflection, \( e \) is the charge of the particle, \( B \) is the magnetic field strength, \( m \) is the mass of the particle, and \( v \) is the velocity of the particle.

Vortex Detectors

In recent experiments, vortex detectors have been used to measure the magnetic moment of particles. These detectors are based on the principle that a charged particle, when deflected in a magnetic field, will emit a vortex-like pattern of light. The strength of this pattern is proportional to the magnetic moment of the particle.

More on Particle Identification

The identification of particles is crucial in particle physics. Various methods are used to measure the properties of particles, including their masses, charges, and momenta. These methods include techniques such as magnetic spectrometers, calorimeters, and detectors that measure the energy deposited in the detector. The combination of these techniques allows for the accurate identification of particles, which is essential for understanding the fundamental forces and interactions in the universe.
discussed in the text.

Figure 4.12. (a) A $\mu^+\mu^-$ event which results from the production of $\pi^+\pi^-$ an

through the full muon system.

delayed muons. Notice the small energy loss in the cathodimeter and the penetration

Figure 4.12. (b) A $\mu^+\pi^-$ event. The same pattern as (a) but both tracks are

experiment means: means, target, and detector are present in nearly every particle physics experiment. Light was produced that was visible through the detector. These same ex- experiments have been repeated with a microscope. See Fig. 1. When the alpha particles struck the zinc sulphide screen, a region appeared in the foil and a detector, which was a screen viewed through a microscope, was used for the alpha particles. 

When a very small metal capsule is placed in the neutron beam, the nucleus of the capsule becomes ionized and emits alpha particles. This is the basis for the so-called "neutron-activated analysis." The development of this technique has led to a better understanding of nuclear reactions and has opened up new possibilities in nuclear physics.
exist in ordinary matter. The position is not found ordinarily because when it could not be a proton, the had region the first equipment particle that does not coincide. Anderson knew it was positive. From his ionization track he knew it was in the direction of the particle's motion. Inside in the magnetic field, from the direction of the particle's motion and the force on the magnetic field, from the direction of the particle's motion and the force on the particle's path, one determined whether the particle had arrived from below or from above the plane. This enabled in the middle of the detection chamber he had placed a metal disk. Photo 5-2. The cloud chamber picture taken by C. D. Anderson showing a particle. (C. D. Anderson. Phys. Rev. 49: 491 (1933)).

5.2. COSMIC RAYS

Directly through a microscope, the shielded, prevented all rays, including the photographic, off the shield. The shielded. The protective shield, which could be observed off the photographic plate, the rays bounced off the shield. AN and SN.

Photo 5-1. Diagram of the apparatus of Geiger and Marsden. The alpha (a)
The muon was discovered as a particle predicted by Hideki Yamanaka of Kyushu University. Yamanaka had shown that the decayed neutrons could be explained by a particle predicted by James Chadwick. The muon was discovered; it was mislabeled for a particle that had been seen before.

In the first few years after the Second World War, many particle discoveries were made studying cosmic rays. All involved particles with very short lifetimes.

2.3 Strange Particles

Decayed into a muon and a neutrino, see Fig. 2.3.

The proton was discovered in cosmic rays on earth and was found that it decayed into a muon and a neutrino. The muon, however, was not known until it was discovered in cosmic rays on earth. The lifetime of the muon was not known.

The muon was later observed to decay into a muon and a neutrino, the muon was found in cosmic rays in the atmosphere of Earth.

The proton was discovered in cosmic rays on earth and was found that it decayed into a muon and a neutrino.

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The proton was discovered in cosmic rays on earth and was found that it decayed into a muon and a neutrino.
2.4. Parity Violation

The n-tive would fi if they were eonseet. Because the effect of the interaction are in fact, the decay process more slowly, because the weight interactions are through the weak interactions, and the field, the wave-function process through the wave interactions. We get the same result for the equal spin states of the field, and the right-handed state, and the left-handed state. d' = \bar{d}'.

Thus the collision and electromagnetic interactions, the new particles would be created in pairs. Each of the new particles could be assigned as a particle of the particle. And the neutrino, a particle of the charge, the charge of the hadrons. The particles were created in collision of neutrinos and protons or between other hadrons.
2. More and More Hurdles

In physics, there were no problems that could be expected when actually existed. They
the known strongly interacting particles could be accounted for by the quarks and
the introduction of the quark model by M. Gell-Mann and C. Quark in 1961. This
the continuous of known particles. Other were possible in this vast collection by
their decay processes. More and more data and treatments were found and they expanded
meaning the tracks of the particles into which they decayed. It was possible to
measure the speed of light; we now have a recognizable difference before decay.
However, by
its elimination less than 10-12. Of course such particles are nothing at nearly the
threshold. Many of the

discovery of a new number of new particles with
that charge pictures led to the
discovery of the bubble chamber; a device that could picture how such a particle can
work. P. 31-32 shows an example from L. W. Hill. More pictures of high-energy physics.

Soon after the invention by D. Glaser, the bubble chamber became the

which gave the proof of antimatter's existence. P. 31-32 shows a picture of an event in a photographic
emulsion. In particular, O. C. Chambers' observation of bubbles and the tracks of
protons in his bubble chamber. In a bubble chamber, the tracks of the particles are
concentrated. The direction of the particles and the number of particles per

strange particles can be studied. The number of tracks per event is provided.

Further investigations of decay showed that the neutrinos in weak interactions

from the direction of the magnetic moment. In the mirror, it would always move in
the opposite direction of the magnetic moment. See P. 31-32.

The measurement of the magnetic moment was a significant breakthrough. The

fabrication of the bubble chamber led to the discovery of new particles. The

antimatter's charge was discovered in 1955. The bubble chamber was invented by D.

Glaser, and the bubble chamber became the standard tool for studying weak interactions.

though studies of decay were prominent in understanding weak interactions.

We call it 'left-handed'.

The spin parallel to the direction of motion is not parallel to it. It is 'anti-parallel'.

Based on quantum mechanics, it is such a measurement will find either
just as can consider 'spin-up' and 'spin-down' for electrons in an atom. The
to measure the component of the spin along the direction of the particle's motion,

particles. If we consider a neutron, with the proton, it can be a particle to be
produced and left-handed could be summarised as follows: it is mostly left-handed.

Further investigation of decay showed that the neutrinos in weak interactions

from the direction of the magnetic moment. In the mirror, it would always move in
the opposite direction of the magnetic moment. See P. 31-32.

Support for simplicity that in the mirror it is always opposite.
Fig. 2.6 A photographic emulsion picture of an antiproton – nucloeon annihilation.

Fig. 2.7 A bubble chamber

Additional nucloeon from the nucleus. [9] Chamberlain et al., Phys. Rev. 102, 921

Reaction thus involved the destruction (annihilation) of both the antiproton and an
emitter than the rest mass sum c' (m/γ = 938 MeV) of the antiproton. The
process because the energy observed (1900 ± 50 MeV) in the outgoing tracks was
not observed by a nucloeon.

Fig. 1962]
1962, a team led by Lederman, Schwitters, and Steinberger used an accelerator at
CERN, where they saw a large flux of neutrinos from the decay of pion products. In
writing a note to a Los Alamos Nuclear Laboratory, when the detector is
sensitive to the neutrino direction following the decay of a pion, their team
achieved. This is only possible by having an intense flux of neutrinos, which
could be detected.

The first direct detection of neutrinos was achieved by Reines and Cowan
in 1958.

2.2. EXPERIMENTS

Important evidence for the weak model came from searching for neutrino
scattering with a detector that could detect two neutrinos colliding. This is
only possible by having an intense flux of neutrinos, which could be detected.

2.7. EXPERIMENTAL RESULTS

The basis of experiments within the pion. The experiments tested the hypothesis
of the weak model. When the pion decays, two neutrinos are emitted.

2.6. STRUCTURE OF THE NEUTRON

When the pion decays, two neutrinos are emitted. The structure of the
proton can then be detected in these neutrinos. The experiments that used
these neutrinos to study the proton's structure can be classified into
three categories: direct, indirect, and semi-direct. Direct experiments
measured the magnetic moment of the proton, while indirect experiments
looked for evidence of flavor changes. Semi-direct experiments
looked for evidence of flavor changes.
Figure 3.3: The peak was observed at SLAC. The peak occurs at 7.9 G2, a mass of about 1.3 times that of a proton, and corresponds to the mass of the 7.9 G2 particle. This is especially exciting because it is the first time that the mass of a neutral current interaction has been observed directly.

Another recent result working at the accelerator at the Brookhaven National Laboratory measured decays of particles produced in the collisions of protons.
This was achieved when the chiral meson, called $Q$, was observed in the reaction $D^0 \rightarrow K^+ \pi^-$, which led to the discovery of the $D^0$ meson. The $D^0$ meson decays into $K^+ \pi^-$, and the $K^+$ and $\pi^-$ are produced as a result of the decay of the neutral kaon. The $D^0$ meson is a member of the $D$ family, which includes the $D^+$ and $D^*$ mesons.

In the reaction $D^0 \rightarrow K^+ \pi^-$, the $K^+$ and $\pi^-$ are produced in a specific angular distribution, which is characteristic of the decay of the $D^0$ meson. The angular distribution of the decay products is determined by the Cabibbo angle, which is a parameter that describes the mixing of quark states in the quark model of particle physics.

The reaction $D^0 \rightarrow K^+ \pi^-$ is a simple example of a charmed meson decay, and it provides a way to study the properties of the charm quark and the charmed hadrons, such as the $D^*$ meson. The measurement of the lifetime and branching ratios of the $D^0$ meson, as well as the study of its decay modes, provides valuable information about the strong interaction and the quark model.

The $D^0$ meson is a member of the $D$ family, which includes the $D^+$ and $D^*$ mesons. The $D^0$ meson is a weakly decaying meson that is produced in hadron-proton collisions. The $D^0$ meson decays into $K^+ \pi^-$, and the $K^+$ and $\pi^-$ are produced in a specific angular distribution, which is characteristic of the decay of the $D^0$ meson. The angular distribution of the decay products is determined by the Cabibbo angle, which is a parameter that describes the mixing of quark states in the quark model of particle physics.

The reaction $D^0 \rightarrow K^+ \pi^-$ is a simple example of a charmed meson decay, and it provides a way to study the properties of the charm quark and the charmed hadrons, such as the $D^*$ meson. The measurement of the lifetime and branching ratios of the $D^0$ meson, as well as the study of its decay modes, provides valuable information about the strong interaction and the quark model.
The observed events indicated that the $W$ and $Z$ had masses in agreement with the predictions of the Standard Model.

The expected events were observed with both weak and electromagnetic interactions. The observed events were consistent with expectations derived from Monte Carlo simulations.

Ultimately, the search succeeded with the discovery of $\eta$. A search was begun for the $\eta$ meson using the new data. The strength of the signal was greater than the expected value of $0.1\%$ for the $\eta$ meson.

In 1977, a collaboration at Fermilab led by Leon Lederman found evidence of the $W$ and $Z$ bosons.

2.12. The $W$ and $Z$ bosons

The discovery of the $W$ and $Z$ bosons is the subject of intense scrutiny at the time.
5.13. Future

5.4. References


1. E. Segre, 'From X-rays to Quarks: Modern Physics and Their Discoveries.'
Explain why there are 8 elements in the second row of the periodic table.

Suggested Student Exercise

The choice of origin is of some importance. We can choose any axes and determine the complete function in a quaternion theory. This also is

\[ \psi \text{ gives the component of } \ell \text{ about the } z\text{-axis}. \]

can have integer values of \( 0 \leq \ell \leq n \) - 1.

This is the orbital quantum number. The square of the orbital quantum number is the principal quantum number. It is related to the radial structure of the wave function in the following way.

The possible states of an electron in an atom can be completely specified by the set of quantum numbers \((n, \ell, m, s)\). The meaning of these quantum numbers is

The Pauli Exclusion Principle is fundamental to the structure of matter. No two electrons can occupy the same state of a system, as a result of the concepts as they apply to the magnetic quantum number.

6. Further Explanations

The chapter provides a more detailed discussion of some of the concepts introduced.
Choose one of the candidates evenly. If you have a favorite, choose one at random and try to introduce a wave of different wavefunctions' potential energies in the same region. One way to understand this is to look at the potential energy's higher frequency associated with the candidate at a particular in a region. This is because the potential energy is lower when the election is closer to the candidates than even.

Note in this discussion that when we talk of a composite object, of even an imaginary vertex, it is what we mean by a bound state. They cannot hide it unless they obtain additional energy from some outside source. By construction of energy, the electrons are bound to the positively charged nucleus. The potential energy calculated reas 

In any of the bound states is less than the mass-energy of an electron. This is not a contribution from adding the electrons. The only mass of the atom or the mass of the nucleus. The only mass of the atom or the mass of the nucleus. The only mass of the atom or the mass of the nucleus.

\[
\sqrt{\frac{2}{m}} \geq \sqrt{\frac{2}{m}}
\]

of an election in that state. The uncertainty principle.

Evaluate various quantities such as the average position of the wavefunction's location.

The square of the wavefunction is the average position of the wavefunction's location. Your students are probably familiar with some kind of picture of election, the wave function represents the relative probability of finding the election at any position in any given state.

For an election in any given state, the relative magnitude of the square of the wave function is chosen to co-ordinate locally in the small region and to integrate out wavefunctions. It is to view the local wave function as a supposition of waves of different wavefunctions' energy. In contrast, it is to view the region in which the particle is localized. This is because the potential energy is lower when the election is closer to the candidates than even.

The second row of the table above shows where the outermost elections are in
The working of the exclusion principle at the level of nucleons explains why

The IIZ is larger stable nuclei have a small excess of nucleons over protons. Protons are somewhat lighter than neutrons, and hence the levels for

ion return, for lighter nuclei are of a significant correction. Hence the levels for

conform with those of other decay with discharge. The residual strong

are approximately equal numbers of nucleons and protons. Since the

electrons, in the same way that the electrons all occupy an atom. For small

a neutron containing a proton and a neutron containing a proton and

nucleons remain to be a even number. For a given number of nucleons to be the

a neutron containing a proton and a proton are the same. Hence we find that the

protons make the residual strong interaction. Hence the mass excess is defined as the

Here is the mass of a proton. This mass excess in defining the residual strong

\[
\frac{A}{Z} \approx \frac{A}{2}
\]

close together, rendering lower mass for the same potential for the

latter potential energy is negative when they are

conform to the condensation or neutrons. Again we define the potential energy to be zero for

the mass of the nucleus is somewhat less than the sum of the masses of its

The same kind of quantum mechanical description of the exclusion principle

as the selection of the excitation. The same kind of quantum mechanical description of the

protons of the nucleus. Hence the attractive interaction is due to the residual strong

in the nucleus. We can define the size of the nucleus by the location of a residual interaction.

In this way we go to the residual strong interaction. The same kind of

4.2. THE STRUCTURE OF THE NUCLEUS

The potential energy is negative in the atom. If the reason that atoms are stable

potential energy is negative in the atom. In effect because the Coulomb term is much weaker than the

effects which are about a factor of ten less than the residual strong potential. The chart shows an average by about a

factor of the exclusion principle. (The exact form of the exclusion principle in the

factor of ten between the residual strong potential and the chart shows it is weaker by about a

factor of the residual strong interaction. The same kind of quantum mechanical description of the

interaction case the only difference is the mass of the exchanged particle. For the

case of the exclusion principle. (Note the same form appears here as in the weak

case of the exclusion principle. (Note the same form appears here as in the weak

electrons to form a hydrogen atom. Some of their Coulomb fields

...
6.3. THE STRUCTURE OF NUCLEONS AND OTHER PARTONS

The protone, we can construct two different kinds of hadrons that contain different

particles, and all these might well wonder what we mean by the mass of

factor of 2 because there are three quarks, each with associated kinetic energies.

The proton and neutron have typical mean kinetic energies of about 100 MeV.

The mass of the proton is approximately 1.2 GeV, whereas the mass of the

electron is much smaller than the nucleon, and the constituents of the

proton contribute a mass that is much smaller than the nucleon, and the nucleons

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6.4. CONTINUUM

The result for Newton's law is the force of a region of color force
of the form f(r) = \( 2 \mathbf{r} \cdot \mathbf{v} \mathbf{r} \).

\[
(f_2 \mathbf{r}) \cdot (f_1 \mathbf{r}) = (f_1 \mathbf{r}) \cdot (f_2 \mathbf{r})
\]

one of Newton's fundamental equations, the first law of motion, is shown below.

\[
2 \mathbf{r} \cdot \mathbf{v} \mathbf{r} = (\mathbf{v} \mathbf{r}) \cdot (\mathbf{r} \mathbf{v})
\]

The problem above is not related to explain this fact, but it is for the equation principle.

The problem is made of three gaskets. Although a gasket is not

and the mass that include the interaction energy are called "continuum" gaskets.

In the above of the equation, the mass and the color are called "continuum"

masses. This is the same pattern, but the results of the same

problem are different. The results shown are different. The results shown are
different. The results shown are different. The results shown are different.

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In the above of the equation, the mass and the color are called "continuum"

masses. This is the same pattern, but the results of the same

problem are different. The results shown are different. The results shown are different. The results shown are different.
There is no exact conversion for naming the dark colors. Physicists often name them 'metals' or 'dielectric'.

Color neutral objects:

The color neutral objects exist in two ways: the overall color is neutral, or the color neutral objects have a similar color to the dark colors.

Colors that are not neutral or color neutral can be converted to white, black, or gray. These objects are called 'color neutral' and have a neutral color.

The neutral colors can be combined to make white (0% red, 0% green, 0% blue) or black (100% red, 100% green, 100% blue).

6.2. COLOR AND COLOR NEUTRALITY

The neutral colors are the colors that are neutral in the color wheel. These colors are red, green, blue, and white.

The neutral colors are the colors that are neutral in the color wheel. These colors are red, green, blue, and white.

The neutral colors are the colors that are neutral in the color wheel. These colors are red, green, blue, and white.

6.2.2. THE DARK CONCEPT OF HARMONY

The dark concept of harmony is the idea that colors that are opposite on the color wheel are harmonious.

These colors are red, green, blue, and white.

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In order to explain the key concepts of particle creation and annihilation, one must first understand the standard model of particle physics. The standard model is a theory that predicts the existence of certain types of particles, their properties, and their interactions. This model is based on the strong, weak, and electromagnetic forces, which are the fundamental forces that govern the interactions between particles.

The standard model is a mathematical framework that describes the behavior of subatomic particles. It consists of three generations of fermions (quarks and leptons), which are the building blocks of matter, and a set of bosons (photons, W and Z bosons, and gluons) that mediate the fundamental forces.

In particle physics, the concept of particle creation and annihilation is crucial for understanding the origin and evolution of the universe. When particles come into contact, they can create new particles in a process called particle production. Conversely, particles can also disappear, or annihilate, in a process called particle annihilation.

The study of particle creation and annihilation is important for various fields, including astrophysics, cosmology, and high-energy physics. Understanding these processes can provide insights into the fundamental nature of matter and the forces that govern it.
First by Opmunement (that the equation represents two particles of the same first to interpret the positively charged particle as a proton. It was soon realized that two particles, both equal and opposite, exist. He found sure that the equation be found to his surprise that the theory automatically contravened not the electron theory. He found an equation that could describe a spin 1/2 particle such as Paul Dirac first found an equation that could describe a spin 1/2 particle such as this. Interacting fermions are governed by a different set of rules. When two electrons are allowed in a theory in which A and B are bosons that do not carry any flux, the process conserves momentum as well as energy. This process would appear like Fig. 1. In this figure, the process at point A is shown at time 0. A particle of type A is sitting at rest at position 0. A particle of type B is moving along a path in the space-time dimensions of space-time. The two particles play positions and the other for time. Interacting fermions we see of those to discuss must be played only by one of the two. Because each particle can be thought of as a single process, each and at each time. We begin by explaining the physics of a single process. This is a function of position and time. The diagram shows the extraction that can be drawn in. If we know all the vertices at a given time, we can draw a diagram like this. Then, we can determine all possible paths of the process. For example, the diagram for a two-dimensional space-time shows all possible paths. We will now try to explain some of the words and pictures that emerge as we move to the diagram. The conservation of energy, the conservation of linear momentum and bosons. For these conservation laws of physics are built in to this formulation. We then proceed to distinguish fermions and bosons. For these distinct properties are used to classify particles. The conservation laws of physics are built into the formulation.
If the energy for a photon is zero, as it is in the case of a photon, a photon has zero mass. Since the momentum of a photon is zero, it has no mass. However, if the energy of a photon is non-zero, it has mass and momentum. The momentum of a photon is related to its energy by the equation:

\[ p = \frac{E}{c} \]

where \( E \) is the energy of the photon and \( c \) is the speed of light. The momentum of a photon is also related to its wavelength by the equation:

\[ p = \frac{h}{\lambda} \]

where \( h \) is Planck's constant and \( \lambda \) is the wavelength of the photon.

The momentum of a particle is related to its energy and mass by the equation:

\[ p = \sqrt{\frac{E^2}{c^2} - m^2 c^4} \]

where \( m \) is the mass of the particle.

For a system of particles, the total energy and momentum are conserved. The conservation of energy and momentum is a consequence of the invariance of the laws of physics under translation and rotation. The conservation of energy and momentum is a fundamental principle in physics, and it is used to solve many problems in physics.
distorted into one another by changing the order in time of the processes. Notice the Fig. 6-4 and Fig. 6-5 can be
simply a short hand for the calculation. Feynman diagrams are a version of a process such as this
same process as the other. This contributes to the total rate of scattering. There are different choices of $\mathbf{q}$ and $\mathbf{k}$. All the processes that contribute to the

When the particle is scattered, for such a short time as that one cannot measure its

Feynman's mass-energy relationship for moving particles.}
Virtual particles appear in the intermediate state of processes.

Only give contribution from very short-lived histories. In the Feynman diagrams, introduce the notion of a virtual particle. It is a disturbance that does not have the right energy-momentum relationship and hence is not a particle. 

\[ \frac{\partial}{\partial x} - \frac{\partial}{\partial y} = \Lambda(x + y) \]

Then make a Taylor series expansion of the square root.

\[ \sqrt{\left(1 + \frac{x}{\Lambda} \right)^2} = \Lambda \]

First rewrite the expression as

Solution

\[ \Lambda = \sqrt{\left(1 + \frac{x}{\Lambda} \right)^2} \]

which gives the usual (low energy) version of the square root.

\[ \Lambda(x + y) \]

show that when \( p \) is small compared to \( m \) we can write this formula

Suggested Student Exercise

The Feynman diagrams are a powerful tool for visualizing particle interactions. The graph represents a particular interaction or transition of quantum states. The arrows indicate the direction of particle flow. The vertices represent interactions, and the lines represent the particles. The Feynman diagrams are used to calculate the probability of a particular process occurring. The diagrams help visualize the exchange of virtual particles and the conservation of energy and momentum.
6.9. DECAYS OF INSTABLE PARTICLES

Interactions between their constituents. We can describe the interaction between quarks more directly in terms of

two quarks exchanging a gluon, Fig. 6.7(a). The same thing is true of neutrino exchange. The process is called


In this hadron, the quark and antiquark within one antiquark combination forms a meson


Two possible Feynman Diagrams for this process. Fig. 6.7(b)

6.8. RESIDUAL STRONG INTERACTIONS

We know that the gravitational potential behaves as \( \frac{1}{r^2} \) to a very high accuracy. The electric and gravitational potentials. We know that the potential must be a

\[
\phi(r) \propto \frac{A}{r^2} \]

Now that we have a massless particle corresponding to the familiar 1/r behavior of

potential which falls off with distance. The

is why processes involving massive particles have a corresponding interaction.
A more familiar example of electrophilic decarboxylation occurs in aromatic processes.

Because of the higher energy of the aromatic system, the decarboxylation is more favored compared to the aliphatic system.

Indeed, the transition state for the aromatic decarboxylation is lower in energy than the aliphatic transition state.

Therefore, the selectivity of the decarboxylation process depends on the electronic properties of the substrate.

The initial reaction into a higher energy state is known. The half-life of the $\frac{1}{2}$ is

$$ (p_n)^{\alpha} + \frac{(p_n)^{\alpha}}{2} \rightarrow \frac{(p_n)^{\alpha}}{2} + \frac{\nabla}{\nabla} $$

Strongly occurring involving heavy hydrogen and the standard model should provide such predictions. Some other examples of a successful model have provided strong predictions. Although this is not enough to predict the standard model we do not know how to deduce the quantum corrections. Among the most notable of these approaches are the strong and superstrong processes. While there are more possibilities than just the one shown here, the structure and quantum corrections are not yet fully defined.

Let us start by analyzing the process at the quantum level. A further concern is the very low energy.

We call this phenomenon of increased charge transfer on the quantum level. This is an important aspect of the process and must be considered in the context of the final process.
6.10. THE HIGGS Boson

A number of good popular books have been written including the following.

Cosmic Codes: Quantum Physics as a Language of Matter, by Hein L. Pagels (Pan)

There are at least two stand models with which the Higgs boson and Z boson model requires some spin zero particles which have no color charge but have an axial vector. These require some spin zero particles which have no color charge but have an axial vector.

The Higgs boson and Z boson model requires some spin zero particles which have no color charge but have an axial vector.
An Introduction to Particle Physics for the General Reader
1986, Cambridge University Press

Neumann, Yvonne; and Kuhn, Yvon: The Particle Hunters
Join the ideas of particle physics to the lives and work of the practitioners.
An accessible history of the development of particle physics, successfully
1986, Macmillan Publishing Company
Crosby, Robert P.; and Mann, Charles C.: The Second Creation
Particle Physics

7.2. Introductory Level
A classical introduction to the ideas of relativity and quantum mechanics.
1996, Cambridge University Press
Garrone, Freight: The Facebook

7.2. Bibliography

Standard Model and How Answers to These and Many Other Questions
By Further Experiments Can We Find the Cues That Will Allow Us to Go Beyond the
are still further questions with yet heavier quarks and charged leptons. Only
and the charged leptons are independent parameters not predicted by the Standard
model contains many such parameters. For example, the mass of all the quarks
it correctly by a single unified theory. Interestingly one can condense very few
that remain the holy grail of particle physics. We want the world described
understanding masses and radii of. Quarks, our single theory of all interactions—
are these questions? Perhaps the most important to
whether by experiment or deus ex machina, the Standard Model is still very far from
the book. The second stage of research is to seek a theory which incorporates the
leptons. The second part of this book is devoted to explaining the things that physicists
7.3 Intermediate Level

A description of how particle physics developed, with emphasis on crucial experiments.

1968, Cambridge University Press
The Experimental Foundations of Particle Physics
Cahn, Robert N.; and Goldhaber, Gerson

7.2 Periodicals

Decades of Elementary Particle Physics.
A historical survey of particle physics, with special emphasis on the role of experimental methods.

1979, Simon and Schuster (Touzelstone Books)
Experimental Methods: The Hunting of the Quark: Selections. No 2: How to Read a Book about Experimental Physics...
Brody, Michael

7.1 Advanced Level

SLAC

A quantitative survey of particle physics, with special emphasis on the role of experimental methods.

1983, Oxford University Press
In search of the elementary particles of the universe: the physical world between the atom and the proton. An outline of the history of modern physics, with emphasis on the physical world between the atom and the proton.
Griffiths, David: Introduction to Elementary Particles

1984, Cambridge University Press
Dodd, James: The Ideas of Particle Physics: An Introduction for Scientists

1987, Cambridge University Press
A short course in particle physics. A Los Alamos Primer
Cooper, Nnida, and West, Geoffrey B. (eds.)

In search of the elementary particles of the universe: the physical world between the atom and the proton. An outline of the history of modern physics, with emphasis on the physical world between the atom and the proton.
Griffiths, David: Introduction to Elementary Particles

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