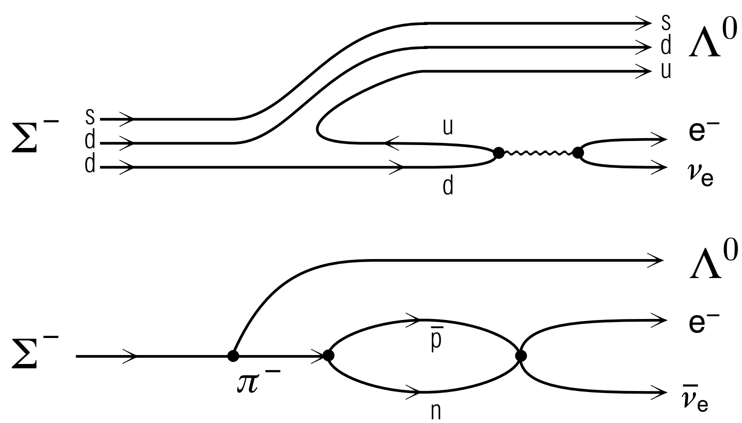
MISN-0-273

PARTICLES AND INTERACTIONS



Project PHYSNET Physics Bldg. Michigan State University East Lansing, MI

PARTICLES AND INTERACTIONS

by
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Title: **Particles and Interactions**

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Input Skills:

1. State the definition of an electron volt (eV) (MISN-0-117).
2. Use the relativistic expression relating energy, momentum, and mass, $E = (p^2c^2 + m^2c^4)^{1/2}$ (MISN-0-24).

Output Skills (Knowledge):

K1. Express energy, mass, or momentum in terms of MeV.

K2. Express angular momentum in units of $\hbar$.

K3. Express charge in units of e, the charge on a proton.

K4. List the four types of forces at work in nature, along with their ranges, and give an example of each force.

K5. Give the relative strengths of the four forces and the typical decay times corresponding to each.

K6. List the class or classes of particles acted on by each of the four forces in nature.

External Resources (Required):

1. K.W. Ford, *Classical and Modern Physics*, Vols. 1 and 3, John Wiley and Sons (1972).

Post-Options:

1. "Particle Properties" (MISN-0-275).

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New authors, reviewers and field testers are welcome.

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1. Reading

1. Sect. 3.5, 3.7, 27.1 in K.W. Ford's *Classical and Modern Physics*, Volumes 1 and 3, John Wiley and Sons, NYC (1972).

2. Forming a Theory

2a. The Goals of Particle Physics. In this unit we present the interactions studied by Particle ("High Energy") physicists. The goal of high energy ("Particle") physics is to understand why particles have the properties they have and why they interact as they do, in terms of a comprehensive theory. Such a comprehensive theory does not exist today but various leads are being followed and some of the characteristics of particles and interactions can be understood in terms of fundamental ideas.

2b. Large Numbers of Particles: Probably None Fundamental. There are now several hundred different types of particles that have been observed. Most physicists believe that few, if any, of these are truly fundamental and that there must be even more fundamental building blocks out of which the known particles are constructed. Quarks are candidates for fundamental building blocks but they have probably not been observed directly. The quark model and the classification of particles that led to it are discussed elsewhere.[1]

3. Interaction of Particles

3a. Identity, Transmutation, and Decay. Particles are identified by their properties, such as mass, charge, intrinsic angular momentum, and others. The overwhelming characteristic of the particle world is that the identities of particles change. To be sure, two particles can interact and just change their directions of motion - they scatter each other. However, if conditions are right, the particles that leave the interaction are not the same particles that entered.

[1]For example, in "SU(3) and the Quark Model" (MISN-0-282).

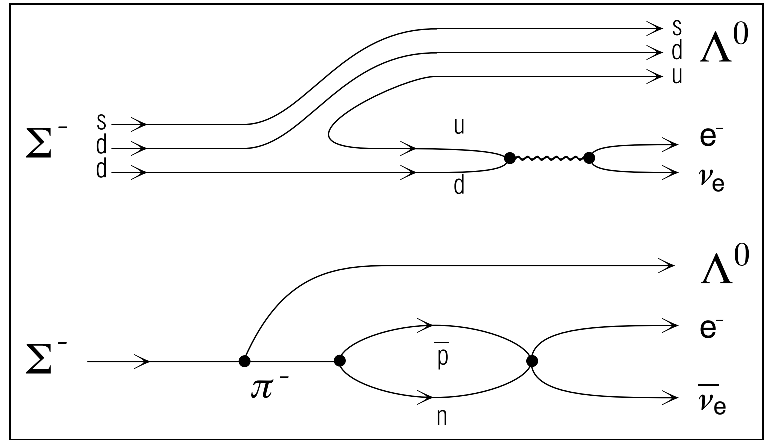

Figure 1. Two particles interact and become three particles.

For the interaction shown in Fig. 1, particles A and B disappear and particles C, D, and F appear. In addition, a single particle may decay into other particles. In fact only a small number of particles are stable against decay.

3b. Relevance of Conserved Quantities. Even though the identities of the particles may change, some quantities remain constant. These are the conserved quantities. Most of our knowledge of particles and their interactions centers around these.

3c. The Four Interactions: Properties, Manifestations. The dynamics of the particle interactions are not well understood at this time. It appears that there are four types of forces at work in nature, although some physicists are trying to show that at least some of them are really different aspects of a single force. The four are named gravitational, weak, electromagnetic and strong.

Although important in the macroscopic world, the gravitational force is so weak that it can be neglected in almost all aspects of particle physics. The other three forces are important.

The various forces are characterized and identified by their ranges, strengths, and the quantities that are conserved when they operate. A summary of some of the properties is given in the table in Appendix A.

The range of a force is an indication of how close the participating particles must come to each other before they influence each other via the force. Relative strengths of forces give some indication of the relative probability that the particles interact when they are within range. Other factors, such as energy and spin, enter the calculation of this probability: our calculation of their influences will be rough and in particular instances could be wrong by an order of magnitude.

The forces not only cause interactions between two particles, but they are also responsible for the decay of a single particle. A particle has a lifetime, the time between creation and decay, that is typical of the species of particle. A species' lifetime is indicative of the type of force that causes the decay. In fact, a measurement of the lifetime is the principal experimental method of determining the force causing a particular decay. Note in the Appendix A table that typical lifetimes are inversely proportional to relative strengths.

In the Appendix A table, under the heading "Particles Acted Upon," are listed those classes of particles that decay or interact with each other via the named force. We shall see later that perhaps not all particles interact via the weak force and that a strong interaction, too fast to be observed, sometimes precedes the weak interaction.

Some nuclei transmute into other nuclei by emitting an electron or positron. This happens when a proton or neutron within a nucleus decays:

$$\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} \quad \text{or} \quad \mathrm{p} \rightarrow \mathrm{n} + \mathrm{e}^+ + \nu_\mathrm{e}$$

where ν_e and $\bar{\nu}_\mathrm{e}$ are neutrinos. Isolated protons can never decay but those in nuclei sometimes can.

3d. Signatures of Specific Interactions. Neutrinos participate in the weak interaction only, so if a neutrino appears as a product particle at least part of the interaction must be weak. There are other weak interactions in which neutrinos do not appear.

A photon in a reaction signals you that an electromagnetic interaction was present. That is, if a photon appears, at least part of the interaction must have been electromagnetic.

Hadrons (mesons and baryons) interact via the strong interaction unless they are prevented from doing so by conservation laws.

4. Problems

Do these problems: Ford, Chap. 3 – E3.5, E3.6, E3.7.

Acknowledgments

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A. Table: Forces of Nature

Range:	Relative Strength:	Typical Decay Time:	Particles Acted Upon:	Examples:
STRONG:				
$\approx 10^{-15}$ m	1	10^{-23} sec.	Hadrons (mesons and baryons)	Binds nucleons in nuclei (nuclear forces)
ELECTROMAGNETIC:				
∞	10^{-2}	10^{-21} sec.	Charged particles	Binds electrons in atoms (atomic forces)
WEAK:				
$<< 10^{-16}$ m	10^{-13}	10^{-10} sec.	Hadrons and leptons	Radio-activity
GRAVITATIONAL:				
∞	10^{-40}	10^{17} sec. ?	All	Attraction of macro-scopic bodies for each other

B. Notes About Units

i. MeV is a common energy unit in particle physics. One electron volt, abbreviated 1 eV, is the kinetic energy obtained by an electron when it moves through a 1 volt potential difference:

$$1\,\text{eV} = 1.602 \times 10^{-19}\,\text{joules}.$$

A common energy unit is the MeV (one million electron volts): $1\,\text{MeV} = 10^6\,\text{eV}$. Another common energy unit is the GeV: $1\,\text{GeV} = 10^3\,\text{MeV} = 10^9\,\text{eV}$.

ii. Since the product mc^2 (where $m =$ mass and $c =$ speed of light) has units of energy, mass is sometimes given in MeV/c^2 or sometimes just MeV (it is common to pick units in which $c = 1$). Given mass in MeV, to get mass in kilograms, multiply by 1.602×10^{-13} and divide by c^2.

iii. The product pc (where $p =$ momentum) has units of energy so momentum is sometimes given in GeV/c or MeV/c or just MeV (using the convention $c = 1$).

iv. Angular momentum is often given in units of $\hbar$ (1.0545×10^{-34} joule seconds).

v. Charge is given in units of the charge on the proton, e (1.602×10^{-19} coulomb).

C. Problem Answers

E3.5 (1) $t < d/v$, and $d/v = 10^{-14}$ s, so answer is η, Σ^0.

(2) $t > d/v$, and $d/v = 12.74 \times 10^{-2}$ s, so answer is n.

E3.6 (1) $\text{p} + \text{e}^- + \bar{\nu}_\text{e} + \nu_\mu + \bar{\nu}_\mu + \gamma + \gamma$.

(2) progressively more negative.

E3.7 (1) [a] positive bends counterclockwise, negative clockwise;

[b] slower is more intense.

(2) negative; more intense is slower, therefore is later in time.