The following document contains the translation and adaption of

> Netzwerk Teilchenwelt (2017): Teilchensteckbriefe. Methodische Anregungen und Hinweise. Retrieved from http://www.teilchenwelt.de/material/materialien-fuer-lehrkraefte/teilchensteckbriefe/

The text has been translated from German to English by Susanne Dührkoop & Julia Woithe who also adapted the activities for an international audience.

ELEMENTARY PARTICLE CARDS

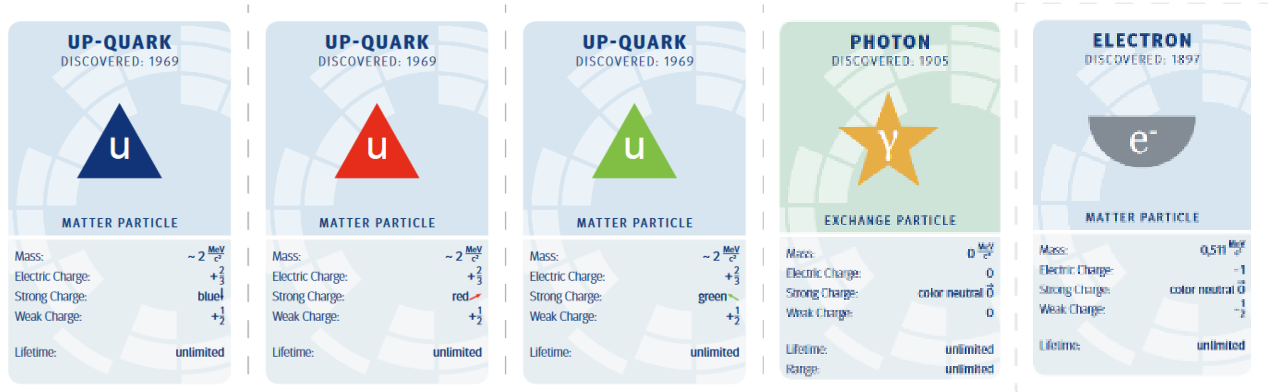
Instructions & ideas for the classroom

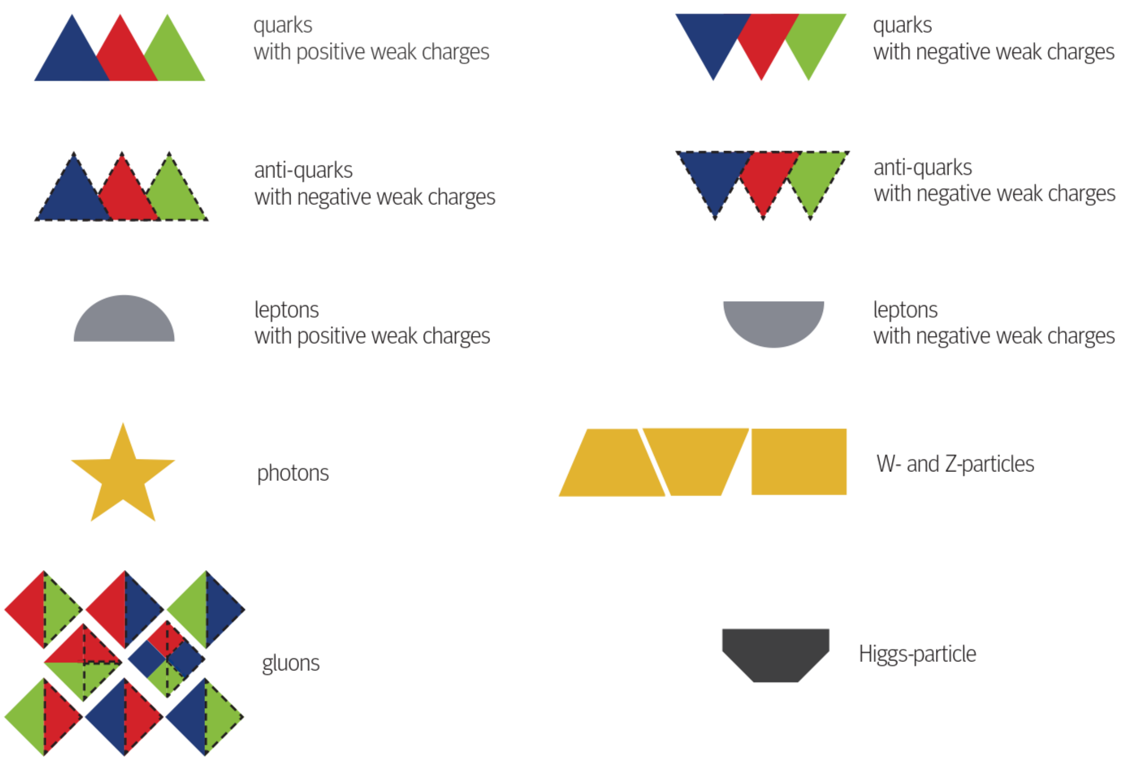
The particle cards can be used to introduce matter, anti-matter and interaction particles of the Standard Model of particle physics into the classroom. In this document, you will find suggestions for the use of the particle cards.

Description

The particle cards can be used in the classroom or in the framework of particle physics masterclasses to introduce matter, anti-matter and interaction particles of the Standard Model of particle physics or to review their properties. In this document, you will find suggestions for the use of the particle cards in your classroom.

The particle cards should be printed in colour on strong paper, cut out and possibly laminated. A set of particle cards consists of 61 cards: 24 matter and 24 anti-matter particles, 12 interaction particles and the Higgs particle. Each elementary particle is represented by a unique symbol. Particles with similar properties are represented using the same symbol shape (see below). Based on the background colours, they can be divided into groups: For matter and anti-matter particles, the background is light blue, for interaction particles bright green. The Higgs particle, which belongs to none of these groups, has a purple background.





General comments

Curriculum links

- The material can be used to introduce elementary particles or to repeat their names and properties.
- The topic of particle physics can be linked to nuclear physics or lessons about radioactivity.

Prior Knowledge

Atomic structure; electrons; electric charge; structure of protons and neutrons (quarks); unit prefixes (kilo, mega, giga ...); electron volt as energy unit, and eV / c^2 as mass unit.

Goals

We suggest the following learning objectives when using the particle cards which need to be adapted to students' prior knowledge and the intended classroom use.

The students ….

- ... get to know the basic properties of elementary particles (masses, charges,...).
- ... describe similarities and differences between elementary particles.
- ... explain differences between quarks and leptons.
- ... describe the classification of matter particles in three generations.
- ... compare the properties of matter and anti-matter particles.
- ... get to know the three types of charges (strong, weak, electric).
- ... learn about interaction particles.
- ... combine particle cards to represent particle systems such as protons or neutrons, or to represent particle transformations.

Time needed

Depending on the method used, you will need 10-20 minutes to explain and have students perform the activity. After that, students' finding should be discussed.

Activity suggestions

Activity 1: Sorting particles

- **Description:** Each participant receives one particle card. For this activity, the Higgs particle should be omitted since it cannot be classified into a group. An instruction for students could be: **"Find students with other particle cards which help you form meaningful groups. Which similarities and which differences do you notice between the particles? Is there an order within your group?"**
- **Hints:** "Look at the symbols / background. Search for particles that have similar properties."
- **Discussion:** The students explain how and why they have formed certain groups. Similarities within the group and differences to other groups are discussed as well as the order within the group. Possible groupings could be for example: quarks, leptons, anti-matter particles, interaction particles.

How would you call your group? Why did you form a group?

- We are all matter particles / anti-matter particles / quarks / neutrinos / interaction particles.
- We have the same background colour / our particle symbols have the same shape.
- We have the same electric, weak or strong charge.

Which properties do you have in common?

- **Electric charge**
  - Quarks have a fractional electric charge. Electrically positively charged quarks such as the up quark have an electric charge of $+2/3$, while electrically negatively charged quarks such as the down quark have an electric charge of $-1/3$.
  - Leptons have an integer electric charge. Neutrinos are electrically neutral, and the electrically charged leptons have an electric charge of +1 or -1.
  - The electric charge of the anti-matter particles is opposite to the corresponding charge of the matter particles.
  - Among the (anti-) matter particles, only the neutrinos are electrically neutral.
  - Most of the interaction particle are electrically neutral (photon, gluons, Z particles) while the W particles have an electric charge.
- **Mass**
  - Photons and gluons have no mass, the remaining interaction particle are very massive (W and Z particles).
  - Neutrinos are very light compared to other elementary particles. Experimental data provides us only with limits for their mass: The mass of neutrinos is less than 0,1 eV / c^2.
- **Strong and weak charge**
  - Quarks have a strong charge (also called colour charge). Quarks are therefore affected by the strong interaction. The interaction particles of the strong interaction (gluons) have eight different combinations of colour charges.

- Matter and anti-matter particles have a half-integer weak charge. Interaction particles have either an integer weak charge (W-bosons) or the weak charge 0 (photons, gluons and Z particles)

- **What is the difference between your particle cards in your group? How would you sort your particles within the group?**
    - according to the electric charge
    - By mass: up quark, down quark, electron, and electron neutrino each have two heavier "copies" that only have other masses.
    - Maybe following the discovery date, in most cases more massive particles have been discovered later.

- **What are the differences between your group and other groups?**
    - Quarks have a fractional electric charge, the electric charge of leptons is an integer number or 0.
    - Quarks have a strong charge (colour charge), leptons don't.
    - Matter and anti-matter particles each have the same mass, but opposite charges.
    - Neutrino masses are much smaller than the mass of any other elementary particle and neutrinos only have a weak charge.

Finally, the properties of the particles can be summarized on the blackboard.

Activity 2: Standard Model puzzle

- **Description:** The students work in groups. Each group receives a full set of cards. An instruction for students could be: "Arrange the elementary particles in meaningful groups. Then think about the similarities and differences of the particles. Is there an order within the groups?"
  The activity focuses on the overall pictures not so much on the individual properties of the particles. Different solutions can be found by the students and should be discussed.

Activity 3: Triplet - Game

- **Description:** This is a modification of the card game Quartets. Before starting the game, students should be introduced to the similarities and differences of the particles, for example using activities 1 or 2. You need one set of cards per game for 2-4 players.
- **Rules:**
    - All gluon cards are sorted out, they are not needed.
    - If you play with 4 players, each player receives 6 cards, for 3 players 7 cards, for 2 players 9 cards.
    - The goal is to build as many triplets as possible.

- Each of these triplets consists of three particles with the same symbolic shape. The groups should be defined beforehand together with the students:
    - Leptons (lower semicircles)
    - Neutrinos (upper semicircles)
    - Quarks with negative weak charge (triangle pointing downwards)
    - Quarks with positive weak charge (triangle pointing upwards)
    - Corresponding anti-particle groups
    - Interaction particles of the weak interaction (W and Z particles)
    - The photon and the Higgs particle remain. Since there is no physical reason to group them together, they are unmatchable cards
- In order to collect triplets, the players in turn ask their right neighbour for a missing card.
- It is only allowed to ask questions about the particle properties listed in the lower text box (mass, charges, lifetime and range).
- If the respondent has a suitable card, he must give it to the questioner; the questioner must take the card, even if he wanted another card. This is a charming difficulty of the game.
- If the respondent does not have a matching card, the questioner draws a card from the pile.
- When played in pairs, the respondent may not return the same card he has just received.
- The person who built the most triplets within a certain time wins.

▪ **Remarks:** To help students, you can distribute an overview chart or project it on the wall during the game. Since the game can take a long time, a time limit (e.g., 15 minutes) should be set in advance.

Method 4: Corner Game

▪ **Description:** Each participant receives a particle card. The teacher announces the criteria according to which the students have to split up in the corners of the room, for example:
- Matter, anti-matter, interaction particles
- Leptons, quarks, interaction particles
- Electric charge number (0, + 1 / -1, fractions)
- Colour charge (colour, anti-colour or colourless)
- Weak charge (half integer / integer)
- Mass ($m = 0$; $0 < m < 20$ MeV/c^2; 20 MeV/c^2 $< m <$ 1.5 GeV/c^2; $m >$ 1.5 GeV/c^2)
- 1st, 2nd, 3rd generation (if previously discussed)

The participants can also line up in a row:
- according to the mass of the particles
- according to the year of their discovery