



# PARTICLE CARDS

## SUGGESTIONS FOR THE USE IN CLASS

The particle profile cards can be used in class or in particle physics masterclasses to introduce matter, antimatter and messenger particles of the standard model of particle physics. In this document you will find suggestions for the use of the particle profile cards.

**IMPRINT Publisher:** Michael Kobel, Thomas Trefzger **Autors:** Michael Kobel (responsible), Manuela Kuhar, Philipp Lindenau, Lachlan McGinness, Susanne Dührkoop **Editorial:** Uta Bilow, Michael Kobel, Felix Lehmann, Philipp Lindenau, Franziska Viebach **Layout:** büro quer, www.buero-quer.de, Netzwerk Teilchenwelt, TU Dresden **Project Management:** Michael Kobel, Uta Bilow | Netzwerk Teilchenwelt | TU Dresden, Institut für Kern- und Teilchenphysik | www.teilchenwelt.de, mail@teilchenwelt.de, Thomas Trefzger | Julius-Maximilians-Universität Würzburg | Lehrstuhl für Physik und ihre Didaktik **Lizenz und Nutzung:** Creative Commons 2.0-by-nc-nd | Licensees may copy, distribute, display and perform only verbatim copies of the work, not derivative works and remixes based on it. Author must be mentioned. For imprint see: [www.teilchenwelt.de/service/impressum](http://www.teilchenwelt.de/service/impressum).

PROJECT MANAGEMENT



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PARTICLE CARDS

## SHORT DESCRIPTION

The particle cards can be used in class or in particle physics masterclasses to introduce matter, antimatter and messenger particles of the standard model of particle physics or to repeat their properties. In this document you will find suggestions for the use of the particle profile cards.

The particle profile cards should be printed in color on thick paper, cut out and possibly laminated. A set of particle cards consists of 61 cards: 24 matter and 24 antimatter particles, 12 messenger particles and the Higgs particle. Each elementary particle has its own symbol. Particles with similar properties have the same symbol shape (see below). The cards have backgrounds according to the type of particle. For matter and antimatter particles, the background is light blue, for messenger particles bright green. The Higgs particle belongs to neither of these groups and has a purple background.

<p><b>UP QUARK</b> DISCOVERED: 1969</p> <p><b>MATTER PARTICLE</b></p> <p>Mass: <math>\sim 2 \frac{\text{MeV}}{c^2}</math> Electric Charge: <math>+\frac{2}{3}</math> Strong Charge: <b>blue</b> Weak Charge: <math>+\frac{1}{2}</math> Lifetime: <b>unlimited</b></p>	<p><b>UP QUARK</b> DISCOVERED: 1969</p> <p><b>MATTER PARTICLE</b></p> <p>Mass: <math>\sim 2 \frac{\text{MeV}}{c^2}</math> Electric Charge: <math>+\frac{2}{3}</math> Strong Charge: <b>red</b> Weak Charge: <math>+\frac{1}{2}</math> Lifetime: <b>unlimited</b></p>	<p><b>ANTIUP QUARK</b> DISCOVERED: 1969</p> <p><b>ANTIMATTER PARTICLE</b></p> <p>Mass: <math>\sim 2 \frac{\text{MeV}}{c^2}</math> Electric Charge: <math>-\frac{2}{3}</math> Strong Charge: <b>anti-green</b> Weak Charge: <math>-\frac{1}{2}</math> Lifetime: <b>unlimited</b></p>	<p><b>PHOTON</b> DISCOVERED: 1905</p> <p><b>MESSENGER PARTICLE</b></p> <p>Mass: <math>0 \frac{\text{MeV}}{c^2}</math> Electric Charge: <math>0</math> Strong Charge: <b>color neutral</b> Weak Charge: <math>0</math> Lifetime: <b>unlimited</b> Range: <b>unlimited</b></p>	<p><b>ELECTRON</b> DISCOVERED: 1897</p> <p><b>MATTER PARTICLE</b></p> <p>Mass: <math>0.511 \frac{\text{MeV}}{c^2}</math> Electric Charge: <math>-1</math> Strong Charge: <b>color neutral</b> Weak Charge: <math>-\frac{1}{2}</math> Lifetime: <b>unlimited</b></p>
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quarks with positive weak charge



quarks with negative weak charge



antiquarks with positive weak charge



antiquarks with negative weak charge



leptons and antileptons with positive weak charge



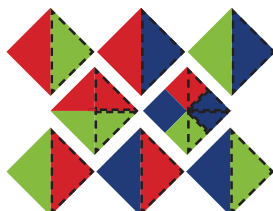
leptons and antileptons with negative weak charge



photons



W and Z particles



gluons



Higgs particle



## GENERAL INFORMATION

### CLASSIFICATION FOR LESSONS

- ▶ The activities and resources here can be used for the introduction of elementary particles or for repetition and consolidation.
- ▶ If particle physics is taught, it can be linked to a series of lessons on nuclear physics or radioactivity.
- ▶ In addition to the introduction of the elementary particles, interactions and the detection of particles with detectors can be discussed in class.
- ▶ The implementing of a particle physics project day (masterclass) enables the students to reinforce their knowledge and gain an insight into modern particle physics. More information can be found at [www.physicsmasterclasses.org](http://www.physicsmasterclasses.org).

### PRIOR KNOWLEDGE

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

### GOALS

The following learning objectives can be pursued using the particle cards. Depending on the student's prior knowledge, some activities may be an introduction or consolidation of elementary particles and their properties. It is convenient to introduce the types of charge before all the particles of the standard model are introduced.

The students...

- ▶ ... learn about the basic properties of elementary particles (mass, charge,...).
- ▶ ... describe similarities and differences between elementary particles.
- ▶ ... explain differences between quarks and leptons.
- ▶ ... describe the order of matter particles in three generations.
- ▶ ... compare the properties of matter and antimatter particles.
- ▶ ... familiarise themselves with the three types of charge (strong, weak, electric).
- ▶ ... learn about the messenger particles of the three interactions that are relevant for particle physics.
- ▶ ... construct composite particles (e.g. proton and neutron) and particle transformations.

### TIME NEEDED

Most activities require 10-20 minutes. After that, additional time will be needed for discussion.



#### **Astro-/particle physics teaching materials (in German)**

[www.teilchenwelt.de/tp](http://www.teilchenwelt.de/tp)

#### **Further information and links (in German)**

[www.teilchenwelt.de/material](http://www.teilchenwelt.de/material)



## INSTRUCTIONS FOR CLASSROOM ACTIVITIES

## ACTIVITY 1: SORT PARTICLES

- ▶ **Description:** Each student receives a particle card. For this method, the Higgs particle should be omitted since it cannot be classified into a group. Give the instruction: „**Form groups with other students who have cards which have something in common. Then consider what similarities and differences the particles have. Is there an order within your group?**“
- ▶ **Notes:** Each student compares the properties of his or her elementary particle with the others. Thus, the students are able to form groups by themselves. The teacher should intervene only when needed, for example „Look at the symbols / background. Search for elementary particles that have similar properties.“
- ▶ **Evaluation:** The students explain how and why they have formed their groups. Students discuss the similarities within their group and differences to other groups: Possible groupings could be for example: quarks, leptons, antimatter or messenger particles.

**How would you name your group ? Why did you form this group?**

- ▶ We are all matter particles/ antimatter particles/ quarks/ neutrinos/ messenger particles.
- ▶ We have the same background color/ 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 electric charge numbers that are multiples of one third. Electrically positive charged quarks like the up quark, have an electric charge number of  $+2/3$ , while electrically negative charged, quarks, such as the down quark, have an electric charge number of  $-1/3$ .
  - ▶ Leptons have integer electric charge numbers. Neutrinos are electrically neutral, and the electrically charged leptons have an electric charge number of  $-1$ .
  - ▶ The electric charge numbers of the antimatter particles is opposite to the corresponding matter particles.
  - ▶ Among the (anti) matter particles, only the neutrinos are electrically neutral.
  - ▶ Most of the messenger particles are electrically neutral (photon, gluons, Z particles) while the W particles have an electric charge number of either  $+1$  or  $-1$ .
- ▶ **Mass**
  - ▶ Photons and gluons have no mass, the remaining messenger particles are very massive (W and Z particles).
  - ▶ Neutrinos are very light compared to other elementary particles. Experimental data provides us only with upper limits for their mass: The mass of neutrinos is less than  $0.1 \text{ eV}/c^2$ .
- ▶ **Strong and weak charge**
  - ▶ Quarks have a strong charge (also called color charge). The three possible color charges of quarks are called red, blue and green. Quarks are therefore subject to the strong interaction. The messenger particles of the strong interaction (gluons) have eight different combinations of color charges.
  - ▶ Matter and antimatter particles have half-integer weak charge numbers. Messenger particles possess either an integer weak charge number (W particles) or the weak charge number 0 (photons, gluons and Z particles).

**How do you differ within the group? How would you sort yourself within the group?**

- ▶ According to the electric charge numbers.
- ▶ By mass: up quark, down quark, electron, and electron neutrino each have two heavier „copies“ which only differ by mass.
- ▶ If applicable, the discovery date. Here it might be noticed that more massive particles tend to have been discovered later.



## INSTRUCTIONS FOR CLASSROOM ACTIVITIES

### What sets you apart from other groups?

- ▶ The electric charge number of quarks comes in multiples of one third, that of leptons is integer or 0.
- ▶ Quarks have a strong charge (color charge), leptons do not.
- ▶ matter and antimatter particles each have the same masses, but opposite charges.

### What is the difference between quarks and leptons?

- ▶ Leptons have an integer electric charge number; quarks come in multiples of one third.
- ▶ Leptons do not have a strong charge. Each quark has one of three possible strong charges (quarks are therefore subject to the strong interaction).

### What is the difference between neutrinos and other matter particles?

- ▶ They have at least five orders of magnitude less mass than the next heavier elementary particle (the electron) and have only a weak charge.

Finally, the properties of the particles can be summarized by using a suitable powerpoint or whiteboard presentation.

## ACTIVITY 2: STANDARD MODEL PUZZLE

- ▶ **Description:** The students work in groups. Each group receives a set of cards. The work tasks reads as follows: **„Arrange the elementary particles into meaningful groups. Then think about which similarities and differences the particles have. Is there an order within the groups?“** The focus here is more on the overall view than on the individual properties of the particles. Competing solutions can arise and be discussed.
- ▶ **Evaluation:** see method 1: sorting particles

## ACTIVITY 3: TRIPLET GAME

- ▶ **Description:** This is a modification of “Go Fish” (Quartet game). It helps students familiarise themselves with particle properties or consolidate their knowledge. Before the game, an overview of the similarities and differences between the elementary particles should be given, for example with activity 1 or 2. You need one set of cards per game for 2-4 players.
- ▶ **Rules:**
  - ▶ All gluons are removed from the pack.
  - ▶ 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 with the students beforehand:
    - ▶ Leptons (semicircles)
    - ▶ Quarks with positive weak charge number (triangle with tip up)
    - ▶ Quarks with negative weak charge number (triangle with tip down)
    - ▶ Corresponding antiparticle groups
    - ▶ Messenger 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 “black peters” (old maids).



## INSTRUCTIONS FOR CLASSROOM ACTIVITIES

- ▶ In order to collect triplets, the player in turn asks his right neighbour for a missing card.
  - ▶ Players must ask questions about the particle properties given in the lower text box (mass, charges, lifetime and range).
  - ▶ If the person in question 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 person in question does not have a matching card, the questioner draws a card from the pile.
  - ▶ When played in pairs, the person in question may not return the same card he has just received.
  - ▶ The person who has built the most triplets within a certain time wins.
- ▶ **Hints:** As an aid, 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.

### ACTIVITY 4: CORNER GAME

- ▶ **Description:** This short game is suitable as an introduction to the beginning of a teaching sequence on particle physics, repetition or as a transition to related topics. Each student receives a particle card. The teacher indicates the criteria according to which the students have to split up in the corners of the room, for example:
  - ▶ Matter, antimatter, messenger particles
  - ▶ Leptons, quarks, messenger particles
  - ▶ Electric charge number (0, +1 / -1, multiples of a third)
  - ▶ Strong color charge (color, anticolor or colorless)
  - ▶ Weak charge number (half integer / integer)
  - ▶ Mass ( $m = 0$ ;  $0 < m < 20 \text{ MeV}/c^2$ ;  $20 \text{ MeV}/c^2 < m < 1.5 \text{ GeV}/c^2$ ;  $m > 1.5 \text{ GeV}/c^2$ )
  - ▶ 1./2./3. 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
- ▶ **Evaluation:** see activity 1: sorting particles. When the students sort themselves according to the mass and year of discovery of their particles, they should note that more massive particles tend to have been discovered later. A transition to modern research with particle accelerators is a good option.