You will need:

• A phone or S’Cool LAB laptop to access the internet
Teacher in Residence!
WHAT IS A TEACHER IN RESIDENCE?
S’COOL LAB

We run workshops for students (and teachers) visiting CERN to support the S’Cool LAB team. We use it to develop and test our new (low cost, 3d-printable) hands-on activities. We work as a team.
<table>
<thead>
<tr>
<th>Resource Name</th>
<th>Topic</th>
<th>Type</th>
<th>Language</th>
<th>Age</th>
<th>Supervision Necessary</th>
<th>Required Materials</th>
<th>Website</th>
<th>Author</th>
<th>Description</th>
<th>Worth Investigating? (number out of 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud Chamber Introduction to the Cloud</td>
<td>Hands on Cloud</td>
<td>Activity</td>
<td>English</td>
<td>16+</td>
<td>Yes</td>
<td>Dry ice, improvisational computers, video conferencing</td>
<td><a href="http://opkg.org/sites/opkg.web.cern.ch/files/SF/Julie_Wonthe">http://opkg.org/sites/opkg.web.cern.ch/files/SF/Julie_Wonthe</a></td>
<td></td>
<td>Instructions for building a cloud chamber from scratch.</td>
<td>9</td>
</tr>
<tr>
<td>International Masterclass Be a physicist/dans the skin</td>
<td>Hands on Activity</td>
<td>Event-based</td>
<td>French</td>
<td>19-19</td>
<td>Yes</td>
<td>Boxes and objects to investigate and test</td>
<td><a href="http://opkg.org/sites/opkg.web.cern.ch/files/iv/Saindrine_Solson-rectanglafinal.pdf">http://opkg.org/sites/opkg.web.cern.ch/files/iv/Saindrine_Solson-rectanglafinal.pdf</a></td>
<td></td>
<td>Students perform an investigation to determine the unknown objects hidden.</td>
<td>8</td>
</tr>
<tr>
<td>CMS HEP Tutorial</td>
<td>Hands on Activity</td>
<td>English</td>
<td>English</td>
<td>9-12</td>
<td>Yes</td>
<td>Boxes and objects to investigate and test</td>
<td><a href="http://opkg.org/resource/2012/cms-hep-tutorial">http://opkg.org/resource/2012/cms-hep-tutorial</a></td>
<td></td>
<td>Students learn programming to handle data from CMS.</td>
<td>7</td>
</tr>
<tr>
<td>Mass Celic Z</td>
<td>Hands on Activity</td>
<td>Computer</td>
<td>English</td>
<td>10-18</td>
<td>No</td>
<td>Computer</td>
<td>Link broken</td>
<td></td>
<td>A resource which helps</td>
<td>6</td>
</tr>
<tr>
<td>The Particle Adventure</td>
<td>Hands on Activity</td>
<td>Computer</td>
<td>English</td>
<td>15-18</td>
<td>No</td>
<td>Computer</td>
<td><a href="http://particleadventure.org/">http://particleadventure.org/</a></td>
<td></td>
<td>A modified version of the popular game similar to the game of life.</td>
<td>5</td>
</tr>
<tr>
<td>Quark-tastic</td>
<td>Standard Game</td>
<td>Game</td>
<td>English</td>
<td>15+</td>
<td>No</td>
<td>Dice, stickers</td>
<td><a href="http://opkg.org/sites/opkg.web.cern.ch/files/Niello_Takal">http://opkg.org/sites/opkg.web.cern.ch/files/Niello_Takal</a></td>
<td></td>
<td>A resource which helps</td>
<td>4</td>
</tr>
<tr>
<td>The Quark Card</td>
<td>Standard Game</td>
<td>Game</td>
<td>English</td>
<td>15+</td>
<td>No</td>
<td>Quark Cards</td>
<td><a href="http://opkg.org/resource/2012/standard-quark-card">http://opkg.org/resource/2012/standard-quark-card</a></td>
<td></td>
<td>A modified version of the popular game similar to the game of life.</td>
<td>3</td>
</tr>
<tr>
<td>Quark Card Deck</td>
<td>Standard Game</td>
<td>Game</td>
<td>English</td>
<td>15+</td>
<td>No</td>
<td>Cards (Available at website)</td>
<td><a href="https://www.jicus.jp/en/promotion/quark-quark-card">https://www.jicus.jp/en/promotion/quark-quark-card</a></td>
<td></td>
<td>A modified version of the popular game similar to the game of life.</td>
<td>2</td>
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<tr>
<td>QCD the game</td>
<td>Standard Game</td>
<td>Game</td>
<td>English</td>
<td>15+</td>
<td>No</td>
<td>Cards (Available at website)</td>
<td><a href="https://www.jicus.jp/en/promotion/quark-quark-card">https://www.jicus.jp/en/promotion/quark-quark-card</a></td>
<td></td>
<td>A modified version of the popular game similar to the game of life.</td>
<td>1</td>
</tr>
<tr>
<td>The world of quarks and their interactions</td>
<td>Standard Game and Activity</td>
<td>English</td>
<td>English</td>
<td>6-12</td>
<td>Yes</td>
<td>Generic Quark cards</td>
<td><a href="http://opkg.org/sites/opkg.web.cern.ch/files/Uni_of_Bristol_Hunters/Quark_cards">http://opkg.org/sites/opkg.web.cern.ch/files/Uni_of_Bristol_Hunters/Quark_cards</a></td>
<td></td>
<td>A game and an activity for primary school children. The game is similar to the game of life, but with the standard model. A Quark based game that allows students to become</td>
<td>0</td>
</tr>
<tr>
<td>Quarkle</td>
<td>Standard Game</td>
<td>Game</td>
<td>English</td>
<td>12+</td>
<td>No</td>
<td>Quarkle Cards</td>
<td><a href="https://www.thegeometer.com/games/quarkland/en/hunters">https://www.thegeometer.com/games/quarkland/en/hunters</a></td>
<td></td>
<td>A modified version of the popular game similar to the game of life.</td>
<td>0</td>
</tr>
</tbody>
</table>

**DATABASE**
WORKGROUPS - HST

Low Cost 3D Printable Experiments

Semiconductors at CERN
Students will learn:

- **Conceptual knowledge essential to understand Feynman diagrams**

- **Knowledge of particle physics interactions and estimation of the probability of certain processes in particle physics using Feynman diagrams.**
KAHOOT

You will need:
• A phone or S’Cool LAB laptop
• Go to https://kahoot.it/

If you would like to use this quiz at home:
https://create.kahoot.it/details/hst-anti-matter/67933d98-8699-4f91-b22f-79792aebb9a0
What we worked on:

- Refined Trap Design
- Student Worksheets
- Teacher Guidelines and Solutions
- Construction Manual
- Paper
TRAP DESIGN
For the following experiment, we’ll concentrate on the area around the electrodes. This is why we’ll use a sketch of the electrodes only, instead of a sketch with the solution.

**Defence**

- [Diagram showing electrode arrangement]

**Name**

- [Diagram showing a different electrode arrangement]

Draw the electric field lines into the sketches of the electrodes of the usual trap and the one you are going to use. Compare the pictures and conclude on what that means for the construction of the trap. We are going to use the sketch to show the movement of charged particles. (Remember, as we use AC voltage the charge will continuously change.)

**Question:**

a) All at one point
b) rectangular configuration
c) diamond-shaped configuration
d) circular configuration

*Example*

<table>
<thead>
<tr>
<th>Student 1</th>
<th>Student 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
</tbody>
</table>

**Experiment 1: Trapping the Spores**

You will now start trapping and see how the spores behave in the trap.

**Prediction:**
Imagine you place some spores in the centre of the ring electrodes. How do you expect them to behave?

Think about how they will be arranged (shape and where they will be positioned).

Decide for one of the figures, a) to d) which are shown bigger than the actual size, and mark the expected position of this shape in the sketch of the cross-section. (See below.)

*Example*

<table>
<thead>
<tr>
<th>Student 3</th>
<th>Student 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
</tbody>
</table>
TEACHER GUIDELINES
AND SOLUTIONS

For the following experiment, we’ll concentrate on the area around the electrodes. This is why we’ll use a sketch of the electrodes only, instead of a sketch with the calling.

**What we will do today:**
- You are going to be an antenna developer today. Your task is to learn how to bring signals with a quadrupole ion trap.
- Your “particles” today will not be elementary particles like electrons, but very big particle systems, so called tetrapole systems (also common, show picture). The system traps look like a fire Souza: it consists of very small spores (or seeds). Because of friction, these spores are electrically charged.

**What is antistatic?**
- Ask students for what they think.
- Every particle has a corresponding antistatic — a very important symmetry in the standard model of particle physics. Most of these particles are identical, for example, they have the same mass. However, their electric charge is opposite.
- One example is the proton, which is the component of the electrons. The proton has a positive electric charge.
- If a particle meets an antistatic it annihilates, they are converted, for example, into two photons. The process can be reversed: If there is enough energy, a particle-antiparticle pair can be produced.

**What would you make for an anti hydrogen atom? (take antiparticle, add positive)**

**Who is antistatic research interesting?**
- We know that during the Big Bang equal amounts of matter and antismatter particles have been produced (charge conservation law). Today, we only see matter around us, the antismatter has disappeared.
- We need to study antismatter, to find out if there may be small differences between particle and antiparticle that could explain why we live in a “matter world.” Or maybe there is an antismatter world somewhere far away in the universe?

**What kind of antistatic experiments are we doing at CERN?**
- One of the many experiments is called GASY.
- Finally try to answer a very simple - fast testing question. Imagine you drop a matter apple on our matter Earth. Everyone agrees, that it will fall down. Now, imagine you drop an antimatter apple on an antismatter Earth. What will happen? Everyone agrees, that the same physics rules apply, so the apple will fall down. On Earth, if we had a switch that could turn off all the matter into antismatter, we wouldn’t notice any difference.

Further information, you might want to discuss with your students, before performing the workshop.
CONSTRUCTION MANUAL

3. Required Materials
The Table 3.1 below presents all the required materials to build the quadruple ion trap. Note that the components highlighted in blue are sufficient if you do not intend to build the blinking circuit.

<table>
<thead>
<tr>
<th>Description</th>
<th>Price</th>
<th>Online Shop</th>
<th>Stock Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x Resistor (10kΩ)</td>
<td>€ 6</td>
<td>2008572</td>
<td></td>
</tr>
<tr>
<td>Multi Contact pins</td>
<td>€ 4</td>
<td>404-230</td>
<td></td>
</tr>
<tr>
<td>1 x Toggle Switch 5V</td>
<td>€ 5</td>
<td>449-6733</td>
<td></td>
</tr>
<tr>
<td>1 x Jumper wires</td>
<td>€ 10</td>
<td>701-14465</td>
<td>741-9442</td>
</tr>
<tr>
<td>Electric Parts (black)</td>
<td>€ 20</td>
<td>835-2290</td>
<td></td>
</tr>
</tbody>
</table>

*Note: any DC switch will work for the non-floating circuit; however, an AC switch is required for the ion trap circuit.

Table 3.1 List of required materials

Three M2.5 x 5 (POWY screw thread), and these M2.5 Washer are also required.

To build the trap you will also need a paintbrush, scissors, duct tape, screwdrivers and soldering equipment.

4.2. Sifting Circuit
A great variation of the quadruple ion trap is to observe the charged particles under a stroboscopic light. This section contains instructions for building an "isolate multiplier", a circuit that causes an LED to turn on and off multiple times per second. This exhaust multiplier contains a switch to switch between stroboscopic and continuous LED's and a potentiometer to change the frequency of the sifting. The frequency should range between 350Hz and 104Hz.

Description
Attach leads to the potentiometer. To do this cut a male-to-male Gore connector (shown in diagram below) in half and strip the ends. Then solder one lead to the middle pin of the Gore connector and label the second lead to either of the side pins.
Template of Hardware Metapaper
For submission to the Journal of Open Hardware

(1) Overview

Title
3D-printable model of a particle trap: development and use in the physics classroom

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4. Keller, Oliver;
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6. Schmalz, Sascha;
7. Wehrl, Edward;
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Abstract
Quadrupole ion traps are modern and versatile research tools used in mass spectrometers, in atomic frequency and time standards, in trapped-ion quantum computing research, and for trapping anti-hydrogen ions at CERN. Despite their educational potential, quadrupole ion traps are seldom introduced into the physics classroom not least because commercial quadrupole ion traps are expensive and difficult to set up. We present an open hardware 3D-printable quadrupole ion trap suitable for the classroom, which is capable of trapping Neoclockdom ions.
The quadrupole ion trap operates using a 3 V 50 Hz alternating current power supply and uses an available multiphase circuit including high luminous LEDs to illuminate the spores, using the ultrasonic effect to exhibit their movement.
The trap can be used in teaching laboratories to enhance high school and university students' understanding of electric fields and their applications.

Metadata Overview
Link: https://zenodo.org/record/1257187
Target group: secondary school students, undergraduate students, and their teachers (skills required: Desktop 3D printing - easy; Point to Point breadboard construction - easy). Replication: For example, the artist's thesis on DIY construction of quadrupole ion traps is available in German [9]. Commercial versions of the project can be purchased at Neoclocktronics and LO Detectors [9, 10]. Future versions of designs may be found at DOI: 10.5281/zenodo.1257187.
See section "Build Details" for more detail.

Keywords
Physics Education; Quadrupole Ion Trap; Paul Trap; Particle Trap.

Introduction
3D printing and ‘making’ in an educational context has become more prevalent and 3D printers are becoming more widespread in schools and universities throughout Europe, America and Australia [7, 10, 12]. There is also increasing focus on modern physics and particle physics in high school curricula [1, 2, 5]. However, particle physics can be an abstract topic as there are a limited number of hands-on experiments that students can perform.

One type of a hands-on experiment that students can perform is the construction of particle traps such as the quadrupole ion trap. Wolfgang Paul and Hans George Dehmelt developed
PAUL TRAP

Everything is available online at:

https://zenodo.org/record/1251787#.Wz9bHNlzaUk
PARTICLE IDENTITIES

Online Game where you can determine what type of particle fits your personality best:

cern.ch/go/fh9J
QUARK PUZZLE

What we worked on:

• Puzzle Design
• Worksheet
• Paper
PUZZLE DESIGN
Mission Briefing: Fugitive Particles

Purpose: To discover patterns and solve various tasks that help us understand the mysterious and elusive particles.

Dimension: It has been theorized that to discover the reality that the quarks obey, unfortunately even though the particles make up everything around us, they are not small things of any kind. That you can take them apart with your hands, only a few big, brave, human scientists still believe in the reality of quarks. Your mission should be to accept the task to use these puzzle pieces to discover the laws that dictate how these particles turn around. You need present your findings as a series of rules that everyone else could use to determine possible and impossible combinations of particles.

Guide to Quark Puzzle Pieces

Each piece is a model of a particle, a “quark”. Every quark has a flavor, an electric charge, and a colour charge. You can find these properties printed on the faces of the puzzle pieces below.

- Flavours include up (u), down (d), charm (c), and anti-down (d̄)
- q2d3 is an example of electric charge
- Examples of colour charge are red and anti-blue (b̄)

Some combinations fit together neatly; others do not. See diagrams below.

<table>
<thead>
<tr>
<th>Good Joint</th>
<th>Bad Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Here the pieces fit together neatly.</td>
<td>Here the pieces do not fit together neatly.</td>
</tr>
</tbody>
</table>

Using groups that fit together nicely, discover the laws and complete the mission.

Note: it is difficult to build a group trying to fit the puzzle by colour charge first and try one piece from each pile.

Debrief - Comparing the Puzzle to Real Quarks (Research Task)

The puzzle provided is only a model and it does not show what real quarks look like. Six colour research tasks is the title below write down the differences and similarities between the puzzle and real quarks. One row has been completed for you as example:

<table>
<thead>
<tr>
<th>Category</th>
<th>Quark Puzzle</th>
<th>Real Particle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>Cube shape</td>
<td>3d particle</td>
</tr>
<tr>
<td>Size</td>
<td>Big</td>
<td>Large</td>
</tr>
<tr>
<td>Unity</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>Colour</td>
<td>Charge</td>
<td>Charge</td>
</tr>
<tr>
<td>Anti</td>
<td>Particles</td>
<td>Anti-particles</td>
</tr>
</tbody>
</table>
Quantum Puzzle Activity for Student Inquiry into Quarks

Abstract

This short paper reports on the work of a puzzle published in Eric Goforth's book "The Physics Teacher" in 2019. Goforth calls for a set of foam-dimensional objects that fit together in accordance with the color-charge symmetries of the standard model of particle physics. We provide a similar set of puzzle pieces and resources to reduce the barriers of implementing the activity into the classroom.

Introduction

There is an increasing emphasis on fundamental particles, including quarks, in the high school physics classroom. However, particle physics in an abstract lab and these are the foundations of classroom activities. In 2019, Eric Goforth presented a two-dimensional quick puzzle, a physical manifestation that allowed students to discover the color-charge symmetries of quarks through inquiry. His quick puzzle pieces could be joined to form a particle system of three quarks (called baryons) and a quark-antiquark pair (called mesons). The puzzle of the puzzle pieces color only "color-charge neutral" combinations of quark puzzle pieces.

In the paper "Goforth's Tetrahedron," it was observed that several students' work involved color-neutral combinations of three-dimensional objects that fit together in a specific shape, such as a sphere or a polyhedron. In 2020, a new version of the puzzle pieces was introduced to teachers, including the 3D printing technology advanced in schools throughout Europe, America, and Australia. This updated version has also been implemented in a three-dimensional puzzle into the classroom.

In this short article, we present a set of printables that we hope will provide a resource for teachers to use in the classroom to:

- Presenting ready-to-use activities/workshops for students
- Increasing the number of objects required from 36 to 12
- Enabling the activity to develop scientific reasoning
- Highlighting particle physics in classrooms

The world needs also to develop students' scientific reasoning, which is key to developing scientific literacy. This puzzle allows teachers the opportunity to use the activity as a way to explore particle physics in their curriculum.

3D Puzzle Pieces

We present an original set of quark puzzle pieces, see Figure 1. These quark pieces can be joined in groups of three to make a color (penta), or two pieces can be put together to make a "flavor-dim" (meson). The pieces only fit together if they are consistent with the color-charge symmetries of the standard model.

Figure 1: Diagram showing 3D printed puzzle pieces. On the left side a red, green, and blue quark are combined to make a baryon. On the right side a red and anti-color charge particle creates a meson. In the inset are single quark pieces.

Note: All colors are printed in the same color as the original particle but have a striped texture. It is not necessary to print the pieces in color as the color charge is labeled on the pieces.

2D Puzzle Pieces

We also present a modified version of Goforth’s 2D puzzle pieces, see Figure 2. In light of the work of Whelan et al., we studied a difficulty with the concept of anti-color charge. We have included stripes on the quark pieces so that students can more easily identify anti-color charge and particles. We also noted that the 2D pieces do not fit neatly (like particles). We also provide a 3D printable version of these 2D puzzle pieces.

Figure 2: Images of Goforth’s modified puzzle pieces. The recent shows how anti-color charge is demonstrated using stripes.

The Classroom Activities

- **Quantum Physics Inquiry:** Using the puzzle pieces, students can explore the concept of color-charge symmetry and its implications on particle interactions.
- **PhysicsLab:** The puzzle pieces can be used as part of a hands-on activity to teach fundamental particle physics concepts.
- **Spectrum Inquiry:** Students can create a model of the standard model of particle physics using the puzzle pieces, allowing them to visualize particle interactions.

The activities described in this paper are designed to be used in the classroom to provide students with a practical and engaging way to learn about particle physics, specifically focusing on quark interactions and color-charge symmetries.
QUARK PUZZLE

2D version is available online at:
https://zenodo.org/record/1286989#.Wz-ABNIzaUk

And 3D will be available on Zenodo at DOI:
DOI: 10.5281/zenodo.1252868
GAME HEADS OR TAILS
REAL OR FAKE PARTICLES

Real Particle

Fake Particle
PION

Real Particle

Fake Particle
PION

Real Particle

Fake Particle
FLASHION

Real Particle

Fake Particle
FLASHION

Real Particle

Fake Particle
STRANGE B MESON

Real Particle

Fake Particle
STRANGE B MESON

Real Particle

Fake Particle
CHARMED SIGMA

Real Particle

Fake Particle
CHARMED SIGMA

Real Particle

Fake Particle
STRANGE KAON

Real Particle

Fake Particle
STRANGE KAON

Real Particle

Fake Particle
CHARMED SIGMA

Real Particle

Fake Particle
BOTTOM LAMDA

Real Particle

Fake Particle
BOTTOM LAMDA

Real Particle

Fake Particle
STRANGE DELTA

Real Particle

Fake Particle
STRANGE DELTA

Real Particle

Fake Particle
BOTTOM SIGMA PRIME

Real Particle

Fake Particle
BOTTOM SIGMA PRIME

Real Particle

Fake Particle
TRIPLE CHARMED XI

Real Particle

Fake Particle
TRIPLE CHARMED XI

Real Particle

Fake Particle
CHARMED DELTA

Real Particle

Fake Particle
CHARMED DELTA

Real Particle

Fake Particle
ETA

Real Particle

Fake Particle
ETA

Real Particle

Fake Particle
STRANGE D MESON

Real Particle

Fake Particle
STRANGE D MESON

Real Particle

Fake Particle
TOP B MESON

Real Particle

Fake Particle
TOP B MESON

Real Particle

Fake Particle