## Background information

**Title:** Particle GO

**Brief Description:** *This activity consists in "building" a particle accelerator by collecting its main components: an RF-cavity to accelerate the particles, a bending magnet to deviate their trajectory, and two quadrupole magnets for focusing. It is possible to change the aim of the activity by replacing the components of the accelerator with the components of another device (e.g., a microscope, a molecule, a machine, etc.)*

**Keywords:** building an object composed of parts, particle accelerators.

**Target audience:** *Students, public*

**Age range:** *11-99*

**Context(s):** *This activity can be done at school, or during public engagement events.*

**Time required:** *In school-based work, the activity can be done in 45 minutes. More time can be assigned to out-of-school activities. For example, one can use the scenario to realise a treasure hunt: in this case more time can be appropriate.*

**Technological tools required:** *AR device (currently only Android phones are supported).*

**Author(s)'s background:** *scientist.*

**Connection with the curriculum:** *The activity is suitable for every subject in which the description of something in terms of components is introduced. In this implementation, we focus on the construction of a particle accelerator, but teachers can use the same template to build an application for collecting the pieces of, e.g., a microscope, or the components of a molecule, a solar system, a motor, etc.*

*In this example, the tool can be used to introduce electromagnetic interactions: electrostatic acceleration, Lorentz Force, and magnetic fields.*

**Learning objectives:** *Learn about anything composed by sub-component. In this particular application particles accelerators are considered.*

*In the particular example, the aim is to reinforce the conceptual understanding of electromagnetic interactions.*

**Guidance for preparation:** *The AR tool must be previously installed in participants' devices. If the activity is part of a game, the game setup must be prepared. Markers can be found in the attached file.*

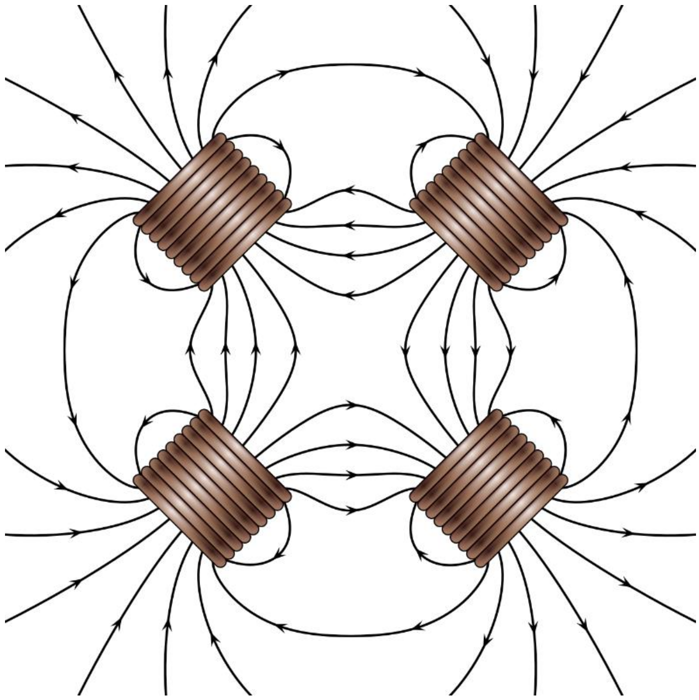
A particle accelerator needs at least four components: a source of energy (an RF-cavity), a bending magnet and two quadrupole magnets.

The RF-cavity is designed such that an electric field oscillates inside it in phase with the passage of the particles, such that the latter gain energy at each stage of the cavity. In the RF-cavity the electric field is always oriented along the cavity axis, such that particles are accelerated in the wanted direction. Leaving the cavity, particles have a given energy, and move straight according to Newton's first Law, at high speed.

In order to guide the trajectory of the particles along curved sections, a bending magnet is needed. A banding magnet is made of two coils that produce a uniform magnetic field. If oriented perpendicularly to the particles' trajectory, the magnetic field causes them to travel through an arc of circumference by means of the Lorentz Force.

When the particles exit the bending magnet, their momentum in the transverse plane may not be zero, and the beam tends to widen in both the horizontal and vertical directions. To squeeze the beam, two quadrupoles arranged to appear rotated 90 degrees relative to each other, are used.

A magnetic quadrupole provides the following magnetic field configuration:



Particles that are exactly in the center of the magnet are not affected. Positively charged particles exiting the page are then pushed toward the center of the magnetic system, in the vertical direction, but are pulled away from it in the horizontal one.

Using a second quadrupole rotated of 90 degrees, makes the beam to be squeezed in the horizontal direction and widen in the vertical one.

The combination of the two magnets causes an overall compression of the beam toward the center (focusing).

## Look around

Look for markers: each marker corresponds to one of the elements needed to build the accelerator. Here we provide the following markers:

| | |
|---|---|
| ALICE | ATLAS EXPERIMENT |
| CMS | LHCb |

When you look at one of the markers through the smartphone display, a 3D model of one of the four components appears. Collect the corresponding marker or take a screenshot.

Arranging the markers in the proper order (RF-cavity, dipole, horizontal quadrupole, vertical quadrupole) it is possible to watch a movie that explain how the LHC accelerator works, using the AR device.

## Investigation/creation

Using the Inventor section of the App, or the desktop application, you can easily customize the game by using your own markers and your own 3D models. Possible ideas are, for example,

- Build a microscope: you will need the 3D models for a light source, a transparent sample to be observed, and two convex lenses. Combining the four markers in a line may lead to the playback of a video showing the sample as observed through the microscope.
- Build a molecule: in this case you need as many markers as the constituents atoms. For water, e.g., you need an Oxygen and two Hydrogen atoms, i.e., two types of markers. Combining together three markers (one oxygen and two hydrogens) leads to the appearance of a 3D model of the water molecule.

## Communication and discussion/presentation

Discuss how Maxwell equations help physicists in building particle accelerators.

The RF-cavity can be thought of as a capacitor that applies a uniform electric field to the accelerating particle.

Dipoles can be exploited to introduce the Lorentz' Force, as well as quadrupoles that, in addition, challenge students in finding the right orientation to focus the beam in one direction.

You can use this game to introduce students to technical aspects of building an accelerator, special relativity, and the standard model.

This activity can be installed via the following QR-code: