

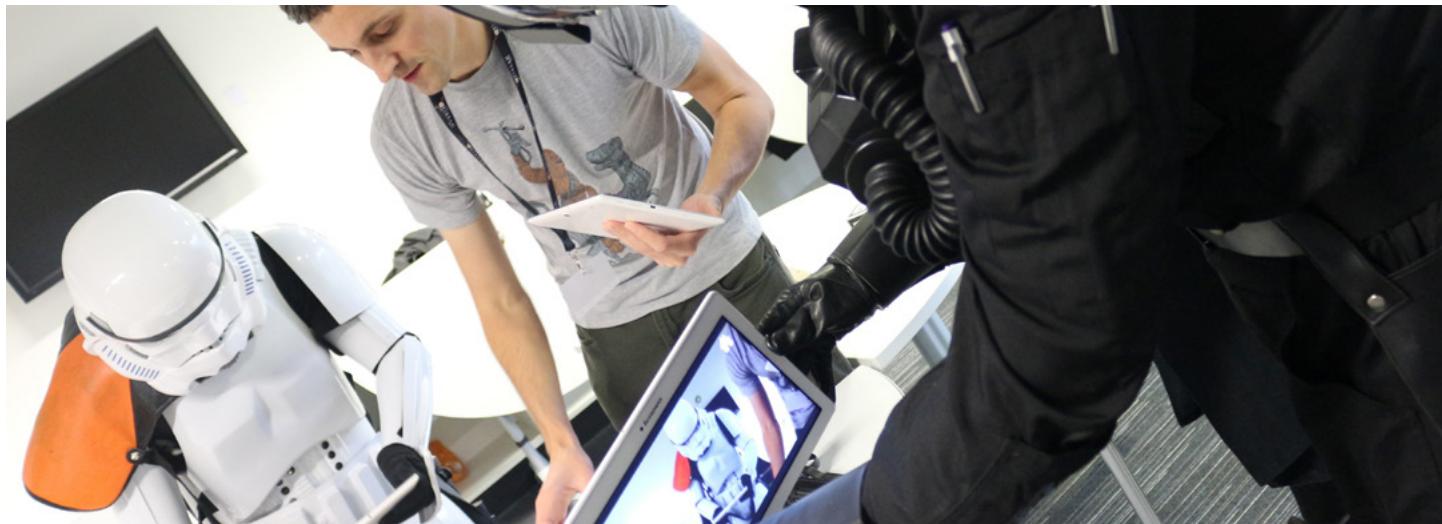


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Build your own virtual accelerator

Carsten P Welsch

Build your own virtual particle accelerator with the aid of the acceleratAR app and gain a hands-on, immersive understanding of how these machines work.

Introduction

In Star Wars, viewers were first introduced to droids when R2-D2 and C-3PO crash landed on Tatooine carrying an important message for Obi-Wan Kenobi. Their clear personalities and character have meant that droids have remained popular ever since – including new addition BB-8 in the recent sequels.

We cannot match the level of sophistication of R2-D2 or BB-8, but we do use machine learning to optimize the control of particle accelerators, artificial intelligence for data analysis from high-energy particle collisions, and augmented reality to understand challenging physics and engineering concepts.

Particle accelerators are unique tools for scientific discoveries; they also find application in many other areas, such as cancer treatment, energy production, or as airport-security scanners.

A stormtrooper using acceleratAR, the virtual accelerator app.
The Cockcroft Institute



They are formed of several essential components: the source of the particles, an element that accelerates them, and different types of magnets that control how wide the beam is and its direction.

To see how these machines work, it is possible to build your own virtual accelerator, using the acceleratAR app. With acceleratAR, you can get a hands-on, immersive understanding of how a particle accelerator works. These activities are designed for 16–19 year olds and teach students about magnets and how particle accelerators work. It should be possible to complete the activities in one lesson, although they could be split over two. All you need is a smartphone or tablet and four different types of paper cubes.

Activity 1 – Build the accelerator components

The fiddly bit is printing and cutting out the blocks. This could be done in advance of the lesson, so that the blocks only need to be taped together in the classroom, which will leave more time for the experiments.

Materials

- Cube printouts from <http://acceleratar.uk/>
- Scissors
- Tape or glue
- Paper
- Cardboard (optional)
- Printer
- Stiff piece of cardboard (such as a business card) to help you fold the printouts
- Smartphone or tablet
- Flat surface on which to construct your accelerator



Procedure

1. Visit <http://acceleratar.uk/>, go to 'Cubes', and download and print the cube patterns. We recommend printing the cubes onto cardboard, or pasting them onto cardboard, to make sure they are more stable and long-lasting.
2. Cut along the outside lines of the cube.



3. Use the stiff piece of cardboard to help you fold the cube.



4. Apply sticky tape or glue to the edges (as indicated in pink) and start forming the cube.



5. Glue or tape the last edge (as indicated in green) to close the cube and secure with extra tape.



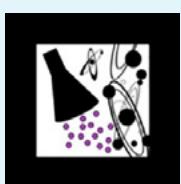
6. Do the same for the three remaining cubes.



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7. You now have the four important components of an accelerator. Discuss their functions using the information provided (you can print out the page from the supporting material).

What does each component of the accelerator do?



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The **particle source** creates the particles, such as protons, to be accelerated. As these particles are charged, they respond to electric and magnetic fields.



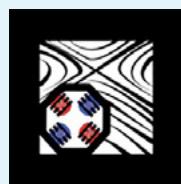
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Dipole magnets are magnets, in which the north and south poles are on opposite sides. In particle accelerators, they are used to bend a beam of charged particles. They are particularly useful when the beam needs to go in a circle, for example, in the Large Hadron Collider (LHC).



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The **radiofrequency (RF) cavity** is a chamber that contains a time-varying electromagnetic field. When the particles pass through, they receive an impulse that accelerates them.



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Quadrupole magnets consist of four magnets arranged in a cross pattern. Together, they create a magnetic field that can squeeze the particles together, focusing the beam at regular intervals.

Activity 2 – Assemble a virtual particle accelerator

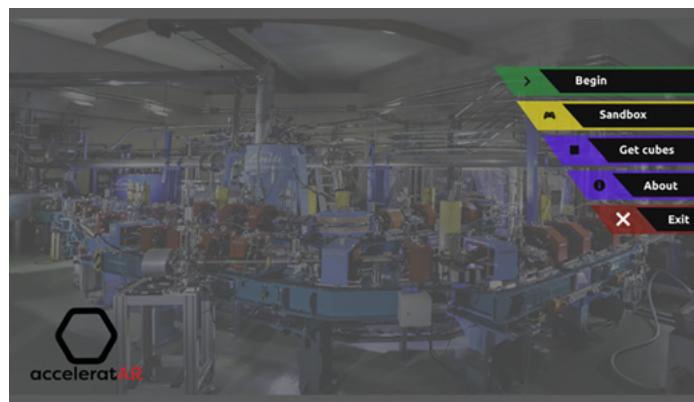
Now that you have the particle accelerator components and know what each component does, you are ready to build your own accelerator!

Materials

- Cubes from Activity 1
- Smartphone or tablet
- [acceleratAR app](#)
- Flat surface on which to construct your accelerator

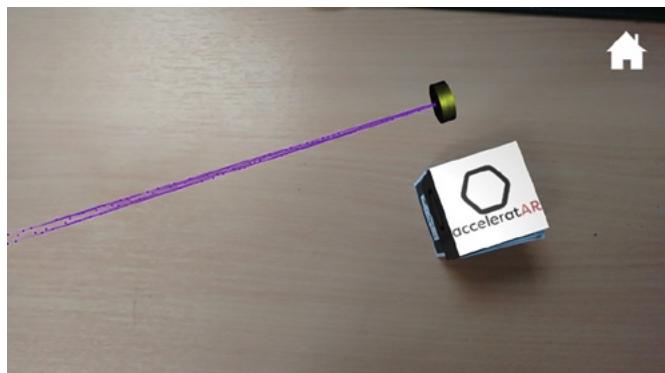
Procedure

1. Install the free [acceleratAR app](#) available from Google Play (it's not currently available from the App Store) onto your smartphone or tablet.
2. Arrange the cubes on a flat surface and launch the app.
3. Select 'Sandbox' from the menu (the yellow option)



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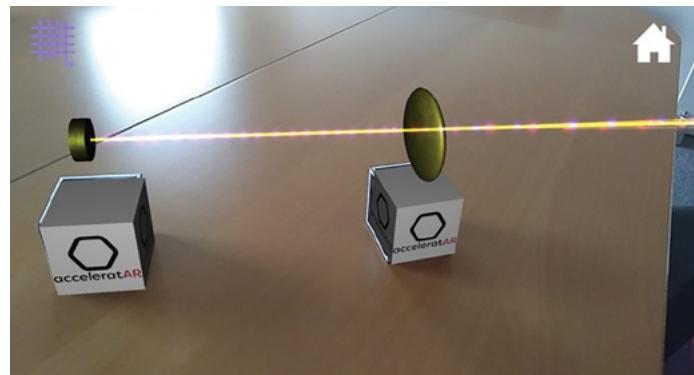
4. Point your device's camera at the particle source: observe the beam of particles appearing at the top of the cube. You can turn the cube to change the direction in which particles are moving.



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Explore the potential

During workshops, students play with the cubes and see for themselves what effect moving the pieces has on the beam; here, we provide structured questions and explanations.



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Add the RF cavity in front of the beam

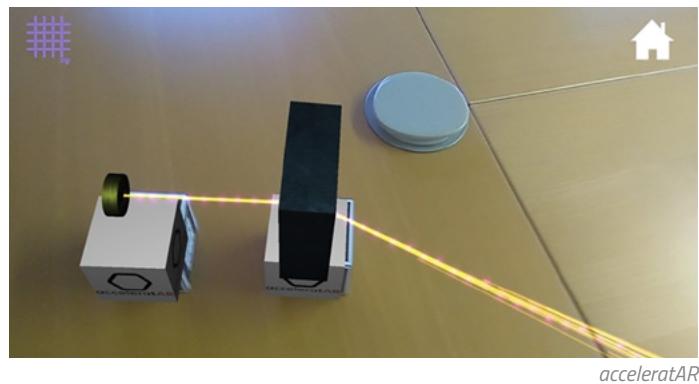
What do you see?

You should see a change in colour after the particles pass through the RF cavity. This means that particles are speeding up.

What is happening?

Each time a beam of particles passes through the RF cavity, it encounters an electric field that transfers energy. The more energetic the particles are, the faster they will go. The LHC has 16 RF cavities that increase the energy of the injected particles to up to 14 times that of their original injection energy.

Next add the magnetic dipole



What do you see?

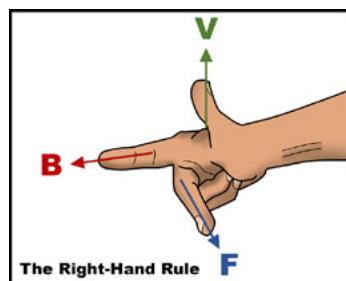
You should see that the direction of the beam is changing. Dipole magnets are the steering wheels of particle beams. In particle accelerators, many dipoles are used to direct the trajectory particles will follow.

How do they work?

Dipoles are magnets with two poles (north and south) used to generate a constant magnetic field that flows from north to south. A charged particle inside the magnetic field will be deflected along a curved path because the magnetic field will imprint a force, the direction of which is perpendicular both to the velocity of the charge and the magnetic field. The right-hand rule can help you to visualize the direction in which the force will act on a charged particle.

The right-hand rule

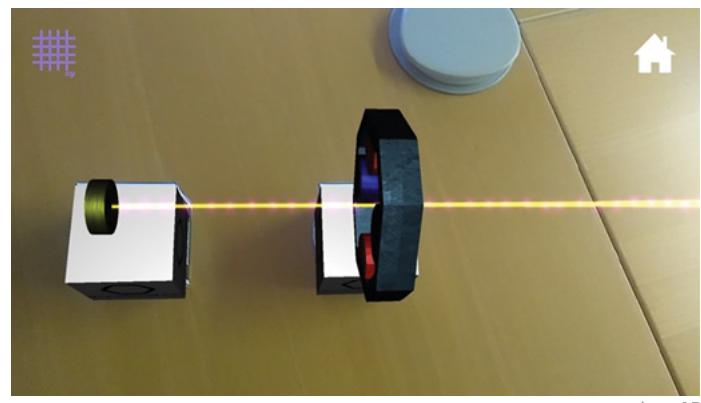
In the image, **V** corresponds to the direction in which the particle is moving and **B** to the direction of the magnetic field. The force that a particle will feel inside the magnetic field will be in the direction of **F**.



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Try to work out which direction the magnetic field is moving in the virtual dipole. Use the right-hand rule, the direction in which the particles are moving, and the direction in which particles are being pushed.

Next add the quadrupole magnet



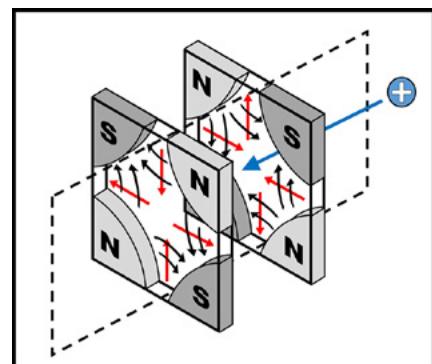
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What do you see?

You should see that the particle beam gets more focused.

Why do we need to focus the beam?

Remember that protons are charged particles. Also, like charges repel each other. This means that a beam of protons will diverge and may escape the vacuum chamber, unless an external force is applied to constrain their height and width. This is achieved by making the beam pass through a magnetic quadrupole.



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The direction of the quadrupole's magnetic field is given by the black arrows.

The red arrows represent the direction of force on a positive charge.

The positively charged particle on the right will pass the first quadrupole, which will squeeze it horizontally and constrain its width. A second magnet, in which the poles are flipped, will constrain the particle's height.

A quadrupole is always focusing in one plane and defocusing in the perpendicular plane. A combination of several quadrupoles can provide an overall focusing effect on a charged particle beam.

Resources

- Find inspiration on engaging your students through Star Wars: Welsch CP (2021) [The physics of Star Wars: introducing accelerator science](#). *Science in School* **54**.
- Create a particle accelerator in your salad bowl: Torres R (2017) [A particle accelerator in your salad bowl](#). *Science in School* **41**: 49–55.
- Build a particle accelerator in your classroom: Brown A, Merkert J, Wilson R (2014) [Build your own particle accelerator](#). *Science in School* **30**: 21–26.
- Read about a teacher's experience at CERN: Watt S (2012) [Nuclear options: a teacher at CERN](#). *Science in School* **23**: 57–60.
- Build a cloud chamber with your students: Barradas-Solas F, Alameda-Meléndez P (2010) [Bringing particle physics to life: build your own cloud chamber](#). *Science in School* **14**: 36–40.
- Watch a video on particle accelerators [used in hospitals](#).
- Look [inside the LHC](#).

AUTHOR BIOGRAPHY

Prof Welsch is head of the Department of Physics at the University of Liverpool and founder of the QUASAR Group. His research focuses on the development of particle accelerators and light sources and devices that can monitor the properties of charged particle beams. His rich career has included several years at CERN and leadership roles in ground-breaking international projects on beam diagnostics. He is also a passionate Star Wars fan.



Carsten Welsch and his lightsabre

The Cockcroft Institute

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