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Accelerators are everywhere, perhaps closer than you think ...

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Did you know that there are more than 30 000 particle accelerators around the world? Where are they, and what are they for?

What is a particle accelerator? The first technological demonstration to accelerate particles was carried out by Ernest O. Lawrence in Berkeley, USA, in 1929. His cyclotron, which he could hold in his hand, opened a new era, enabling many scientific discoveries. Since then, tools that take subatomic particles and speed them up are used in many applications, from early cathode-ray televisions, which preceded light-emitting diode (LED) and flatscreen televisions, to giant machines used to smash and study the particles themselves.

In these activities, which are suitable for students aged 11–16, students can use an interactive map to find and learn about the accelerators near them.[1]

Particle accelerators

There are three main types of particle accelerator: linear accelerators (often called LINACS) or one of two types of circular accelerators – cyclotrons or synchrotrons.

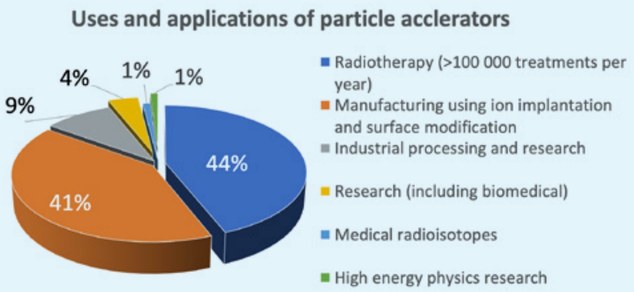
The European Synchrotron Radiation Facility (ESRF) in Grenoble.
Image: © ESRF.

The European XFEL linear particle accelerator in Hamburg.
Image: © XFEL

The most powerful are the ones used in research to observe and describe the atomic and subatomic world and to understand the laws of the universe. Particle accelerators are the basis of one third of all Physics and Chemistry Nobel Prizes ever awarded.[2] These are the ones most people think of when they think of particle accelerators.

The CERN Large Hadron Collider (LHC) in Geneva
© CERN

Accelerator applications

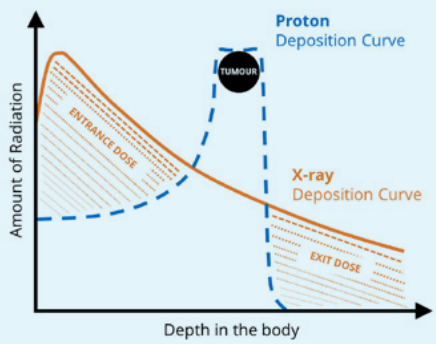


1. Cancer therapy centres

These particle accelerators generate beams of photons, protons, or ions to irradiate tumours.

Photon (X-ray) therapy centres are the most common, with hundreds in hospitals all over the world. They were first used on a patient in 1953 in London, UK, and they use linear accelerators to generate X-rays.

Proton therapy uses both cyclotrons and synchrotrons to generate proton beams. There are more than 50 proton cancer therapy centres in hospitals globally, with many more under construction. The ones in Europe are listed on publicly available data sources and so are included on the map.



Radiation delivered by high-energy X-rays has a large entrance and exit dose, damaging healthy tissue. In contrast, the place where protons stop inside the body can be controlled by changing their energy.
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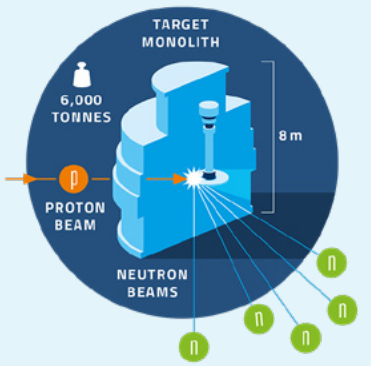
2. Light sources

A synchrotron light source is a special kind of electron accelerator aimed at producing strong, intense light, which can be used to study matter and address many scientific questions in biology, chemistry, and materials science. Like with a giant microscope, the photon beams (X-rays) generated are scattered by the sample atoms and then detected/observed. To find answers to these questions, we need to investigate and look at things closer and, for that, we need light – very bright, X-ray light.

3. Neutron sources
To look even closer at a sample, instead of synchrotron light, we can use a neutron beam. When they are moving very fast, neutrons act a little like light, and we can detect the way they bounce or scatter off a sample to find out about that sample's structure. But neutrons are bound in the nucleus of the atom, so a lot of energy is required to get them out. We can extract neutrons from atoms like uranium using nuclear fission, in a nuclear reactor, such as at the Institut Laue Langevin (ILL) in Grenoble, France.

Another method to obtain a larger and more controllable flux of neutrons is to use the technique of spallation: neutrons of a heavy atom, like mercury or tungsten, are struck with high-energy protons that have been accelerated to almost the speed of the light. This is how the new European Spallation Source (ESS) ERIC in Sweden will work, just like some existing spallation sources, such as the Spallation Neutron Source in Oak Ridge, USA; the J-PARC in Japan; the ISIS Neutron and Muon Source in the UK; or the Chinese Spallation Neutron Source (C-SNS).



The accelerator at ESS generates high-energy protons, which hit the tungsten target, releasing a high flux of neutrons for scientists to use. *©ESS*

4. High-energy physics
Some particle accelerators are used to understand the very nature of particles. Often this uses a type of accelerator called a collider. Here, particles are typically accelerated in opposite directions towards one another until they collide and the particles themselves break apart, revealing what is inside. This helps particle physicists to understand the basic building blocks of the universe – the fundamental particles – and they have used this knowledge to build and test the standard model of fundamental particles.

The largest and most famous machine is the Large Hadron Collider (LHC) at CERN on the border of France and Switzerland. This is a circular accelerator, a synchrotron, with a perimeter of 27 km!

However, there are many more particle accelerators. The vast majority of particle accelerators are used in hospitals for the treatment of cancer or to create radioisotopes for treating cancer. Many more are used in industry, for example, in ion implantation to strengthen material performance or in the manufacture of semiconductors. So, if all these are counted, some people have calculated that globally there are more particle accelerators than branches of McDonald's.

Activity 1: Where are the accelerators?

Particle accelerators can be found all around the world. Some are used for researching particle physics – high-energy physics research labs. Some are behind neutron- and X-ray-generating research facilities – synchrotrons, or neutron sources. And many are located in hospitals, particularly those with cancer treatment centres.

Together with your students, explore a map prepared as part of the Accelerate Your Teaching online course: can you find an accelerator in your country?

This map was produced in 2024 as part of a project called Accelerating Teaching, which aims to bring disparate information about publicly listed accelerators and their uses together in one place for teachers. It is designed to be user friendly rather than comprehensive and will not be continuously updated. For current information on synchrotron light sources and particle accelerators, see the resources at the end of the article.

This activity takes about 30 minutes.

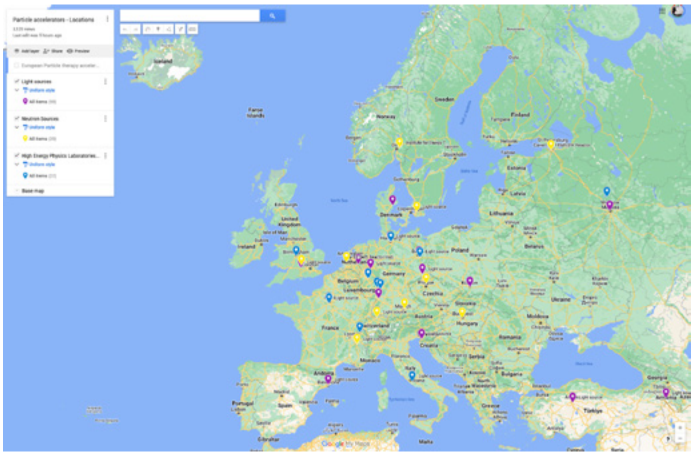
Note: The map shows only a handful of the actual accelerators. Around 41% of accelerators are actually used in manufacturing. In addition, many of those used in medicine are not listed on public lists, as they are owned by private companies, or just form part of the normal medical infrastructure.

Materials

- Device with access to the internet (one per student)
- Online accelerator map
- Information on accelerators, e.g., the Accelerator infosheet, Accelerator applications infosheet, and short videos on an animated introduction to particle accelerators and the diverse uses of particle accelerators

Procedure

1. Hand out the infosheets and show the videos.
2. Show the accelerator map to the students. Explain that the map actually only shows a small subset of accelerators, since those belonging to private companies aren't included.
3. Ask students what their general thoughts are after looking at the map.
4. What is the closest accelerator to the school (including medical accelerators)? Ask students to use the measure function on Google Maps to measure the distance between the school and the nearest accelerator.
5. What is the closest large research facility?
6. Which continent has the highest number of accelerators? And the fewest?
7. Which type source is most common (neutron source, synchrotron light source, high-energy physics centre, or proton therapy centre)?



Screenshot of the map activity

Particle accelerators – locations, made with Google My Maps. Map data ©2015Google

Activity 2: Case study

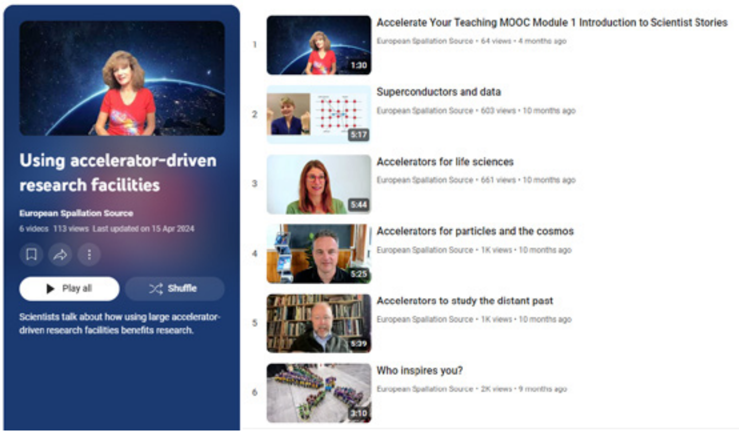
In this activity, which takes about 90 minutes, students select an accelerator and research it in more depth.

Materials

- Device with access to the internet (one per student)
- Online accelerator map
- Video series showing scientists' stories about people who use these types of accelerators

Procedure

1. Divide the students into groups of three to five students. Each group should decide whether to focus on
   a. European proton cancer therapy centres,
   b. light sources, or
   c. neutron sources at high-energy physics research centres.
2. Ask each group to pick one of the accelerators from the map and prepare a short (2–4 min) presentation on its societal importance and/or ethical considerations.



A playlist of short videos of how people use accelerators for a range of different research studies

3. Students should be encouraged to use both the websites of the actual facility and the videos about people who use them.
4. Finally, a representative chosen by the group presents their results to the whole class. Encourage students to ask questions after each presentation, focusing on the societal importance and/or ethical considerations of the accelerator facility chosen.

Discussion

This activity provides students with an opportunity to gain insights into the location of research facilities and other places that might house a particle accelerator. Additionally, it allows them to search for and compare information on the sociogeographic effects of having an accelerator in a certain geographical location, or the ethical implications of the type of work done at that facility. Students should research these topics themselves, but if they need a bit of guidance or inspiration, the Teacher Notes in the supporting material can be used to give them a hint or ask them some leading questions.

Conclusion

In combination with a physics lesson, students can use additional resources to investigate further the science of how particle accelerators work, like with a video introducing particle accelerators and their importance from Science ABC.[1] For more particle physics teaching ideas, check out the materials resources offered by Accelerate Your Teaching and the resources section below.

References

[1] A video by Science ABC describing linear and circular accelerators and their respective applications: https://www.youtube.com/watch?v=vIeRLeQq7V4&t=204s

[2] Haussecker EF, Chao AW (2011) The influence of accelerator science on physics research. *Physics in Perspective* **13**: 146–160. doi: 10.1007/s00016-010-0049-y

Resources

Teaching materials

- Further teaching resources for particle physics can be found through Accelerate Your Teaching: Lewis J (2024) Accelerate your teaching with links to cutting-edge science. *Science in School* **67**.
- Discover CERN's new science education and outreach centre: Woithe J (2024) CERN Science Gateway: a guide for teachers. *Science in School* **66**.
- Explore how Star Wars can be used to engage students with accelerator science: Welsch CP (2021) The physics of Star Wars: introducing accelerator science. *Science in School* **54**.
- Build a Gauss cannon to model linear acceleration and spallation: Lewis J, Michalak L (2024) Build a linear accelerator model. *Science in School* **67**.
- Build a virtual accelerator to learn about the different components of accelerator science: Welsch CP (2021) Build your own virtual accelerator. *Science in School* **54**.
- Let your students experience the challenges faced by particle accelerator scientists while learning about the physics of waves: Torres R (2023) Surfatron: catch the wave of accelerators. *Science in School* **62**.
- Create a particle accelerator in your salad bowl: Torres R (2017) A particle accelerator in your salad bowl. *Science in School* **41**: 49–55.
- Learn about the use of proton beams for cancer therapy: Welsch CP (2021) Death Star or cancer tumour: proton torpedoes reach the target. *Science in School* **55**.
- Read about the discovery of the Higgs boson at CERN and what we know about it: Chatzidaki P et al. (2022) Ten things we've learned about the Higgs boson in the past ten years. *Science in School* **59**.
- Learn about how cosmic rays from space can affect electronics on Earth: ILL (2023) What does particle physics have to do with aviation safety? *Science in School* **62**.
- Find out how magnetic 'storms' could help us achieve better, faster data storage: Chandran A (2023) Information revolution: how ultra-short bursts of light could help us improve data storage. *Science in School* **62**.
- Read about how X-ray free-electron lasers are used to investigate particle structures: Wilson R (2021) Plant solar power: unlocking the secrets of photosynthesis with X-ray free-electron lasers. *Science in School* **54**.

Deep-dive resources aimed at teachers

- Accelerate Your Teaching online course for teachers. (Requires free enrolment to access this map activity and all other materials.)
- Online courses by the Nordic Particle Accelerator Program.
- Sheehy S (2022) The Matter of Everything: Twelve Experiments that Changed Our World. Bloomsbury. ISBN: 9781526618962
- CERN resources for teachers.

Resources suitable for students

- An animated introduction to particle accelerators by Suzie Sheehy.
- A glossary of terms to get started on particle physics.
- A simple video a video introducing particle accelerators from Science ABC.
- General information about particle physics for students:
  - A video introducing CERN in 2 minutes.
  - An interview with a former CERN director on the story behind the Higgs boson: Hayes (2012) Accelerating the pace of science: interview with CERN's Rolf Heuer. *Science in School* **25**: 6–12.
  - Educational resources from the Cockcroft Institute.
- A video to extend the discussion on particle accelerators.

AUTHOR BIOGRAPHY

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Christine Darve is an engineering scientist at ESS. Before that, she designed and tested particle accelerator equipment at Fermilab in the USA and CERN in Switzerland. Christine is the former chair of the Forum on International Physics at the American Physical Society and chair of the Accelerator Science working group of the International Union of Pure and Applied Physics. She organized the Nordic Particle Accelerator Program and co-founded the African School of Fundamental Physics and Applications.