Accelerators

Accelerators were invented in the 1930s to provide energetic particles to investigate the structure of the atomic nucleus. Since then, it has been used to investigate many aspects of particle physics. It works to speed up and increase the energy of a beam of particles by generating electric fields that accelerate the particles, and magnetic fields that steer and focus them.

An accelerator comes either in the form of a ring (a circular accelerator), where a beam of particles travels repeatedly round a loop, or in a straight line (a linear accelerator), where the particle beam travels from one end to the other. At CERN a number of accelerators are joined together in sequence to reach successively higher energies.

The type of particle used depends on the aim of the experiment. The Large Hadron Collider (LHC) accelerates and collides protons, and also heavy lead ions. One might expect the LHC to require a large source of particles, but protons for beams in 27-kilometre ring come from a single bottle of hydrogen gas, replaced only twice per year to ensure that it is running at the correct pressure

Types of Accelerators

Particle accelerators can be split into two fundamental types, electrostatic accelerators and oscillating field accelerators. Electrostatic accelerators, such as the Cockcroft-Walton accelerator and the Van de Graaff accelerator make use of what is known as an electrostatic field. Electrostatic fields are simply electric fields that do not change with time.

The main disadvantage of using electrostatic fields is that very large electric fields need to be generated to accelerate particles to experimentally useful energies, which would be difficult and dangerous to maintain.

This disadvantage led to the development of the second type of accelerator: the oscillating field accelerator. This type of accelerator requires electric fields that periodically change with time.

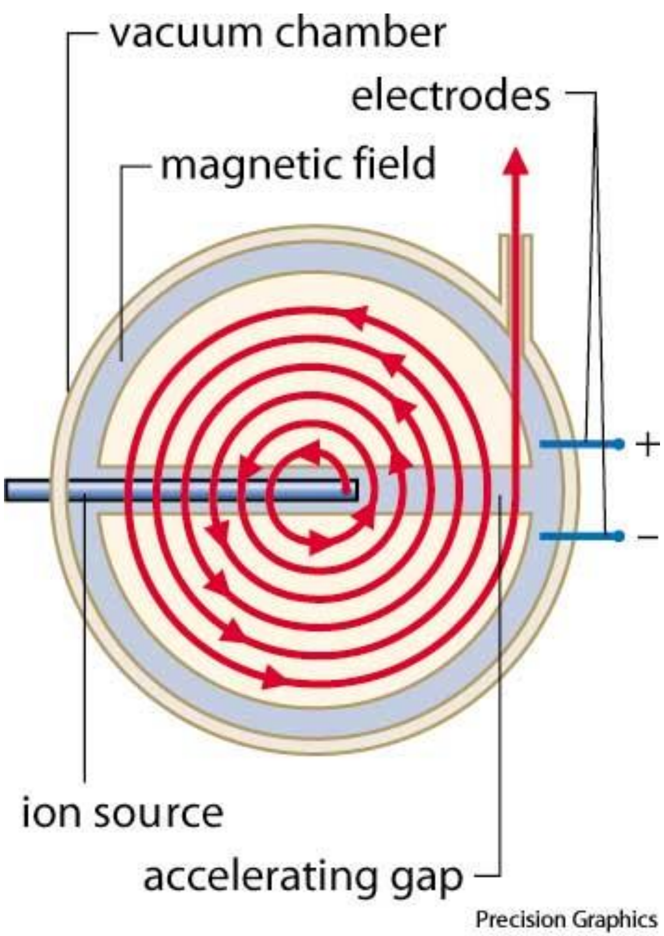
Clever use of this oscillating electric field has allowed high energy physicists to accelerate particles to extremely high energies, leading to many key discoveries that shape our view of the universe.

Main categories of particle accelerators

Main categories of particle accelerators are detailed below.

- The Cockcroft-Walton and Van de Graaff Accelerators
- The Linear Accelerator (Linac)
- The Cyclotron
- The Betatron
- The Synchrotron
- The Storage Ring Collider

Particle accelerators (cont.)



Cyclotron

- ❑ Cyclotron: Does not employ alternating magnetic field; the magnetic field is constant.
  Particle orbit is helical.

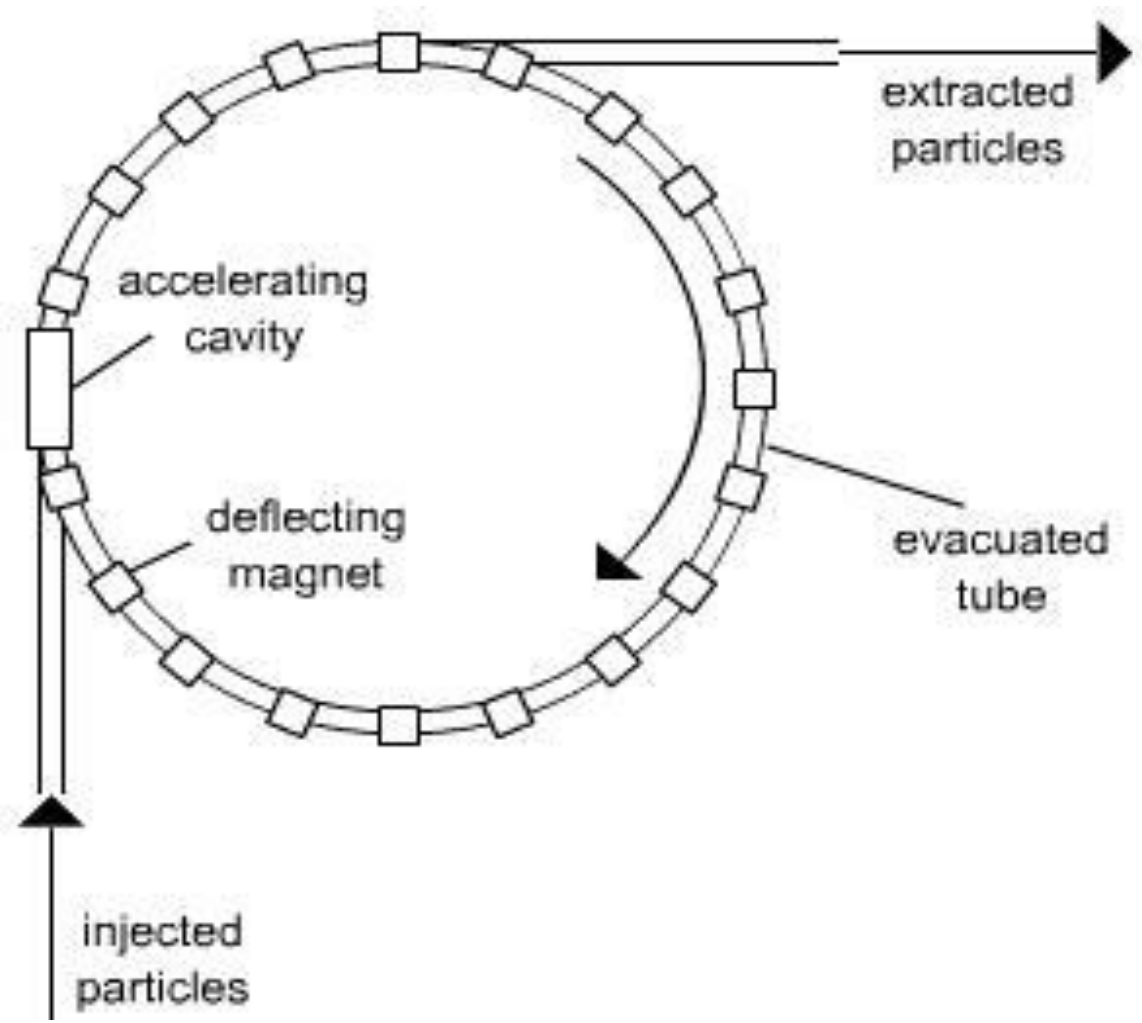
- ❑ Betratron: Employs an oscillating magnetic field.
  Particle orbit is circular.

Synchrotron

Notice: particles travel in a **ring**, not a **disk.**

Magnetic field gradually increases as energy increases.

Allows for cheaper construction compare to cyclotron.



CERN

The **European Organization for Nuclear Research** (French: derived from the name *Conseil Européen pour la Recherche Nucléaire*), is a European research organization that operates the largest particle physics laboratory in the world. CERN is an official United Nations Observer. Established in 1954, the organization is based in a northwest suburb of Geneva on the Franco–Swiss border, and has 22 member states. Israel is the only non-European country granted full membership.

The term CERN is also used to refer to the laboratory, which in 2013 had 2,513 staff members, and hosted some 12,313 fellows, associates, apprentices as well as visiting scientists and engineers representing 608 universities and research facilities. CERN's main function is to provide the particle accelerators and other infrastructure needed for high-energy physics research – as a result, numerous experiments have been constructed at CERN through international collaborations. CERN is also the birthplace of the World Wide Web invented in 1989 by British scientist Tim Berners-Lee, has grown to revolutionize communications worldwide

The 1984 Nobel Prize for Physics was awarded to Carlo Rubbia and Simon van der Meer for the developments that resulted in the discoveries of the W and Z bosons. The 1992 Nobel Prize for Physics was awarded to CERN staff researcher Georges Charpak "for his invention and development of particle detectors, in particular the multiwire proportional chamber".

The accelerator complex in CERN

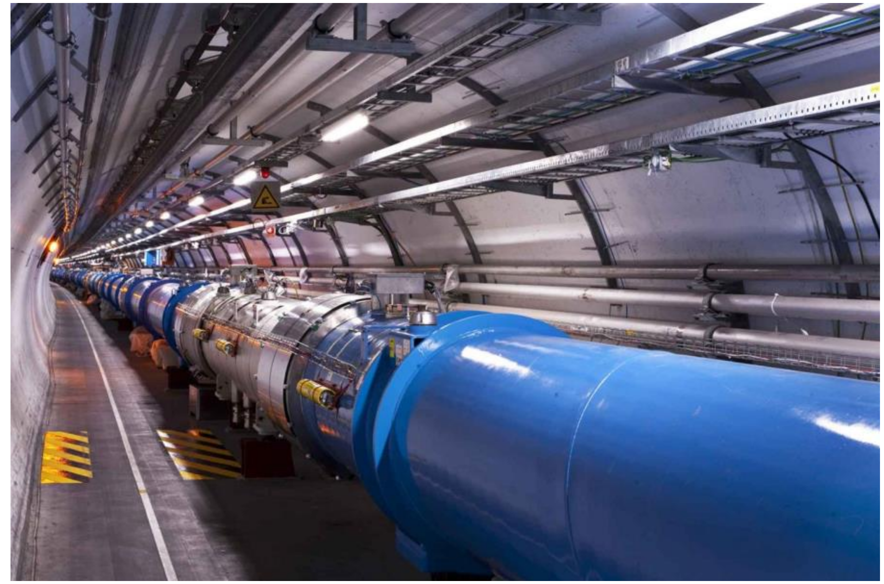
The accelerator complex at CERN is a succession of machines that accelerate particles to increasingly higher energies. Each machine boosts the energy of a beam of particles, before injecting the beam into the next machine in the sequence. In the Large Hadron Collider (LHC) – the last element in this chain – particle beams are accelerated up to the record energy of 6.5 TeV per beam. Most of the other accelerators in the chain have their own experimental halls where beams are used for experiments at lower energies.

The proton source is a simple bottle of hydrogen gas. An electric field is used to strip hydrogen atoms of their electrons to yield protons. Linac 2, the first accelerator in the chain, accelerates the protons to the energy of 50 MeV. The beam is then injected into the Proton Synchrotron Booster (PSB), which accelerates the protons to 1.4 GeV, followed by the Proton Synchrotron (PS), which pushes the beam to 25 GeV. Protons are then sent to the Super Proton Synchrotron (SPS) where they are accelerated to 450 GeV.

The protons are finally transferred to the two beam pipes of the LHC. The two beams are brought into collision inside four detectors – ALICE, ATLAS, CMS and LHCb – where the total energy at the collision point is equal to 13 TeV.

Protons are not the only particles accelerated in the LHC. Lead ions for the LHC start from a source of vaporized lead and enter Linac 3 before being collected and accelerated in the Low Energy Ion Ring (LEIR). They then follow the same route to maximum energy as the protons.

Images of CERN



SPring-8

SPring-8 is a large synchrotron radiation facility which delivers the most powerful synchrotron radiation currently available. Consisting of narrow, powerful beams of electromagnetic radiation, synchrotron radiation is produced when electron beams, accelerated to nearly the speed of light, are forced to travel in a curved path by a magnetic field. The research conducted at SPring-8, located in Harima Science Park City, Hyogo Prefecture, Japan, includes nanotechnology, biotechnology and industrial applications. The name "SPring-8" is derived from "**S**uper **P**hoton **ring**-**8** GeV" (8 GeV, or 8 giga electron volts, being the power output of the ring).

SPring-8 was opened in 1997 to industrial, academic and government users, domestic and international. Any user whose application is accepted may use the facility. SPring-8 is managed by RIKEN, with the Japan Synchrotron Radiation Research Institute (JASRI) in charge of operation, maintenance and promotion of use.

Spring 8 in (Kyoto) Japan

Application of Synchrotron Radiation

Life Science: Atomic structure analysis of protein macromolecules and elucidation of biological functions; Mechanism of time-dependent biological reactions; Dynamics of muscle fibers

Materials Science: Precise electron distribution in novel inorganic crystals; Structural phase transition at high pressure / high or low temperature; Atomic and electronic structure of advanced materials of high Tc superconductors, highly correlated electron systems and magnetic substances; Local atomic structure of amorphous solids, liquids and melts

Chemical Science: Dynamic behaviors of catalytic reactions; X-ray photochemical process at surface; Atomic and molecular spectroscopy; Analysis of ultra-trace elements and their chemical states; Archeological studies

Application of Synchrotron Radiation (cont.)

Earth and Planetary Science: *In situ* X-ray observation of phase transformation of earth materials at high pressure and high temperature; Mechanism of earthquakes; Structure of meteorites and interplanetary dusts

Environmental Science: Analysis of toxic heavy atoms contained in bio-materials; Development of novel catalysts for purifying pollutants in exhaust gases; Development of high quality batteries and hydrogen storage alloys

Industrial Application: Characterization of microelectronic devices and nanometer-scale quantum devices; Analysis of chemical composition and chemical state of trace elements; X-ray imaging of materials; Residual stress analysis of industrial products; Pharmaceutical drug design

Medical Application: Application of high spatial resolution imaging techniques to medical diagnosis of cancers and capillaries

General Features of Synchrotron Radiation

- ❑ Ultra-bright
- ❑ Highly directional
- ❑ Spectrally continuous or quasi-monochromatic.
- ❑ Linearly or circularly polarized
- ❑ Pulsed with controlled intervals

Beamline of Spring8 **(as an example)**

BL02B2 Powder Diffraction

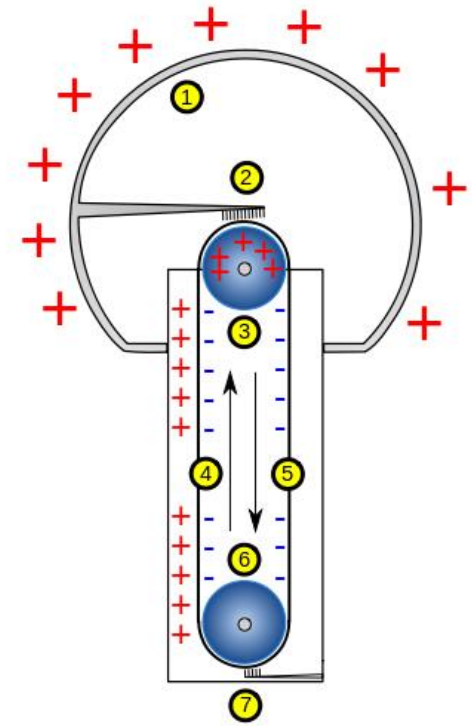
❖Charge density studies closely related to properties of functional materials
❖Structural aspects of phase transition
❖Ab initio structure determination using powder diffraction data
❖Structural refinements by Rietveld method
❖Thin-film diffraction
❖In-situ difftaction experimnent under gas adsorption and/or photo irradiation

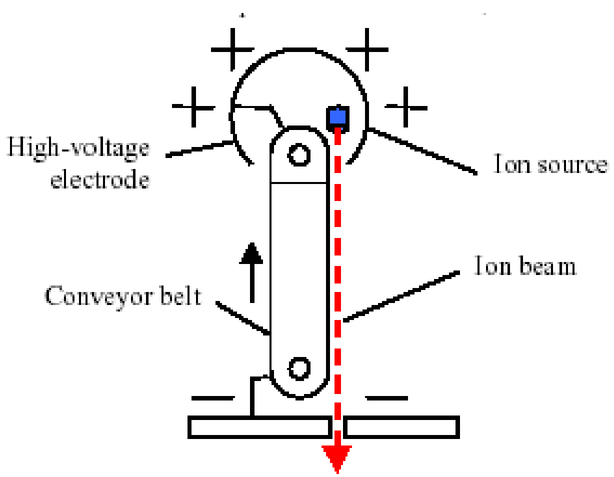
BL03XU Advanced Softmaterial

❖Research development of organic or polymer materials as thin files, fiber, bulk, film, and solution.
❖Structural analysis of materials using X-ray scattering measurements.
❖X-ray measurement for polymer thin film or organic thin film
❖Innovations in the manufacturing process for soft and polymer materials.
❖Observation on a structure changing under a controlled environment by real-time X-ray measurement with a large processing apparatus
❖Observation of a change in the hierarchal structure at Å~μm scale by simultaneous measurement

A Van de Graaff accelerator

A Van de Graaff accelerator consists of a large metallic sphere (1) at the top of an insulating column. Within the column is a belt made from a conducting material (4 & 5) pulled taught over two pulleys (3 & 6). One of the pulleys is attached to an electric motor driving the belt (6), at either end of the belt is a brush of metallic wires (2 & 7), the lower brush (7) is attached to a voltage source which transfers a charge to the belt via the brush, the belt then carries the charge up (4) to the second brush which will transfer the charge to the large metal sphere known as the electrode. The charge build-up generated in the electrode results in a potential difference between the electrode and the ground. Van de Graaff generator (~20MV).





Safety of Van de Graaff accelerator

- Do not allow students to use the Van de Graaff generator unsupervised.
- People with cardiac pacemakers should never operate the generator or come in contact with it.
- Obviously, we are dealing with high voltage here. Stay about three feet away from the collector while it is charged.
- Always discharge the collector dome between experiments and when you are finished.
- The motor produces a lot of heat that could damage the belt or the motor itself. Do not run the generator continuously for long periods of time.
- Leave the upper and lower combs alone.
- Keep the entire device clean and dry.
- Handle the aluminum parts with care.