RAL Masterclasses 2016

A Very Brief Guide to ACCELERATORS

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Microscopes & Telescopes ~ 400 Years Ago

Galileo’s telescope, ~1609, Florence
Magnification ~30

Siderius Nuncius,
Galileo Galilei, 1610

Compound microscope
~1670, Glasgow
Magnification ~30

Micrographia
Robert Hooke, 1665
Probing Matter

Higher energies mean shorter wavelengths:

\[ \lambda = \frac{h}{p} \]

- **Radio**: $10^3$ m
- **Microwave**: $10^{-2}$ m
- **Infrared**: $10^{-5}$ m
- **Visible**: $0.5 \times 10^{-6}$ m
- **Ultraviolet**: $10^{-8}$ m
- **X-ray**: $10^{-10}$ m
- **Gamma Ray**: $10^{-12}$ m

About the size of...

- Buildings
- Humans
- Honey Bee
- Pinhead
- Protozoans
- Molecules
- Atoms
- Atomic Nuclei

Frequency (Hertz)

- $10^4$ Hz
- $10^8$ Hz
- $10^{12}$ Hz
- $10^{15}$ Hz
- $10^{16}$ Hz
- $10^{18}$ Hz
- $10^{20}$ Hz

Energy (eV)

- $10^{-10}$ eV
- $10^{-4}$ eV
- $4.13$ eV
- $10^2$ eV
- $10^6$ eV
Small Scales and Large Scales - Today


Large Hadron Collider (2009)
Charged Particle Beams

Force on charged particle is given by the Lorentz Force

\[ \vec{F} = q\vec{E} + q\vec{v} \times \vec{B} \]

Electric Field

**Acceleration**

Magnetic Field

**Bending**

Cathode(-)  Anode(+)

\[ \text{p}^+ \quad \text{e}^- \]

Thrust or Movement

Magnetic field

\[ \text{Current} \]
John Cockroft & Ernest Walton Voltage Multiplier
Cavendish Laboratory, 1932.

\[ p + Li \rightarrow \alpha + \alpha \]

Max. accelerating voltage \( \sim 1 \text{MV} \)
Cockroft/Walton Pre-Injectors

665 kV ISIS, RAL (replaced 2004)

750kV FermiLab

Limited by BREAKDOWN!
Linear Accelerators

Alternating voltage. Each step gives a small energy increase to the particle.
Circular Accelerators

**Cyclotron:** First circular particle accelerator built by Ernest O. Lawrence & Stanley Livingston at Berkeley in 1930. Energy = 80 keV, Diameter = 13cm

\[ f = \frac{qB}{2\pi m} \]

\[ r = \frac{mv}{qB} \]

One of World’s largest cyclotrons (TRIUMF). Lower six sectors of electromagnet Weight 4000 tonnes, Field = 5.6 kG, Current = 18,500 A
In a **Collider**, bunches of particles/antiparticles circulate in opposite directions.
Focussing Magnets

Quadrupole (LEP)

Strong Focussing
Beam alternately focussed in horiz and vert planes.

Sextupole (LEP)
Correction of chromatic spread.
Super Proton Synchrotron
CERN, Geneva
(6km circumference)

High vacuum!
Radio Frequency Cavities

Large Electron Positron Collider (LEP) 1989-2000

- 27 km circumference
- 3,000 bending magnets
- 800 focussing magnets
- 11,000 revolutions/sec
Tevatron, FermiLab (Chicago)

Collided protons and anti-protons

Energy = 1 TeV (1000 GeV)

4 mile circumference
Collides two proton beams
Energy up to 7 TeV (7000 GeV)
27 km circumference
Synchrotron Radiation

Diamond Light Source

“IF I HAVE SEEN FURTHER IT IS BY STANDING ON THE SHOULDERS OF GIANTS”

ISAAC NEWTON
Cosmic Particles

Interactions in the atmosphere
Low flux of particles
Difficult to identify/control

Accelerators!
Cosmic Rays - Highest Energy Particles

1 particle/m²/second

1 particle/m²/year

1 particle/km²/year

LHC beam energy

1 particle/km²/century
Electromagnetic waves accelerate particles in the same way that waves propel surfers.

*Timing is vital!*
International Linear Collider (ILC)

- 31 km long – $e^+e^-$ collider.
- Collisions between bunches of 5 nanometres in height.
- 14,000 collisions/second.

- Energy 0.5 – 1 TeV
- 16,000 superconducting cavities made of pure niobium.
- Maximise accelerating gradient (31.5 MV/m).
Compact Linear Collider (CLIC)

- Energy 0.5 – 5 TeV.
- Room temperature.
- Accelerating gradient 100 MV/m.
- High frequency travelling wave structure (12 GHz).