Modern Particle Accelerators and Detectors: A Household Survey

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Alyson Clarke
• High school All Star swimmer
• My niece

To do well in her sport, she really needs to know how to ACCELERATE
Deena Greer

• Physician
• My wife

To ACCELERATE healing, she needs to DETECT problems that are impossible to see

How Do We Accelerate?

Let’s ask Alyson

We drop things!
How Do We “Drop” Particles?

We can only build so many accelerators next to cliffs

Deena has a better idea! VOLTS

The Van de Graaff Accelerator

- Start with positively charged particles at high voltage
- Let them “fall” to ground potential
- They accelerate during the process

**A Problem:**
- Difficult to make \( q > 2 \)
- Difficult to make \( V \) larger than a few million volts

\( \Rightarrow \) Difficult to make \( E \) large!
The Tandem Van de Graaff Accelerator

- Start with negative ions at ground
- Let them “fall” to positive high voltage
- Strip many electrons off the ion to produce a large positive charge
- Let the positive charge “fall” back to ground
- The particles accelerate during both steps

Can achieve energies of 10’s of millions of electron volts (MeV), or velocities up to 20% of the speed of light

Can Investigate Many Nuclear Reactions

- Very useful to study reactions with a broad range of light to intermediate mass nuclei
- Alpha particles (the nuclei of helium atoms) can be accelerated to ~30 MeV, representing 7.5 MeV/nucleon or ~13% of the speed of light.
- Can penetrate to the nucleus of essentially any atom up to lead

Alpha particle
Charge = +2

Lead nucleus
Charge = +82
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Maybe Even I Can Do This!

Well, maybe not

Not Useful for Reactions with Heavy Nuclei

- Can accelerate gold nuclei to ~200 MeV, but this is only ~1 MeV/nucleon or 5% of the speed of light
- Not energetic enough to penetrate to the nucleus of a second heavy atom!

Gold nucleus
Charge = +79

Lead nucleus
Charge = +82

We need another trick!
Another Trick

To go high, pump *many* times!

Swing Sets \( \Rightarrow \) Particle Accelerators

Uncle Carl, do I need to explain *everything* to you?

ALTERNATES
The Cyclotron

- The first accelerator to use alternating voltages was the cyclotron
- Invented by Ernest Lawrence in the late 1920's
- Combines alternating voltages with magnetic fields

![Diagram of the cyclotron](image-url)
A Modern Example

The Texas A&M K500 Superconducting Cyclotron -- can accelerate alpha particles to 280 MeV and uranium over 2000 MeV (40% and 14% of the speed of light, respectively)

Another Application: the Linear Accelerator

The 2-mile long Stanford Linear Accelerator speeds electrons up to 45-50 GeV (billions of electron volts) or ~99.99999995% of the speed of light.
RHIC at Brookhaven National Laboratory

- Accelerates gold nuclei to 19,700 GeV or 99.996% of the speed of light

- Two separate beams collide with each other.

- Au+Au with each at 19,700 GeV is equivalent to a single Au nucleus of 4,200,000 GeV hitting a second Au nucleus at rest
The Principle Behind All Particle Detectors

Electrons in the Detector Material

Energetic Particle
Some Historical Background – the First Tracking Detector

Clouds

The Cloud Chamber

Figure 1.3 An early particle detector: Wilson's cloud chamber. (Science Museum, London.)
Another Important Historical Detector

The Bubble Chamber

Figure 2.15 Example of charmed-particle production and decay in the hydrogen bubble chamber BEBC exposed to a neutrino beam at the CERN SPS. (Courtesy CERN.)
Maybe I Can Build a Detector, Too?

STAR: the Solenoidal Tracker At RHIC
A Modern Workhorse Nuclear and Particle Physics Detector

Semiconductor diodes – “Ge” and “Si” detectors

Ge and Si Detectors

Can be used to measure energies precisely, or positions precisely, or both.
A Single Ge Detector

The most precisely calibrated Ge detector in the world is at Texas A&M.

The STAR Silicon Vertex Tracker

Used to measure charged-particle positions to a few thousandths of an inch.
Another Modern Workhorse Nuclear and Particle Physics Detector

Gaseous detectors

One Example: the **Time Projection Chamber**

The time to reach the end of the TPC determines the distance drifted in the gas. Provides 3-D information about particle positions.
The STAR Time Projection Chamber

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Yet a Third Modern Workhorse Nuclear and Particle Physics Detector

“Scintillation” and Cherenkov detectors. Emit a flash of light when an energetic charged particle passes through.
Scintillator and Cherenkov Detectors

Can have very fast response (few x 10^{-9} sec). Therefore, often used for “triggering”.

Gammasphere – an Array of Ge and Scintillator Detectors

Combining the “best of both worlds”.

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The **STAR** Detector

STAR Event from a Au+Au Collision
Solar Neutrino Detectors

- Not all modern nuclear and particle physics detectors are based at accelerators.
- 2002 Nobel Prize in Physics was awarded for pioneering measurements of the neutrinos that are emitted from the sun.
- Neutrinos are really hard to detect!
- Very large detectors → use “common” materials

Homestake Mine Solar Neutrino Experiment

- 100,000 gallons of dry cleaning solution, a mile underground
- Detect less than 10 (!!!) individual Ar atoms per month
Kamioka, Super-K, and SNO Experiments

Large water tanks, deep underground, used as Cherenkov detectors

Super-K Neutrino Detector
A Neutrino Event in Super-K

Super-Kamiokande
Run 7436 Event 34054156
94-02-11 03:46:45
Depth: 154 kbl, 0.71 kgf
Overs: E Hiko, 1296 (1464)
Trigger D. 243
Ng: 15
Fully-Reconstructed

Rosid(ns)
> -182
180 - 182
177 - 178
174 - 176
31 - 32
30 - 31
29 - 30
22 - 24
0 - 22
-32 - 0
-64 - -56
-80 - -60
-91 - -80
-114 - -93
-116 - -117

ring2
ring1
decay electron

SNO: Sudbury Neutrino Observatory
In spite of our modern technologies, there are some things we will **never** detect!

this time ?????

But We Are Doing Pretty Well!