First – Brief Tuesday Recap
States of Matter
Material Strength
Superconductivity
Silicon-based Semiconductors

**Pure Silicon**
- Blue dots: Silicon nuclei

**N-Type Silicon**
- Red dot: Phosphorous nucleus
- The phosphorous atom creates an extra electron.

**P-Type Silicon**
- Green dot: Boron nucleus
- The boron atom creates a hole.
Diodes

A combination of one \( n \)-type semiconductor and one \( p \)-type semiconductor

It allows the flow of current in only one direction
Familiar Diodes
Transistors

A combination of one type of semiconductor sandwiched in between two semiconductors of the opposite type
Transistors

A combination of one type of semiconductor (base) sandwiched in between two semiconductors of the opposite type

A small amount of electrical charge run into or out of the base can change the electric fields at each junction, thus controlling the current through the transistor

Transistors can be used as amplifiers (cell phone, radio) or switches (computers)
Then and now

1947

2012

NVIDIA's graphics card (GF100) has more than 3 billion transistors
Great Idea: Nuclear energy depends on the conversion of mass into energy
Why Study Nuclei?

What we learn about the nucleus can generate new ideas and technologies in the fields of space science, homeland security, biology/ecology, etc.
Isotopes
An example

<table>
<thead>
<tr>
<th>Protons (Elements)</th>
<th>Neutrons (Isotopes)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7</strong></td>
<td></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td></td>
</tr>
<tr>
<td><strong>N</strong></td>
<td><strong>C</strong></td>
</tr>
<tr>
<td>14.0067</td>
<td>C 9</td>
</tr>
<tr>
<td></td>
<td>127ms</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td><strong>B</strong></td>
</tr>
<tr>
<td>12.011</td>
<td>B 8</td>
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<tr>
<td></td>
<td>770ms</td>
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<tr>
<td><strong>N 12</strong></td>
<td><strong>C 10</strong></td>
</tr>
<tr>
<td>11.0ms</td>
<td>19.3s</td>
</tr>
<tr>
<td><strong>N 13</strong></td>
<td><strong>C 11</strong></td>
</tr>
<tr>
<td>9.97m</td>
<td>20.3m</td>
</tr>
<tr>
<td><strong>N 14</strong></td>
<td><strong>C 12</strong></td>
</tr>
<tr>
<td>99.63%</td>
<td>98.89%</td>
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<tr>
<td><strong>N 15</strong></td>
<td><strong>C 13</strong></td>
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<tr>
<td>0.37%</td>
<td>1.11%</td>
</tr>
<tr>
<td><strong>N 16</strong></td>
<td><strong>C 14</strong></td>
</tr>
<tr>
<td>7.10s</td>
<td>5730y</td>
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<td><strong>N 17</strong></td>
<td><strong>C 15</strong></td>
</tr>
<tr>
<td>4.17s</td>
<td>2.45s</td>
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<tr>
<td><strong>N 18</strong></td>
<td><strong>C 16</strong></td>
</tr>
<tr>
<td>0.63s</td>
<td>0.75s</td>
</tr>
<tr>
<td><strong>N 19</strong></td>
<td></td>
</tr>
<tr>
<td>0.42s</td>
<td></td>
</tr>
</tbody>
</table>

Protons – atomic number and element – chemical properties
Neutrons – isotope (variety of element) – nuclear properties
Nucleons – mass number (neutrons and protons)
Abundance
Half-life
The Strong Force

Strong force
Holds nucleus together
Operates over short distances
Binding energy
Binding Energy

Nuclei weigh less than the sum of the masses of their protons and neutrons

\[(2m_p + 2m_n) > m(^4\text{He})\]

\[BE = (2m_p + 2m_n) - m(^4\text{He})\]
Radioactivity
What’s Radioactive?

Radioactivity or radioactive decay
Radiation

Mass of nucleus is greater than mass of decay products
Extra mass $\rightarrow$ kinetic energy of radiation

$^{240}_{94}\text{Pu} \rightarrow ^{236}_{92}\text{U} + ^4_2\text{He}$
Using a Geiger Counter to Detect Radioactivity
The Kinds of radioactive Decay

Alpha decay
Release of particle; composed of 2 protons and 2 neutrons

Proton decay

Neutron decay

Beta decay
Emission of electron or positron
Neutrino
Effect; weak force

Gamma Radiation
Electromagnetic radiation
Three Common Types of Radioactive Decay

**Alpha decay**
- Uranium-238 (92 protons) → Thorium-234 (90 protons) → 2 neutrons, 2 protons

**Beta decay**
- Neutron → Proton (positive charge) + Electron (negative charge) + Neutrino (no charge)

**Gamma radiation**
- Protons adopt a lower energy state
  - Photon emitted
Identification of the Alpha Particle

Initially

Radioactive material

Several months later

Helium atoms

alpha particles
Decay Chains

Decay chains
Series of decays
Continues until stable isotope appears
Radiation and Health

Ionization
Stripping electron(s)
Long-term effects
Cancer
Birth defects
Damaging Effects of Radiation

(a) The truck doesn't get far, but totals whatever it hits.

(b) The car travels farther than the truck, does less damage per foot traveled than the truck.

(c) The motor bike makes it through the alley, doing less damage per foot traveled.
Indoor Radon

Decay of uranium-238
Radon-222
Undergoes alpha decay
Can build up
Increase ventilation
The Science of Life

The CAT Scan
The Science of Life

Proton Therapy
The Science of Life

Radioactive tracers
Radiometric Dating

Radiometric dating
Measurement of half-life
Carbon-14
Half-life = 5700 years
Geology
Need longer half-lives
The Shroud of Turin
Use of Potassium-Argon Dating
Energy from the Nucleus
Nuclear Fission

Fission
Splitting of nucleus
Nuclear Reactor
Extracts energy
Meltdown unlikely, but possible

Energy released due to differences in binding energies ~170 MeV
Or
~2.7 x 10^-11 J
per nucleus...
Fukushima

Sandy?
Fusion

4 protons combine to form He
Some mass converted to energy
Sunlight

\[4p \rightarrow \text{He} \]
\[4 \times 7.29 - 2.42 = 26.74 \text{ MeV}\]
Technology

ITER: the future of fusion
Science in the Making

Superheavy elements
Thinking More about the Nucleus

Nuclear waste
Management
Yucca Mountain project
  • Controversial