Tour of the Subatomic Zoo

lecture 4

Wednesday January 29, 2003

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How more new particles were predicted

Back to the mid 1800’s - at the time various electric and magnetic effects had been seen but were not well understood

1) Behavior of electrical charges - attractive and repulsive forces

2) Behavior of currents in wires - forces between wires carrying moving charge
Two effects

Magnetic

Electric

Electromagnetic

Faraday did experiments.
Maxwell did theories.

The end result was a fusing of electricity and magnetism into electromagnetism.
In 1928 Paul Dirac (age 26) tried to do the same. It explained the motion of electrons in their tiny and fast world.
Dirac found the only way he could be consistent with all three theories:

- Quantum theory
  - Planck
- Relativity
  - Einstein
- Electromagnetic
  - Maxwell

There must exist a particle with the same mass as the electron but with positive charge, called positron \( (e^+) \): mass = electron mass, spin = electron spin, charge = +1.
The positron was discovered in 1932 by Anderson.
Antimatter predicted by a theory and discovered only 4 years later.
Positrons have been used in medical diagnosis since the 60’s (PET scan - short for Positron Emission Tomography). They give biochemical information about the body.
Positronium (used in semiconductor research) was first produced in 1951.

\[ p + e^- = \text{hydrogen} \]

\[ e^- + e^+ = \text{positronium} \]
Particle Recap

- proton (p)  antiproton (\(\bar{p}\))
- neutron (n) antineutron (\(\bar{n}\))
- electron (e) positron (\(e^+\))
- neutrino (\(\nu\)) antineutrino (\(\bar{\nu}\))

<table>
<thead>
<tr>
<th>name</th>
<th>mass</th>
<th>charge</th>
<th>spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>antiproton</td>
<td>1</td>
<td>-1</td>
<td>1/2</td>
</tr>
<tr>
<td>antineutron</td>
<td>1</td>
<td>0</td>
<td>1/2</td>
</tr>
</tbody>
</table>
What happens when matter and antimatter meet?

**ANNIHILATION**

- $e$ + $e^+$ = ENERGY
- $p$ + $\bar{p}$ = MORE ENERGY
- $n$ + $\bar{n}$ = MORE ENERGY

MUST BE AN EXACT MATTER/ANTIMATTER PAIR
Reverse process of annihilation

**PAIR PRODUCTION**

ENERGY → $e^{-}, e^{+}$

MORE ENERGY → $p, \bar{p}$

MUCH MORE ENERGY → $\uparrow, \downarrow$

ALWAYS MAKES A MATTER/ANTIMATTER PAIR
ENOUGH ENERGY

how much is enough?
in this case at least
$2 \times (m_p + m_e)$

generally more than
the sum of the masses
of the final particles
Where did all the antimatter go?
We don’t know

Our world is naturally mostly matter

Some antimatter around due to particle reactions in space - not much reaches us though

We can produce antimatter in accelerators and have been doing so for almost 50 years

Scientists at CERN were first to produce antihydrogen in 1995

9 atoms in 3 weeks lasted billionths of a second and went about 10 meters
### Particle Equations

<table>
<thead>
<tr>
<th>In math</th>
<th>In particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x + 1 = 4$</td>
<td>$n \rightarrow p \ e^- \ \bar{\nu}$</td>
</tr>
<tr>
<td>$-x - 1 = -4$</td>
<td>$\bar{n} \rightarrow \bar{p} \ e^+ \ \nu$</td>
</tr>
<tr>
<td>$2x + 1 = 5$</td>
<td></td>
</tr>
<tr>
<td>$2x = 5 - 1$</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Multiply by -1</th>
<th>Change all particles to antiparticles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bring number to other side and negate</td>
<td>Bring particle to the other side and change it to the antiparticle</td>
</tr>
</tbody>
</table>