Physics 107  
Lec 35  

**Standard Model**

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
</tr>
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<tbody>
<tr>
<td>$u$</td>
<td>$c$</td>
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<tr>
<td>$d$</td>
<td>$s$</td>
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<tr>
<td>$t$</td>
<td>$b$</td>
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**Leptons**

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_e$</td>
<td>$\nu_x$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>$\nu_I$</td>
</tr>
<tr>
<td>$e^-$</td>
<td>$\mu^-$</td>
</tr>
</tbody>
</table>

Maxwell understood that electrical field stored energy $\frac{Q}{\text{volume}} = \frac{1}{2} \varepsilon_0 E^2$, $\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ in MKS units and magnetic field stored energy $\frac{B^2}{\text{volume}}$. 

$\mu_0 = 4\pi \times 10^{-7} \text{Tm/A}$

**Standard Model**

All three EM, weak, strong forces mediated by fields = "Gauge Bosons"

- EM Field: $\gamma$ (boson) = photon
- Weak Field: $Z^0$ and $W^\pm$ bosons
- Strong Field: $g$ = gluon

*Note: gravity is not included (yet?)*

1940s Feynman: QED = quantum electrodynamics

**Feynman diagrams** summarize interactions

Example: $e^-$ scattering off $e^-$ (plain collision)

- Time $\uparrow$

$-$ = particle

$\sim$ = field

$\triangleright$ = virtual

$\triangleright$ = photon

$\triangleright$ = electric field

$\triangleright$ = space
More interaction examples:

\[ e^- \text{--} e^+ \text{--} \text{annihilation} \]

In principle can be reversed!

But wait, is that only possibility? How about:

\[ \mu^- \rightarrow \mu^+ \text{ or } \bar{\nu} \rightarrow \nu \text{ or even } \]

\[ e^- + e^+ \rightarrow \mu^- + \mu^+ \text{ or } e^+ + e^- \rightarrow \bar{q} q \text{ no change} \]

\[ \rightarrow \mu^- + \mu^+ \text{ or } \rightarrow e^+ + e^- \rightarrow \text{ new particle: Mesons} \]

Examples:

\[ \pi^+ = u d \quad 139.57 \text{ MeV} \]
\[ \pi^- = \bar{u} d \quad 134.98 \text{ MeV} \]

What about anti-matter? Why is universe composed of matter???