USEFUL INFORMATION – CLASSES 2 AND 3

- Many relativity examples and problems involve interactions and decays of the following particles. This is a subset of a much larger particle zoo:
  
  **photon** ($\gamma$) – Massless. Stable.
  **electron, positron** ($e^-, e^+$) – Stable.
  **muon** ($\mu^-, \mu^+$) – essentially, a heavy electron. Unstable,
    - Only decay mode: $\mu^- \rightarrow e^-\bar{\nu}_e\nu_\mu$, $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$.
  **neutrino, antineutrino** ($\nu, \bar{\nu}$) – Neutral partners to the electron, muon (and an even heavier version of the electron, called the tau). The subscript identifies the charged partner ($\nu_e = \text{electron neutrino}$). Massless (until I tell you otherwise). Stable.
  **pion** ($\pi^+, \pi^-, \pi^0$) – The lightest of the composite particles (made of quarks). Contains up and down quarks. Because of their low mass, pions are produced copiously in most high energy interactions. Unstable,
    - *Almost* exclusive decay modes: $\pi^+ \rightarrow \mu^+\nu_\mu$, $\pi^- \rightarrow \mu^-\bar{\nu}_\mu$, $\pi^0 \rightarrow \gamma\gamma$.
  **kaon** ($K^+, K^-, K^0$) – The second lightest of the composite particles. Contains a strange quark and either an up or down quark. Unstable,
    - Typical decays: $K^+ \rightarrow \mu^+\nu_\mu$, $K^- \rightarrow \mu^-\bar{\nu}_\mu$, $K^0 \rightarrow \pi^+\pi^-$. 
  **proton** ($p$) – Stable.
  **neutron** ($n$) – Unstable,
    - Only decay mode: $n \rightarrow pe^-\bar{\nu}_e$.

The “mass hierarchy” for these particles is:

$$m_n > m_p > m_K > m_\pi > m_\mu > m_e > m_\gamma = m_\nu = 0$$
• Useful information on units we will use for the first sections of Q2C:

<table>
<thead>
<tr>
<th>Units</th>
<th>SI Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>1 eV = 1.602 × 10(^{-19}) J</td>
</tr>
<tr>
<td></td>
<td>1 MeV = 1 × 10(^{6}) eV = 1.602 × 10(^{-13}) J</td>
</tr>
<tr>
<td></td>
<td>1 GeV = 1000 MeV = 1.602 × 10(^{-10}) J</td>
</tr>
<tr>
<td>Momentum</td>
<td>1 MeV/c = 5.344 × 10(^{-27}) kg m/s</td>
</tr>
<tr>
<td>Mass</td>
<td>1 MeV/c(^{2}) = 1.783 × 10(^{-30}) kg</td>
</tr>
<tr>
<td>Length</td>
<td>1 fermi (fm) = 1 × 10(^{-15}) m</td>
</tr>
</tbody>
</table>

• Physicists often use “Natural Units”: \( \hbar = c = 1 \)
  
  - 1 unit of mass = 1 GeV
  - 1 unit of length = 1 GeV\(^{-1}\) = 0.1975 fm
  - 1 unit of time = 1 GeV\(^{-1}\) = 6.588 × 10\(^{-28}\) s