Particle Properties

You don’t have to remember this information! In an exam the masses of the particles are given on the constant sheet. Any other required information will be given to you.

**What you should know**, or be able to work out, is:

- the quantum numbers, and if they are conserved are or not
- the force responsible for a decay, from the lifetime
- the main decay modes, using a Feynman diagram
- that the +,− and 0 superscripts correspond to the electric charge of the particles
- the relationship between a particle and its antiparticle.

Anti-particles are named in the tables. Anti-particles have the same mass, same lifetime, opposite quantum numbers from the particle. Anti-particles decay into the anti-particles of the shown modes. For example, an anti-muon, μ⁺, has a mass of 105.7 MeV/c² and a lifetime of $2.197 \times 10^{-6}$ s. Its quantum numbers are $L_e = 0, L_\mu = -1, L_\tau = 0$ and $Q = +1$. Its main decay mode is $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$.

Quantum Numbers

The following quantum numbers are conserved in **all** reactions:

- Baryon Number, $B$. $B = +1/3$ for quarks and $B = -1/3$ for antiquarks. Therefore $B = 1$ for baryons and $B = 0$ for mesons.
- The three lepton flavour quantum numbers: $L_e, L_\mu, L_\tau$.
- Electric charge, $Q$.

There are six quantum numbers are used to describe quark flavour, which hadrons also carry:

- Strangeness, $S \equiv N(\bar{s}) - N(s)$
- Charm, $C \equiv N(c) - N(\bar{c})$
- Bottomness, or beauty, $B \equiv N(\bar{b}) - N(b)$
- Topness, $T \equiv N(t) - N(\bar{t})$
- Isospin, $I$, and the third component of the isospin, $I_Z$ (or $I_3$): $-I < I_Z < I$. For single quarks, the isospin quantum number give information about the number of up and down quarks, with the third component ($I_Z$) used to differentiate between up and down. In hadrons, isospin combines in the same way as spin: using Clebsch-Gordan coefficients.

The first four quantum numbers is conserved in strong and electromagnetic interactions, but not in the weak interactions. Isospin is conserved in strong interactions, but not in electromagnetic and weak interactions.
Table 1: The leptons of the Standard Model. The masses of the neutrinos are so small, that we can ignore them in most reactions. The concepts of lifetime and decay mode don’t really make sense for the neutrinos.

<table>
<thead>
<tr>
<th>Lepton</th>
<th>Symbol</th>
<th>Anti-particle</th>
<th>mass  (MeV/c²)</th>
<th>L_e</th>
<th>L_µ</th>
<th>L_τ</th>
<th>Q (e)</th>
<th>Lifetime (s)</th>
<th>Main Decay Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>e⁻</td>
<td>e⁺</td>
<td>0.511</td>
<td>+1</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>Stable</td>
<td>-</td>
</tr>
<tr>
<td>muon</td>
<td>µ⁻</td>
<td>µ⁺</td>
<td>105.7</td>
<td>0</td>
<td>+1</td>
<td>0</td>
<td>-1</td>
<td>2.197 × 10⁻⁶</td>
<td>e⁻ν_eν_µ</td>
</tr>
<tr>
<td>tau</td>
<td>τ⁻</td>
<td>τ⁺</td>
<td>1777</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>-1</td>
<td>2.91 × 10⁻¹³</td>
<td>e⁻ν_eν_µ, µ⁻ν_µν_τ, hadrons + ν_τ</td>
</tr>
<tr>
<td>electron neutrino</td>
<td>νₑ</td>
<td>νₑ⁻</td>
<td>∼0</td>
<td>+1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>muon neutrino</td>
<td>ν_µ</td>
<td>ν_µ⁻</td>
<td>∼0</td>
<td>0</td>
<td>+1</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>tau neutrino</td>
<td>ν_τ</td>
<td>ν_τ⁻</td>
<td>∼0</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: The quarks of the Standard Model. Quarks are always found in bound states, therefore it doesn’t always make much sense to talk about the masses and lifetimes of the individual quarks.

<table>
<thead>
<tr>
<th>Quark</th>
<th>Symbol</th>
<th>Anti-quark</th>
<th>I</th>
<th>I_Z</th>
<th>S</th>
<th>C</th>
<th>B</th>
<th>T</th>
<th>Q(e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>down</td>
<td>d</td>
<td>d</td>
<td>1/2</td>
<td>-1/2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1/3</td>
</tr>
<tr>
<td>up</td>
<td>u</td>
<td>ū</td>
<td>1/2</td>
<td>1/2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+2/3</td>
</tr>
<tr>
<td>strange</td>
<td>s</td>
<td>ŝ</td>
<td>0</td>
<td>-</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1/3</td>
</tr>
<tr>
<td>charm</td>
<td>c</td>
<td>c̄</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>0</td>
<td>+2/3</td>
</tr>
<tr>
<td>bottom</td>
<td>b</td>
<td>b̄</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-1/3</td>
</tr>
<tr>
<td>top</td>
<td>t</td>
<td>t̄</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+1</td>
<td>+2/3</td>
</tr>
<tr>
<td>Meson</td>
<td>Symbol</td>
<td>Anti-particle</td>
<td>quark composition</td>
<td>mass (MeV/c²)</td>
<td>I</td>
<td>S</td>
<td>C</td>
<td>B</td>
<td>Lifetime (s)</td>
</tr>
<tr>
<td>------------------</td>
<td>--------</td>
<td>---------------</td>
<td>------------------</td>
<td>--------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>------</td>
<td>--------------</td>
</tr>
<tr>
<td>Charged Pion</td>
<td>π⁺</td>
<td>π⁻</td>
<td>ud</td>
<td>139.6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.60 x 10⁻⁸</td>
</tr>
<tr>
<td>Neutral Pion</td>
<td>π⁰</td>
<td>Self</td>
<td>(dd - uu)/√2</td>
<td>135.0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.83 x 10⁻¹⁶</td>
</tr>
<tr>
<td>Charged Kaon</td>
<td>K⁺</td>
<td>K⁻</td>
<td>us</td>
<td>493.7</td>
<td>1/2</td>
<td>+1</td>
<td>+1</td>
<td>0</td>
<td>1.24 x 10⁻⁸</td>
</tr>
<tr>
<td>Neutral Kaon</td>
<td>K⁰</td>
<td>K⁰</td>
<td>ds</td>
<td>-</td>
<td>1/2</td>
<td>+1</td>
<td>+1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>K-short</td>
<td>K_S</td>
<td>-</td>
<td>(K⁰ + K⁰)/√2</td>
<td>497.7</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.89 x 10⁻¹⁰</td>
</tr>
<tr>
<td>K-long</td>
<td>K_L</td>
<td>-</td>
<td>(K⁰ - K⁰)/√2</td>
<td>497.7</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.2 x 10⁻⁸</td>
</tr>
<tr>
<td>Eta</td>
<td>η₀</td>
<td>Self</td>
<td>(dd + uu - 2ss)/√6</td>
<td>547.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>&lt; 10⁻¹⁸</td>
</tr>
<tr>
<td>Eta-Prime</td>
<td>η¹</td>
<td>Self</td>
<td>(dd + uu - 2ss)/√6</td>
<td>957.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>&lt; 10⁻²⁰</td>
</tr>
<tr>
<td>Charged Rho</td>
<td>ρ⁺</td>
<td>ρ⁻</td>
<td>ud</td>
<td>770</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.4 x 10⁻²³</td>
</tr>
<tr>
<td>Baryon</td>
<td>Symbol</td>
<td>quark composition</td>
<td>mass (MeV/c²)</td>
<td>$I$</td>
<td>$I_Z$</td>
<td>$S$</td>
<td>Lifetime (s)</td>
<td>Main Decay Modes</td>
<td></td>
</tr>
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<td>--------</td>
<td>-------------------</td>
<td>---------------</td>
<td>------</td>
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<td>------</td>
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<td>------------------</td>
<td></td>
</tr>
<tr>
<td>Proton</td>
<td>$p$</td>
<td>uud</td>
<td>938.272</td>
<td>1/2</td>
<td>1/2</td>
<td>0</td>
<td>Stable</td>
<td></td>
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<tr>
<td>Neutron</td>
<td>$n$</td>
<td>ddu</td>
<td>939.6</td>
<td>1/2</td>
<td>−1/2</td>
<td>0</td>
<td>920</td>
<td>$p\bar{e}\nu_e$</td>
<td></td>
</tr>
<tr>
<td>Lambda</td>
<td>$\Lambda^0$</td>
<td>uds</td>
<td>1115.6</td>
<td>0</td>
<td>0</td>
<td>−1</td>
<td>$2.6 \times 10^{-10}$</td>
<td>$p\pi^-, n\pi^0$</td>
<td></td>
</tr>
<tr>
<td>Sigma Plus</td>
<td>$\Sigma^+$</td>
<td>uus</td>
<td>1189.4</td>
<td>1</td>
<td>−1</td>
<td>−1</td>
<td>$0.8 \times 10^{-10}$</td>
<td>$p\pi^0, n\pi^+$</td>
<td></td>
</tr>
<tr>
<td>Sigma Zero</td>
<td>$\Sigma^0$</td>
<td>uds</td>
<td>1192.5</td>
<td>1</td>
<td>0</td>
<td>−1</td>
<td>$6 \times 10^{-20}$</td>
<td>$\Lambda^0\gamma$</td>
<td></td>
</tr>
<tr>
<td>Sigma Minus</td>
<td>$\Sigma^-$</td>
<td>dds</td>
<td>1197.3</td>
<td>1</td>
<td>+1</td>
<td>−1</td>
<td>$1.5 \times 10^{-10}$</td>
<td>$n\pi^-$</td>
<td></td>
</tr>
<tr>
<td>Delta</td>
<td>$\Delta^{++}$</td>
<td>uuu</td>
<td>1232</td>
<td>3/2</td>
<td>3/2</td>
<td>0</td>
<td>$0.6 \times 10^{-23}$</td>
<td>$p\pi^+$</td>
<td></td>
</tr>
<tr>
<td>Delta</td>
<td>$\Delta^+$</td>
<td>uud</td>
<td>1232</td>
<td>3/2</td>
<td>1/2</td>
<td>0</td>
<td>$0.6 \times 10^{-23}$</td>
<td>$p\pi^0$</td>
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<tr>
<td>Delta</td>
<td>$\Delta^0$</td>
<td>udd</td>
<td>1232</td>
<td>3/2</td>
<td>−1/2</td>
<td>0</td>
<td>$0.6 \times 10^{-23}$</td>
<td>$n\pi^0$</td>
<td></td>
</tr>
<tr>
<td>Delta</td>
<td>$\Delta^-$</td>
<td>ddd</td>
<td>1232</td>
<td>3/2</td>
<td>−3/2</td>
<td>0</td>
<td>$0.6 \times 10^{-23}$</td>
<td>$n\pi^−$</td>
<td></td>
</tr>
<tr>
<td>Cascade Zero</td>
<td>$\Xi^0$</td>
<td>uss</td>
<td>1315</td>
<td>1</td>
<td>+1</td>
<td>−2</td>
<td>$2.9 \times 10^{-10}$</td>
<td>$\Lambda^0\pi^0$</td>
<td></td>
</tr>
<tr>
<td>Cascade Minus</td>
<td>$\Xi^-$</td>
<td>dss</td>
<td>1321</td>
<td>1</td>
<td>−1</td>
<td>−2</td>
<td>$1.64 \times 10^{-10}$</td>
<td>$\Lambda^0\pi^−$</td>
<td></td>
</tr>
<tr>
<td>Omega Minus</td>
<td>$\Omega^-$</td>
<td>sss</td>
<td>1672</td>
<td>0</td>
<td>0</td>
<td>−3</td>
<td>$0.82 \times 10^{-10}$</td>
<td>$\Xi^0\pi^−, \Lambda^0K^−$</td>
<td></td>
</tr>
<tr>
<td>Lambda-C</td>
<td>$\Lambda_c^+$</td>
<td>udc</td>
<td>2281</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$2 \times 10^{-13}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Selected baryons. Anti-baryons are symbolised by an overline, e.g. $\Sigma^-=\bar{u}\bar{u}\bar{s}$ is the antiparticle of $\Sigma^+$. 