### QUARKS

The $u$-, $d$-, and $s$-quark masses are estimates of so-called “current-quark masses,” in a mass-independent subtraction scheme such as $\overline{\text{MS}}$ at a scale $\mu \approx 2$ GeV. The $c$- and $b$-quark masses are the “running” masses in the $\overline{\text{MS}}$ scheme. For the $b$-quark we also quote the $1S$ mass. These can be different from the heavy quark masses obtained in potential models.

#### $u$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

- Mass $m = 1.5$ to 4 MeV $^{[a]}$
- Charge $= \frac{2}{3} e$  $l_z = +\frac{1}{2}$
- $m_u/m_d = 0.3$ to 0.7

#### $d$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

- Mass $m = 4$ to 8 MeV $^{[a]}$
- Charge $= -\frac{1}{3} e$  $l_z = -\frac{1}{2}$
- $m_s/m_d = 17$ to 22
- $\overline{m} = (m_u+m_d)/2 = 3.0$ to 5.5 MeV

#### $s$

$I(J^P) = 0(\frac{1}{2}^+)$

- Mass $m = 80$ to 130 MeV $^{[a]}$
- Charge $= -\frac{1}{3} e$  Strangeness $= -1$
- $(m_s - (m_u + m_d)/2)/(m_d - m_u) = 30$ to 50

#### $c$

$I(J^P) = 0(\frac{1}{2}^+)$

- Mass $m = 1.15$ to 1.35 GeV
- Charge $= \frac{2}{3} e$  Charm $= +1$

#### $b$

$I(J^P) = 0(\frac{1}{2}^+)$

- Charge $= -\frac{1}{3} e$  Bottom $= -1$

- Mass $m = 4.1$ to 4.4 GeV ($\overline{\text{MS}}$ mass)
- Mass $m = 4.6$ to 4.9 GeV ($1S$ mass)
The charge of the top quark is $\frac{2}{3}e$. Its mass is $174.3 \pm 5.1$ GeV (direct observation of top events) and $178.1^{+10.4}_{-8.3}$ GeV (Standard Model electroweak fit).

### t Decay Modes

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Fraction ($\Gamma_i/\Gamma$)</th>
<th>Confidence Level (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Wq (q = b, s, d)$</td>
<td>[b,c] (9.4 ± 2.4)%</td>
<td>95%</td>
</tr>
<tr>
<td>$Wb$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\ell \nu $ anywhere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau \nu \tau b$</td>
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</tr>
<tr>
<td>$\gamma q (q = u, c)$</td>
<td>$[d] &lt; 5.9 \times 10^{-3}$</td>
<td>95%</td>
</tr>
</tbody>
</table>

**$\Delta T = 1$ weak neutral current ($T1$) modes**

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>$Zq (q = u, c)$</td>
<td>$[e] &lt; 13.7$</td>
<td>95%</td>
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</tbody>
</table>

### Free Quark Searches

All searches since 1977 have had negative results.

### Notes

[a] The ratios $m_u/m_d$ and $m_s/m_d$ are extracted from pion and kaon masses using chiral symmetry. The estimates of $u$ and $d$ masses are not without controversy and remain under active investigation. Within the literature there are even suggestions that the $u$ quark could be essentially massless. The $s$-quark mass is estimated from SU(3) splittings in hadron masses.

[b] $\ell$ means $e$ or $\mu$ decay mode, not the sum over them.

[c] Assumes lepton universality and $W$-decay acceptance.

[d] This limit is for $\Gamma(t \to \gamma q)/\Gamma(t \to Wb)$.

[e] This limit is for $\Gamma(t \to Z q)/\Gamma(t \to Wb)$. 