# 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 estimated from charmonium, bottomonium, $D$, and $B$ masses. They are the "running" masses in the $\overline{\text{MS}}$ scheme. 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 4.5 MeV [a] Charge $= \frac{2}{3}\ e$ $I_z = +\frac{1}{2}$
$m_u/m_d = 0.2$ to 0.7

## *d*

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

Mass $m = 5$ to 8.5 MeV [a] Charge $= -\frac{1}{3}\ e$ $I_z = -\frac{1}{2}$
$m_s/m_d = 17$ to 22
$\overline{m} = (m_u + m_d)/2 = 2.5$ to 5.5 MeV

## *s*

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

Mass $m = 80$ to 155 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 $m = 1.0$ to 1.4 GeV Charge $= \frac{2}{3}\ e$ Charm $= +1$

## *b*

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

Mass $m = 4.0$ to 4.5 GeV Charge $= -\frac{1}{3}\ e$ Bottom $= -1$

## *t*

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

Charge $= \frac{2}{3}\ e$ Top $= +1$

Mass $m = 174.3 \pm 5.1$ GeV (direct observation of top events)
Mass $m = = 178.1^{+10.4}_{-\ 8.3}$ GeV (Standard Model electroweak fit)

| ***t* DECAY MODES** | | Fraction ($\Gamma_i/\Gamma$) | Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|---|
| $W\,q(q = b,\ s,\ d)$ | | | | – |
| $W\,b$ | | | | – |
| $\ell\,\nu_\ell$ anything | [b,c] | ( 9.4±2.4) % | | – |
| $\tau\,\nu_\tau\,b$ | | | | – |
| $\gamma\,q(q{=}u,c)$ | [d] | < 3.2 % | 95% | – |
| **$\Delta T = 1$ weak neutral current (*T1*) modes** | | | | |
| $Z\,q(q{=}u,c)$ | *T1* [e] | < 13.7 % | 95% | – |

## *b′* (4*th* Generation) Quark, Searches for

Mass $m >$ 199 GeV, CL = 95% ($p\overline{p}$, neutral-current decays)
Mass $m >$ 128 GeV, CL = 95% ($p\overline{p}$, charged-current decays)
Mass $m >$ 46.0 GeV, CL = 95% ($e^+e^-$, all decays)

## 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 $\Gamma(t \to\ \gamma\,q)/\Gamma(t \to\ W\,b)$.

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