above. Each method involves its own set of approximations and errors. In most cases, the errors are a best guess at the size of neglected higher-order corrections. The expansion parameter for the approximations is not much smaller than unity (for example it is $m_K^2/\Lambda_\chi^2 \approx 0.25$ for the chiral expansion), so an unexpectedly large coefficient in a neglected higher-order term could significantly alter the results. It is also important to note that the quark mass values can be significantly different in the different schemes. For example, assuming that the HQET mass m_b is 4.7 GeV, and $\overline{\alpha}_s(m_b) \approx 0.2$ gives the $\overline{\rm MS}$ b-quark mass $\overline{m}_b(\mu = m_b) = 4.3$ GeV using the one-loop formula in Eq. (2). The heavy quark masses obtained using HQET, QCD sum rules, or lattice gauge theory are consistent with each other if they are all converted into the same scheme. When using the data listings, it is important to remember that the numerical value for a quark mass is meaningless without specifying the particular scheme in which it was obtained.

References

1. R. Tarrach, Nucl. Phys. **B183**, 384 (1981).
2. H. Georgi and H.D. Politzer, Phys. Rev. **D14**, 1829 (1976).
3. M.A. Shifman, A.I. Vainshtein, and V.I. Zakharov, Nucl. Phys. **B147**, 385 (1979).
4. C.T.H. Davies, *et al.*, Report No. SCRI-94-39 [hep-lat/9404012].
5. N. Isgur and M.B. Wise, Phys. Lett. **B232**, 113 (1989), *ibid* **B237**, 527 (1990);
   M.B. Voloshin and M. Shifman, Sov. J. Nucl. Phys. **45**, 292 (1987), *ibid* **47**, 511 (1988);
   S. Nussinov and W. Wetzel, Phys. Rev. **D36**, 130 (1987).
6. H. Georgi, Phys. Lett. **B240**, 447 (1990).
7. E. Eichten and B. Hill, Phys. Lett. **B234**, 511 (1990).
8. H. Georgi, in *Perspectives of the Standard Model*, ed. R.K. Ellis, C.T. Hill, and J.D. Lykken (World Scientific, Singapore, 1992);
   B. Grinstein, in *High Energy Phenomenology*, ed. R. Huerta and M.A. Pérez (World Scientific, Singapore, 1992).
9. A.F. Falk, M. Neubert, and M.E. Luke, Nucl. Phys. **B388**, 363 (1992).
10. M. Neubert, SLAC Report No. SLAC-PUB-6263 (June 1993), submitted to Phys. Reports.
11. S. Narison, Phys. Lett. **B197**, 405 (1987).
12. S. Weinberg, Trans. N.Y. Acad. Sci. **38**, 185 (1977).
13. See for example, H. Georgi, *Weak Interactions and Modern Particle Theory* (Benjamin/Cummings, Menlo Park, 1984).
14. J. Gasser and H. Leutwyler, Phys. Reports **87**, 77 (1982).
15. D.B. Kaplan and A.V. Manohar, Phys. Rev. Lett. **56**, 2004 (1986).
16. J. Gasser and H. Leutwyler, Nucl. Phys. **B250**, 465 (1985).
17. A. Manohar and H. Georgi, Nucl. Phys. **B234**, 189 (1984).
18. H. Leutwyler, Nucl. Phys. **B337**, 108 (1990).
19. P. Langacker and H. Pagels, Phys. Rev. **D19**, 2070 (1979);
    H. Pagels and S. Stokar, Phys. Rev. **D22**, 2876 (1980);
    H. Leutwyler, Nucl. Phys. **B337**, 108 (1990);
    J. Donoghue and D. Wyler, Phys. Rev. Lett. **69**, 3444 (1992);
    K. Maltman, T. Goldman and G.L. Stephenson Jr., Phys. Lett. **B234**, 158 (1990).
20. K. Choi, Nucl. Phys. **B383**, 58 (1992).
21. J. Donoghue and D. Wyler, Phys. Rev. **D45**, 892 (1992).

u

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

Mass m = 2 to 8 MeV Charge = $\frac{2}{3}$ e $I_z = +\frac{1}{2}$

m_u/m_d = 0.25 to 0.70

d

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

Mass m = 5 to 15 MeV Charge = $-\frac{1}{3}$ e $I_z = -\frac{1}{2}$

m_s/m_d = 17 to 25

s

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

Mass m = 100 to 300 MeV Charge = $-\frac{1}{3}$ e Strangeness = −1

$(m_s - (m_u + m_d)/2)/(m_d - m_u)$ = 34 to 51

LIGHT QUARKS — u, d, s

u-QUARK MASS

The u-, d-, and s-quark masses are estimates of so-called "current-quark masses," in a mass- independent subtraction scheme such as $\overline{\rm MS}$ at a scale $\mu \approx 1$ GeV. The ratios m_u/m_d and m_s/m_d are extracted from pion and kaon masses using chiral symmetry. The estimates of d and u 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.

VALUE (MeV)	*DOCUMENT ID*		*TECN*
2 to 8 OUR EVALUATION			
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[1] CHOI	92B	THEO
5.8	[2] BARDUCCI	88	THEO
5.1±1.5	[3] GASSER	82	THEO
1.8±0.7	[4] PAGELS	80	THEO
5.6±2.9	[5] PAGELS	80	THEO
4.2	[6] WEINBERG	77	THEO
4	[7] GASSER	75	THEO

[1] CHOI 92B argues that $m_u = 0$ is okay based on instanton contributions to the chiral coefficients. Disagrees with DONOGHUE 92 and DONOGHUE 92B.

[2] BARDUCCI 88 renormalized quark mass at 1 GeV. Uses a calculation of the effective potential for $\overline{\psi}\psi$ in QCD, and estimates for $\Sigma(p^2)$.

[3] GASSER 82 uses chiral perturbation theory for the mass ratios, and uses QCD sum rules to extract the absolute values. The renormalization scale is 1 GeV.

[4] PAGELS 80 uses lowest-order chiral perturbation theory plus an estimate of $\langle \overline{q}q \rangle$.

[5] PAGELS 80 uses lowest-order chiral perturbation theory plus an estimate of $\langle \overline{q}q\overline{q}q \rangle$ correlation function.

[6] WEINBERG 77 assumes that the baryon SU(3) splittings are equal to m_s.

[7] GASSER 75 uses inelastic electron scattering and SU(6).

d-QUARK MASS

See the comment for the u quark above.

VALUE (MeV)	*DOCUMENT ID*		*TECN*
5 to 15 OUR EVALUATION			
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[8] ADAMI	93	THEO
	[9] NEFKENS	92	THEO
8.4	[10] BARDUCCI	88	THEO
	[11] DOMINGUEZ	87	THEO
	[12] KREMER	84	THEO
8.9±2.6	[13] GASSER	82	THEO
4.3±0.7	[14] PAGELS	80	THEO
14.6±5.7	[15] PAGELS	80	THEO
7.5	[16] WEINBERG	77	THEO
6	[17] GASSER	75	THEO

[8] ADAMI 93 obtain $m_d - m_u = 3 \pm 1$ MeV at μ=0.5 GeV using isospin-violating effects in QCD sum rules.

[9] NEFKENS 92 results for $m_d - m_u$ are 3.1 ± 0.4 MeV from meson masses and 3.6 ± 0.4 MeV from baryon masses.

[10] BARDUCCI 88 renormalized quark mass at 1 GeV. Uses a calculation of the effective potential for $\overline{\psi}\psi$ in QCD, and estimates for $\Sigma(p^2)$.

[11] DOMINGUEZ 87 uses QCD sum rules to obtain $m_u + m_d = 15.5 \pm 2.0$ MeV and $m_d - m_u = 6 \pm 1.5$ MeV.

[12] KREMER 84 obtain $m_u + m_d = 21 \pm 2$ MeV at $Q^2 = 1$ GeV^2 using SVZ values for quark condensates; they obtain $m_u + m_d = 35 \pm 3$ MeV at $Q^2 = 1$ GeV^2 using factorization values for quark condensates.

[13] GASSER 82 uses chiral perturbation theory for the mass ratios, and uses QCD sum rules to extract the absolute values. The renormalization scale is 1 GeV.

[14] PAGELS 80 uses lowest-order chiral perturbation theory plus an estimate of $\langle \overline{q}q \rangle$.

[15] PAGELS 80 uses lowest-order chiral perturbation theory plus an estimate of $\langle \overline{q}q\overline{q}q \rangle$ correlation function.

[16] WEINBERG 77 assumes that the baryon SU(3) splittings are equal to m_s.

[17] GASSER 75 uses inelastic electron scattering and SU(6).