

# PDG App for Smartphones

iPhone and Android

**In progress**



Summary Tables

Reviews

Products

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US DOE  
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# Summary Tables

## Summary Tables

Gauge and Higgs Bosons ( $\gamma$ ,  $g$ ,  $W$ ,  $Z$ , ...)

Leptons ( $e$ ,  $\mu$ ,  $\tau$ , ... neutrinos ...)

Quarks ( $u$ ,  $d$ ,  $s$ ,  $c$ ,  $b$ ,  $t$ ,  $b'$ ,  $t'$ , Free)

Mesons

Baryons

Searches (Monopoles, SUSY, Technicolor, Compositeness, ...)

Tests of Conservation Laws

# Summary Tables

## SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle Listings of the  
*Review of Particle Physics*  
 J. Beringer *et al.* (PDG), PR D86, 010001 (2012)  
 Available at <http://pdg.lbl.gov>  
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 (Approximate closing date for data: January 15, 2012)

### GAUGE AND HIGGS BOSONS

**$\gamma$**   $I(J^{PC}) = 0,1(1^{--})$   
 Mass  $m < 1 \times 10^{-18}$  eV  
 Charge  $q < 1 \times 10^{-35}$  e  
 Mean life  $\tau$  = Stable

**$g$   
or gluon**  $I(J^P) = 0(1^-)$   
 Mass  $m = 0$  [a]  
 SU(3) color octet

**graviton**  $J = 2$   
 Mass  $m < 7 \times 10^{-32}$  eV

**$W$**   $J = 1$   
 Charge =  $\pm 1$  e  
 Mass  $m = 80.385 \pm 0.015$  GeV  
 $m_Z - m_W = 10.4 \pm 1.6$  GeV  
 $m_{W^+} - m_{W^-} = -0.2 \pm 0.6$  GeV  
 Full width  $\Gamma = 2.085 \pm 0.042$  GeV  
 $\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$   
 $\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$   
 $\langle N_p \rangle = 0.92 \pm 0.14$   
 $\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$

$W^-$  modes are charge conjugates of the modes below.

$W^+$ DECAY MODES	Fraction ( $\Gamma_j/\Gamma$ )	Confidence level	$\rho$ (MeV/c)
$\ell^+ \nu$	[b] $(10.80 \pm 0.09) \%$		–
$e^+ \nu$	$(10.75 \pm 0.13) \%$		40192
$\mu^+ \nu$	$(10.57 \pm 0.15) \%$		40192
$\tau^+ \nu$	$(11.25 \pm 0.20) \%$		40173
hadrons	$(67.60 \pm 0.27) \%$		–

# Reviews

## Reviews

- Constants, Units, Atomic and Nuclear Properties
- Standard Model and Related Topics
- Particle Properties
- Hypothetical Particles and Concepts
- Astrophysics and Cosmology
- Experimental Methods and Colliders
- Mathematical Tools
- Kinematics, Cross-Section Formulae, and Plots
- Authors, Online information, History plots

## 11. THE CKM QUARK-MIXING MATRIX

Revised March 2012 by A. Ceccucci (CERN), Z. Ligeti (LBNL), and Y. Sakai (KEK).

### 11.1. Introduction

The masses and mixings of quarks have a common origin in the Standard Model (SM). They arise from the Yukawa interactions of the quarks with the Higgs condensate. When the Higgs field acquires a vacuum expectation value, quark mass terms are generated. The physical states are obtained by diagonalizing the up and down quark mass matrices by four unitary matrices,  $V_{L,R}^{u,d}$ . As a result, the charged current  $W^\pm$  interactions couple to the physical up and down-type quarks with couplings given by

$$V_{\text{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}. \quad (11.2)$$

This Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2] is a  $3 \times 3$  unitary matrix. It can be parameterized by three mixing angles and a  $CP$ -violating phase,

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}, \quad (11.3)$$

where  $s_{ij} = \sin \theta_{ij}$ ,  $c_{ij} = \cos \theta_{ij}$ , and  $\delta$  is the phase responsible for all  $CP$ -violating phenomena in flavor changing processes in the SM. The angles  $\theta_{ij}$  can be chosen to lie in the first quadrant.

It is known experimentally that  $s_{13} \ll s_{23} \ll s_{12} \ll 1$ , and it is convenient to exhibit this hierarchy using the Wolfenstein parameterization. We define [4–6]

$$s_{12} = \lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}, \quad s_{23} = A\lambda^2 = \lambda \left| \frac{V_{cb}}{V_{us}} \right|, \\ s_{13}e^{i\delta} = V_{ub}^* = A\lambda^3(\rho + i\eta) = \frac{A\lambda^3(\bar{\rho} + i\bar{\eta})\sqrt{1 - A^2\lambda^4}}{\sqrt{1 - \lambda^2[1 - A^2\lambda^4(\bar{\rho} + i\bar{\eta})]}}. \quad (11.4)$$

These ensure that  $\bar{\rho} + i\bar{\eta} = -(V_{ud}V_{ub}^*)/(V_{cd}V_{cb}^*)$  is phase-convention independent and the CKM matrix written in terms of  $\lambda$ ,  $A$ ,  $\bar{\rho}$  and  $\bar{\eta}$  is unitary to all orders in  $\lambda$ . To  $\mathcal{O}(\lambda^4)$ ,

$$V = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4). \quad (11.5)$$

Unitarity implies  $\sum_i V_{ij}V_{ik}^* = \delta_{jk}$  and  $\sum_j V_{ij}V_{kj}^* = \delta_{ik}$ . The six vanishing combinations can be represented as triangles in a complex plane. The most commonly used unitarity triangle arises from

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0, \quad (11.6)$$

by dividing each side by  $V_{cd}V_{cb}^*$  (see Fig. 1). The vertices are exactly  $(0, 0)$ ,  $(1, 0)$  and, due to the definition in Eq. (11.4),  $(\bar{\rho}, \bar{\eta})$ . An important goal of flavor physics is to overconstrain the CKM elements, many of which can be displayed and compared in the  $\bar{\rho}, \bar{\eta}$  plane.

## Standard Model and Related Topics

Can fill the screen

- Quantum Chromodynamics (rev.)
- Electroweak model and constraints on new physics (rev.)
- Cabibbo-Kobayashi-Maskawa quark-mixing matrix (rev.)
- CP* violation (rev.)
- Neutrino mass, mixing, and oscillations (rev.)
- Quark model (rev.)
- Grand Unified Theories (rev.)
- Heavy-Quark and Soft-Collinear Effective Theory (new)
- Lattice Quantum Chromodynamics (new)
- Structure Functions (see below for more figures) (rev.)
- Structure Functions--additional figures (see above)(rev.)
- Fragmentation functions in  $e^+ e^-$ ,  $ep$ , and  $pp$  collisions (rev.)
- Tests of Conservation Laws (rev.)
- CPT* Invariance Tests in Neutral Kaon Decay (rev.)
- CP* Violation in  $K_S \rightarrow 3\pi$
- CP* Violation in  $K_L$  Decays (rev.)
- $V(u)$ ,  $V(us)$ , Cabibbo Angle, and CKM Unitarity (rev.)



**Deployment in a few months?**