

## Standard Model Input Parameters: How many are there?

### Standard Model Masses (MeV/c<sup>2</sup>)

lepton	mass	quark	mass*	boson mediator	mass
$\nu_e$	$<2 \times 10^{-6}$	$u$	2	$\gamma$	0
$\nu_\mu$	$<0.2$	$d$	5	$g$	0
$\nu_\tau$	$<18$	$s$	100	$W$	80,420
$e$	0.511	$c$	1,200	$Z$	91,190
$\mu$	106	$b$	4,300	$H$ (Higgs)	125,000
$\tau$	1,777	$t$	174,000		

\*Light quark masses are imprecise and model dependent. Effective masses in mesons and baryons are significantly larger than these bare-mass estimates.

In the simplest version of the standard model the neutrinos are massless so there are 10 input mass parameters (the  $W$  and  $Z$  mass can be derived from other inputs).

### Standard Model Coupling Constants (dimensionless weight factors used in evaluating Feynman diagram vertices)

interaction	coupling	expression*	value
em: U(1)	$g_e$	$e\sqrt{4\pi k/\hbar c}$	0.3028
weak: SU(2)	$g_W$	$g_e/\sin\theta_w$	0.6295
	$g_Z$	$g_W/\cos\theta_w$	0.7180
strong: SU(3)	$g_s$		1.214

\*Weak mixing angle is  $\theta_w = 28.76^\circ$ .

These coupling constants give 3 input interaction parameters ( $g_e, \theta_w, g_s$ ) to the standard model. To obtain the  $W$  and  $Z$  mass we also need the magnitude of the Higgs field which is  $v = 246$  GeV (or we can use the related Fermi coupling constant  $\sqrt{2}G_F = 1/v^2$ ). In either case, this parameter can be determined from the muon lifetime.

There are a total of 18 input parameters in the simple (massless neutrino) standard model. Here we have given 14 of these inputs. The remaining 4 inputs define the CKM matrix which describes cross-generational mixing of the weak interaction.

There is now good experimental evidence that neutrinos have non-zero mass. This introduces 3 more mass inputs and 4 more parameters describing cross-generational mixing of the neutrinos (neutrino oscillations) giving a **total of 25 input parameters**.

Values given here are from: "Introduction to Elementary Particles" by David Griffiths (2010).