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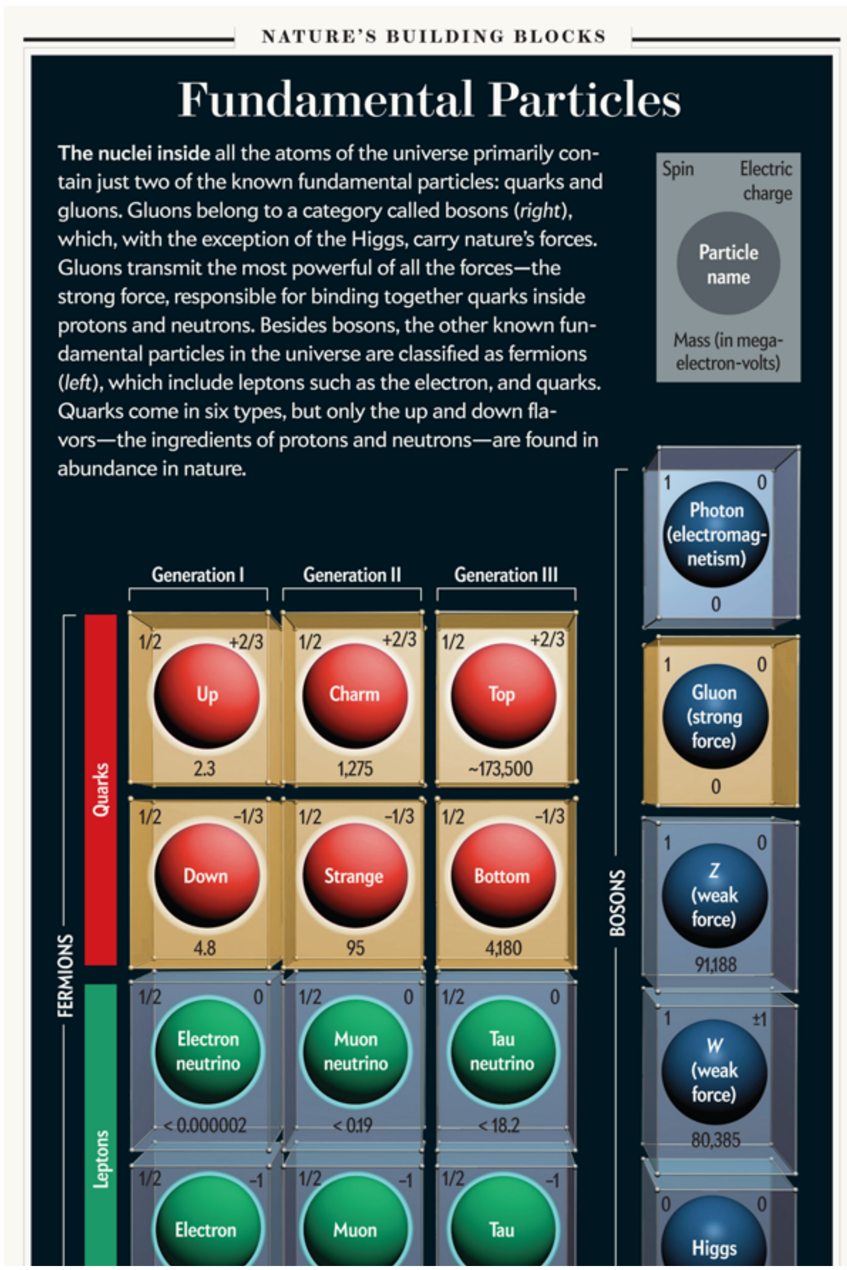
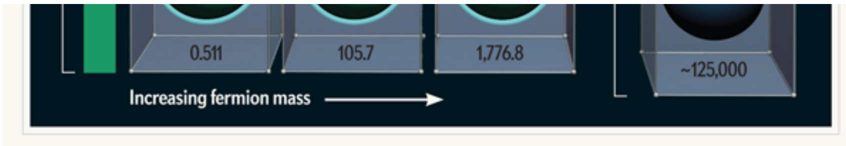
Subatomic Particles over Time: Graphics from the Archive, 1952 to 2015

By Jen Christiansen | April 15, 2015

In the May issue of *Scientific American*, a familiar friend makes an appearance: a chart of fundamental particles. These particles—fermions (which include constituents of matter such as electrons and quarks) and bosons (usually carriers of force)—are at the very heart of the Standard Model of particle physics. Visualizing them in table form has become a bit of a tradition here at the magazine, as a way to introduce readers to the cast of characters in articles on the topic, and to provide context for theorized and newly described particles.

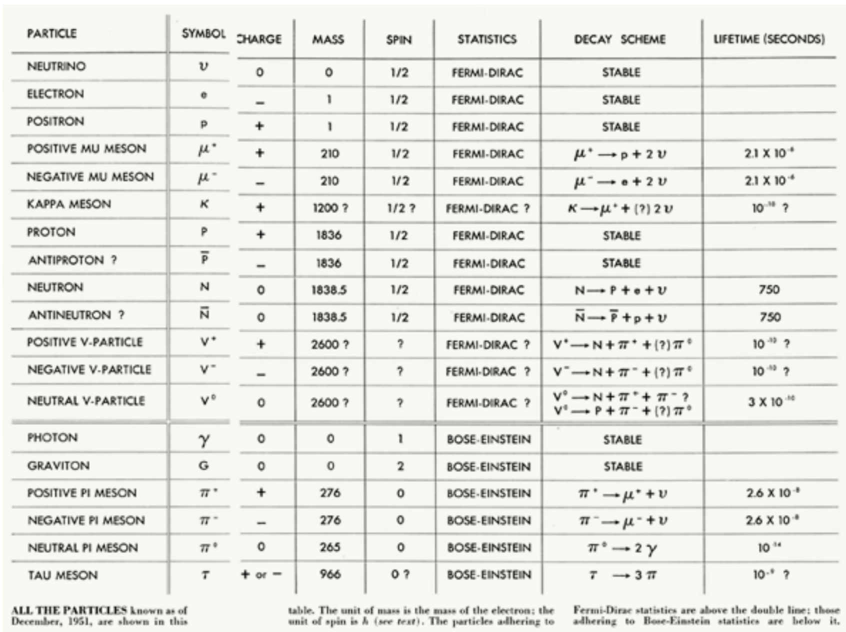




Fundamental particles: From “The Mysteries of the World’s Tiniest Bits of Matter” by Rolf Ent, Thomas Ullrich and Raju Venugopalan, in Scientific American, May 2015. Graphic by Moonrunner Design.

Below is a time-ordered series of my favorite particle zoo tables from the *Scientific American* archive, starting with a comprehensive particle list from 1952, morphing into the discovery-driven Standard Model classifications of the 1970s and beyond. Variation reflects the shifting state of particle physics knowledge over time, different themes addressed by the full articles the tables accompany, and aesthetic trends (influenced by the rendering and print production tools available at the time).

All the particles known as of December, 1951, including fundamental species such as electrons, composite particles, including protons and neutrons (each made of quarks), and theorized particles such as the graviton (which still has not been confirmed): From “The Multiplicity of Particles” by Robert E. Marshak, in *Scientific American*, January, 1952. Graphic by Sara Love

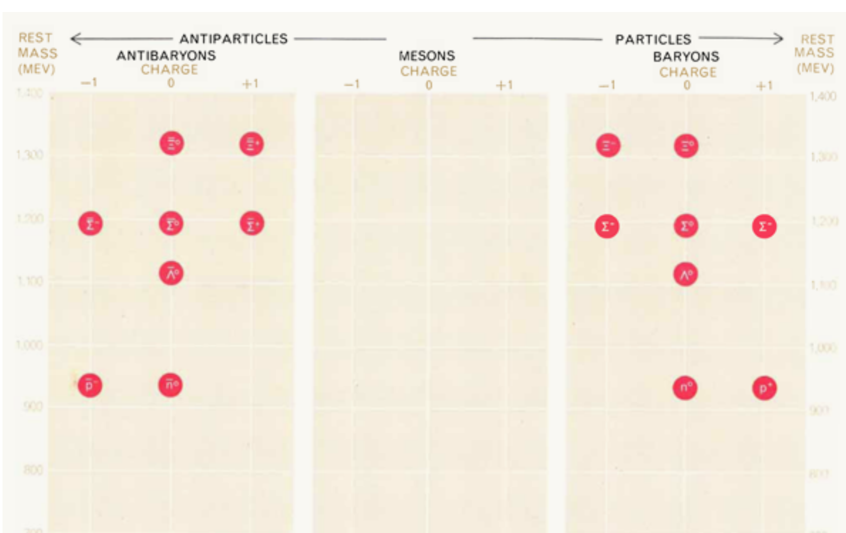


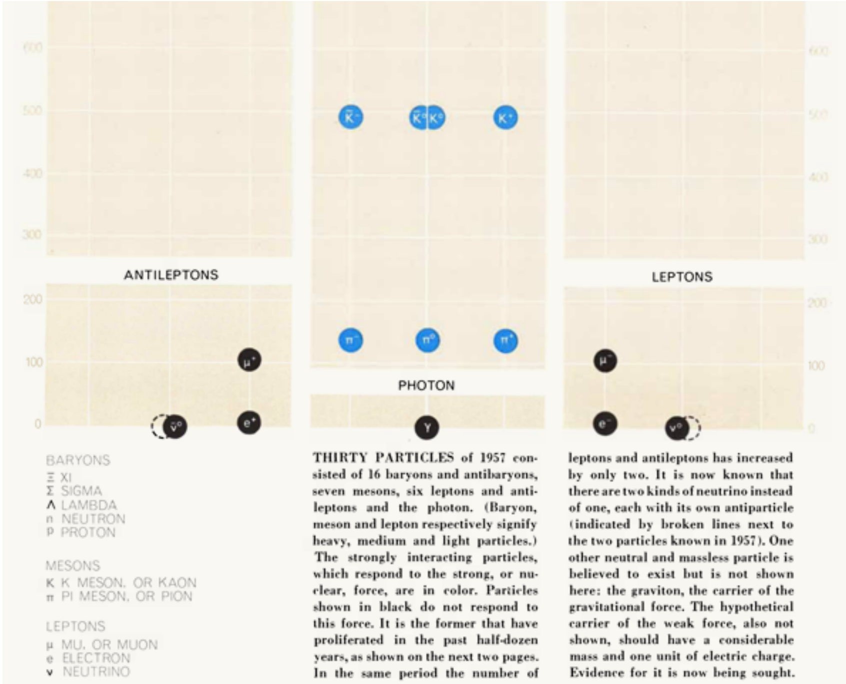
PARTICLE	SYMBOL	CHARGE	MASS	SPIN	STATISTICS	DECAY SCHEME	LIFETIME (SECONDS)
NEUTRINO	υ	0	0	1/2	FERMI-DIRAC	STABLE	
ELECTRON	e	–	1	1/2	FERMI-DIRAC	STABLE	
POSITRON	p	+	1	1/2	FERMI-DIRAC	STABLE	
POSITIVE MU MESON	μ^+	+	210	1/2	FERMI-DIRAC	$\mu^+ \rightarrow p + 2\upsilon$	2.1×10^{-6}
NEGATIVE MU MESON	μ^-	–	210	1/2	FERMI-DIRAC	$\mu^- \rightarrow e + 2\upsilon$	2.1×10^{-6}
KAPPA MESON	κ	+	1200 ?	1/2 ?	FERMI-DIRAC ?	$\kappa \rightarrow \mu^+ + (?)\, 2\upsilon$	10^{-10} ?
PROTON	P	+	1836	1/2	FERMI-DIRAC	STABLE	
ANTIPROTON ?	$\bar{P}$	–	1836	1/2	FERMI-DIRAC	STABLE	
NEUTRON	N	0	1838.5	1/2	FERMI-DIRAC	$N \rightarrow P + e + \upsilon$	750
ANTINEUTRON ?	$\bar{N}$	0	1838.5	1/2	FERMI-DIRAC	$\bar{N} \rightarrow \bar{P} + p + \upsilon$	750
POSITIVE V-PARTICLE	V^+	+	2600 ?	?	FERMI-DIRAC ?	$V^+ \rightarrow N + \pi^+ + (?)\, \pi^0$	10^{-10} ?
NEGATIVE V-PARTICLE	V^-	–	2600 ?	?	FERMI-DIRAC ?	$V^- \rightarrow N + \pi^- + (?)\, \pi^0$	10^{-10} ?
NEUTRAL V-PARTICLE	V^0	0	2600 ?	?	FERMI-DIRAC ?	$V^0 \rightarrow N + \pi^+ + \pi^-$? $V^0 \rightarrow P + \pi^- + (?)\, \pi^0$	3×10^{-10}
PHOTON	γ	0	0	1	BOSE-EINSTEIN	STABLE	
GRAVITON	G	0	0	2	BOSE-EINSTEIN	STABLE	
POSITIVE PI MESON	π^+	+	276	0	BOSE-EINSTEIN	$\pi^+ \rightarrow \mu^+ + \upsilon$	2.6×10^{-8}
NEGATIVE PI MESON	π^-	–	276	0	BOSE-EINSTEIN	$\pi^- \rightarrow \mu^- + \upsilon$	2.6×10^{-8}
NEUTRAL PI MESON	π^0	0	265	0	BOSE-EINSTEIN	$\pi^0 \rightarrow 2\gamma$	10^{-14}
TAU MESON	τ	+ or –	966	0 ?	BOSE-EINSTEIN	$\tau \rightarrow 3\pi$	10^{-9} ?

ALL THE PARTICLES known as of December, 1951, are shown in this table. The unit of mass is the mass of the electron; the unit of spin is $\hbar$ (*see text*). The particles adhering to Fermi-Dirac statistics are above the double line; those adhering to Bose-Einstein statistics are below it.

Graphic by Sara Love

Thirty Particles of 1957: From “Strongly Interacting Particles” by Geoffrey F. Chew, Murray Gell-Mann and Arthur H. Rosenfeld, in *Scientific American*, February 1964. Graphic by Joan Starwood





THIRTY PARTICLES of 1957 consisted of 16 baryons and antibaryons, seven mesons, six leptons and antileptons and the photon. (Baryon, meson and lepton respectively signify heavy, medium and light particles.) The strongly interacting particles, which respond to the strong, or nuclear, force, are in color. Particles shown in black do not respond to this force. It is the former that have proliferated in the past half-dozen years, as shown on the next two pages. In the same period the number of leptons and antileptons has increased by only two. It is now known that there are two kinds of neutrino instead of one, each with its own antiparticle (indicated by broken lines next to the two particles known in 1957). One other neutral and massless particle is believed to exist but is not shown here: the graviton, the carrier of the gravitational force. The hypothetical carrier of the weak force, also not shown, should have a considerable mass and one unit of electric charge. Evidence for it is now being sought.

Graphic by Joan Starwood

Subatomic particles (top) and quark hypothesis (bottom): From “Electron-Positron Annihilation and the New Particles” by Sidney D. Drell, in *Scientific American*, June 1975. Graphics by George V. Kelvin

		PARTICLE	SYMBOL	MASS	CHARGE	SPIN	LEPTON NUMBER	MU-NESS	BARYON NUMBER	LIFETIME
		PHOTON	γ	0	0	1	0	0	0	STABLE
LEPTONS		ELECTRON	e^-	.5	−1	$\frac{1}{2}$	+1	0	0	STABLE
		POSITRON	e^+	.5	+1	$\frac{1}{2}$	−1	0	0	STABLE
		ELECTRON NEUTRINO	ν_e	0	0	$\frac{1}{2}$	+1	0	0	STABLE
		ELECTRON ANTINEUTRINO	$\bar{\nu}_e$	0	0	$\frac{1}{2}$	−1	0	0	STABLE
		MUON	μ^-	106	−1	$\frac{1}{2}$	+1	+1	0	10^{-6}
		ANTIMUON	μ^+	106	+1	$\frac{1}{2}$	−1	−1	0	10^{-6}
		MUON NEUTRINO	ν_μ	0	0	$\frac{1}{2}$	+1	+1	0	STABLE
		MUON ANTINEUTRINO	$\bar{\nu}_\mu$	0	0	$\frac{1}{2}$	−1	−1	0	STABLE
HADRONS	BARYONS	PROTON	p	939	+1	$\frac{1}{2}$	0	0	+1	STABLE
		ANTIPROTON	$\bar{p}$	939	−1	$\frac{1}{2}$	0	0	−1	STABLE
		NEUTRON	n	939	0	$\frac{1}{2}$	0	0	+1	10^{3}
		ANTINEUTRON	$\bar{n}$	939	0	$\frac{1}{2}$	0	0	−1	10^{3}
	MESONS	PION	π^+	137	+1	0	0	0	0	10^{-8}
			π^-	137	−1	0	0	0	0	10^{-8}
			π^0	137	0	0	0	0	0	10^{-15}
		RHO MESON	ρ^+	750	+1	1	0	0	0	10^{-23}
			ρ^-	750	−1	1	0	0	0	10^{-23}
			ρ^0	750	0	1	0	0	0	10^{-23}
		PSI (3095)	ψ	3095	0	1	0	0	0	10^{-20}
		PSI (3684)	ψ	3684	0	1	0	0	0	10^{-20}

SUBATOMIC PARTICLES are classified according to the kinds of interactions in which they participate. The hadrons take part in “strong” interactions; the leptons do not; the photon interacts only electromagnetically. The hadrons are divided into mesons and baryons, which differ in their spin angular momentum and in other properties. The classification is reflected in quantum numbers such as lepton number, mu-ness and baryon number. The newly discovered particles, psi(3095) and psi(3684), are mesons. Their most perplexing property is their lifetime, which is 1,000 times longer than that of other particles of comparable mass, such as the rho meson.

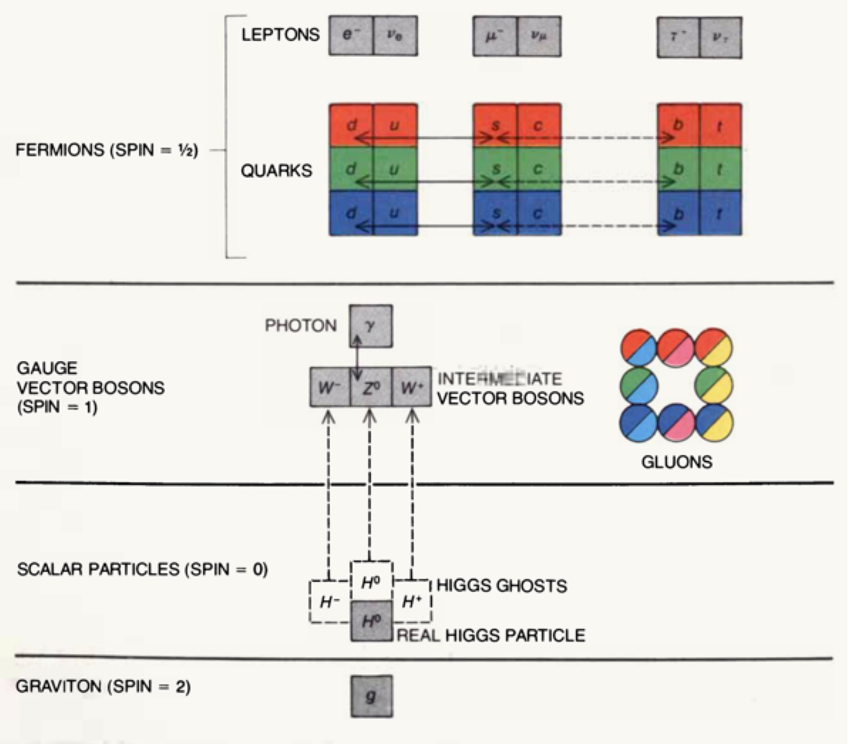
QUARK		CHARGE	BARYON NUMBER	CHARM	COLOR
u	u_r	$+2/3$	$+1/3$	0	RED
	u_y				YELLOW
	u_b				BLUE
d	d_r	$-1/3$	$+1/3$	0	RED
	d_y				YELLOW
	d_b				BLUE
s	s_r	$-1/3$	$+1/3$	0	RED
	s_y				YELLOW
	s_b				BLUE
	c_r				RED

c	c_y	$+2/3$	$+1/3$	$+1$	YELLOW
	c_b				BLUE

QUARK HYPOTHESIS states that hadrons are not elementary particles but composites of more fundamental entities called quarks. The original formulation of the theory, proposed independently by Murray Gell-Mann and George Zweig, postulated three quarks, *u*, *d* and *s*. Charge and baryon number (and other quantities not shown) are assigned to them according to the principle that baryons are made up of three quarks and mesons of a quark and an antiquark. Modifications of the theory add a fourth quark, *c*, which exhibits a property arbitrarily called charm, and propose that each quark exists in three states, distinguished by another property, called color. Thus there could be three, four, nine, 12 or more quarks.

Graphics by George V. Kelvin

Standard model of elementary-particle interactions: From "Gauge Theories of the Forces Between Elementary Particles" by Gerard't Hooft, in *Scientific American*, June 1980. Graphic by Gabor Kiss



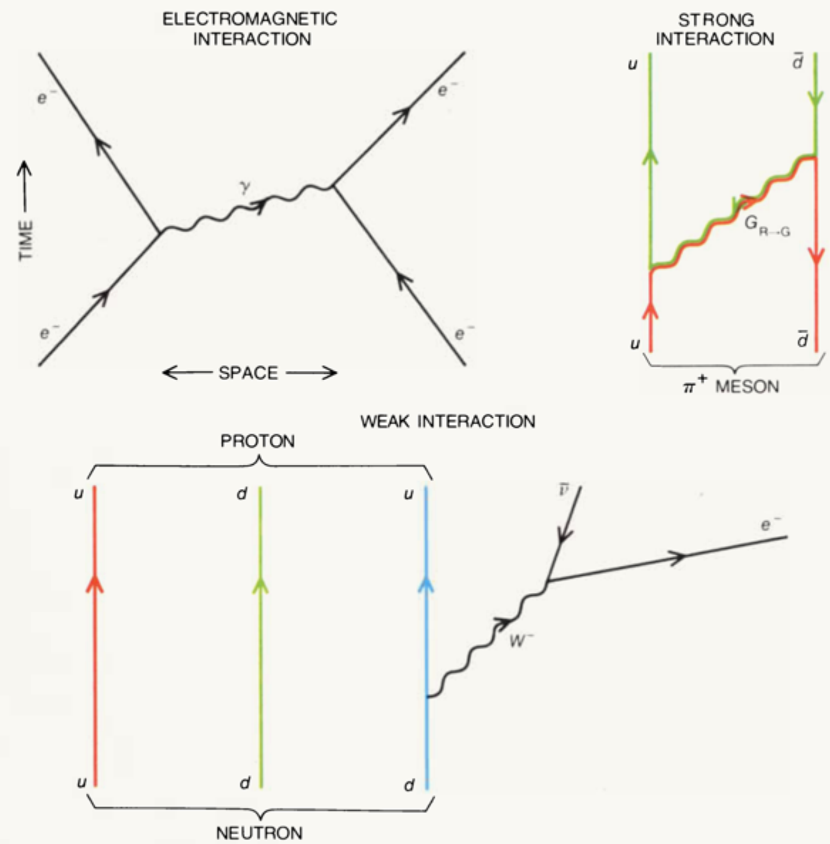
STANDARD MODEL of elementary-particle interactions describes the four forces of nature by means of three non-Abelian gauge theories. The fundamental particles of matter are six leptons and six flavors of quark, each of the flavors being present in three colors. Electromagnetism and the weak force are mediated by the gauge particles of the Weinberg-Salam-Ward model, namely the massless photon and a triplet of very massive vector bosons, the W^+, W^- and Z^0. The strong force is attributed to the eight massless gluons of quantum chromodynamics. Gravitation results from the exchange of a massless spin-two particle, the graviton, which is described by another local gauge theory: the general theory of relativity. In addition there is one surviving Higgs particle, which is massive and electrically neutral. In the coming years the search for the massive vector bosons and the Higgs particle will serve as tests of this synthesis.

Graphic by Gabor Kiss

Leptons and Quarks (top) and three forces of nature (bottom): From "A Unified Theory of Elementary Particles and Forces" by Howard Georgi, in *Scientific American*, April 1981. Graphics by Gabor Kiss

	LEPTONS		QUARKS					
THIRD GENERATION	ν_τ	0	t	$+2/3$	t	$+2/3$	t	$+2/3$
	τ^-	-1	b	$-1/3$	b	$-1/3$	b	$-1/3$
SECOND GENERATION	ν_μ	0	c	$+2/3$	c	$+2/3$	c	$+2/3$
	μ^-	-1	s	$-1/3$	s	$-1/3$	s	$-1/3$
FIRST GENERATION	ν_e	0	u	$+2/3$	u	$+2/3$	u	$+2/3$
	e^-	-1	d	$-1/3$	d	$-1/3$	d	$-1/3$

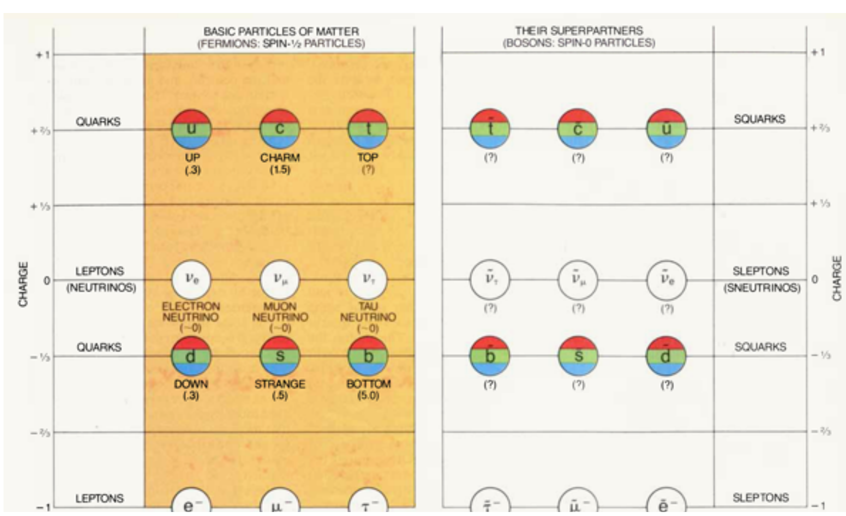
LEPTONS AND QUARKS differ in a number of important properties, and so they have generally been classified in separate families. One of the most conspicuous differences is in electric charge, which is shown here for each particle: the lepton charges are integers, whereas the quark charges are fractions. Furthermore, the leptons exist as free particles, whereas the quarks are found only as constituents of the composite particles called hadrons. It is customary to divide the leptons and the quarks into three generations; only the particles of the first generation have a place in the structure of ordinary matter. The *t* quark has not been observed experimentally.

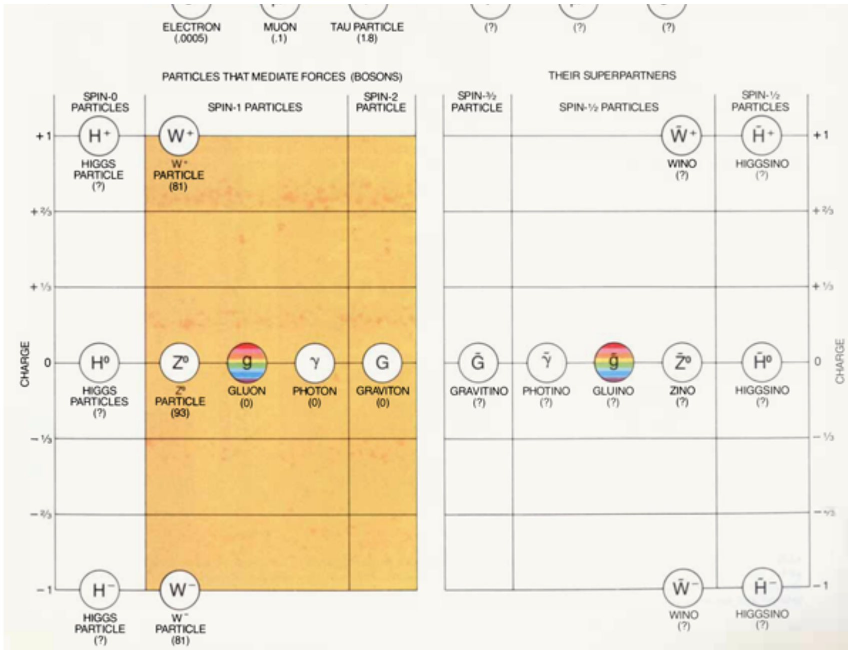


THREE FORCES OF NATURE bring about interactions between the elementary particles. Each such interaction can be described as the exchange of a "virtual" particle, which is the carrier of the force. In an electromagnetic interaction particles with electric charge exchange a photon (γ). The strong force is conveyed by gluons (G), which are exchanged by particles with color charge. Particles with weak charge can exchange a W^- (*shown here*) or a W^+ or a Z^0. In the diagrams the charge of an antiparticle is given by an arrow pointing backward in time.

Graphics by Gabor Kiss

Supersymmetry posits that for every ordinary particle there exists a "superpartner": From "Is Nature Supersymmetric?" by Howard E. Haber and Gordon L. Kane, in *Scientific American*, June 1986. Graphic by Gabor Kiss

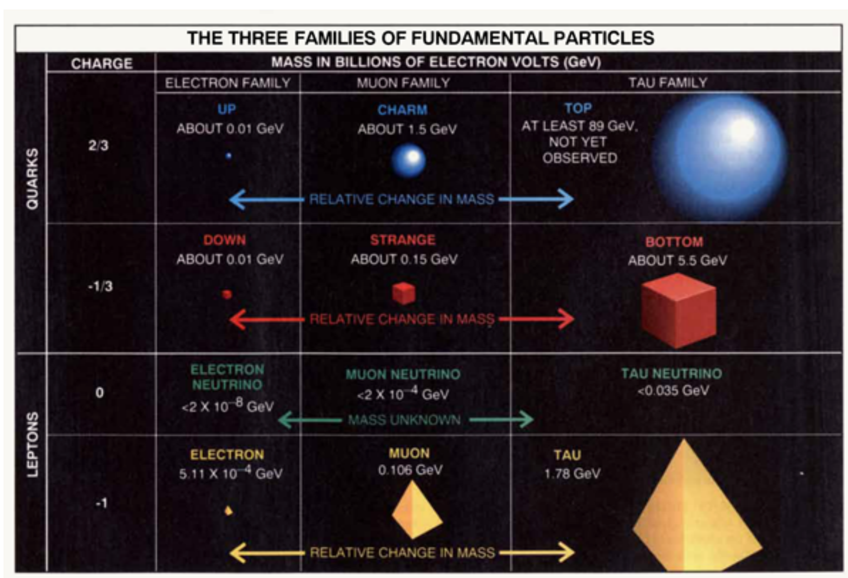




SUPERSYMMETRY posits that for every ordinary particle there exists a "superpartner" having similar properties—except for a quantity known as spin. According to existing theory, there are two kinds of ordinary particles: those that are the basic constituents of matter (*yellow section of top table*) and those that mediate the forces, or interactions, among those constituents (*yellow section of bottom table*). The basic constituents of matter are known as leptons and quarks. More generally they can be categorized as fermions. A fermion is a particle that behaves as though it carries a spin, or an intrinsic angular momentum, equal to half-integer units (1/2, 3/2 and so on) of Planck's constant, which is itself the fundamental unit of angular momentum in quantum theory. The basic particles that mediate forces, on the other hand, are bosons: particles whose spins are integer units (0, 1, 2 and so on) of Planck's constant. According to supersymmetry, each ordinary fermion should have a superpartner that is a boson (*right half of top table*) and each ordinary boson should have a superpartner that is a fermion (*right half of bottom table*). The bracketed number below each particle is its mass, when known, in billions of electron volts. (The graviton has not yet been found, but it is expected to be massless.) Not shown are the antiparticles of the particles in the top table. (An antiparticle is identical with another particle in mass but opposite to it in electric charge; the W^- boson, for instance, is the antiparticle of the W^+ boson.)

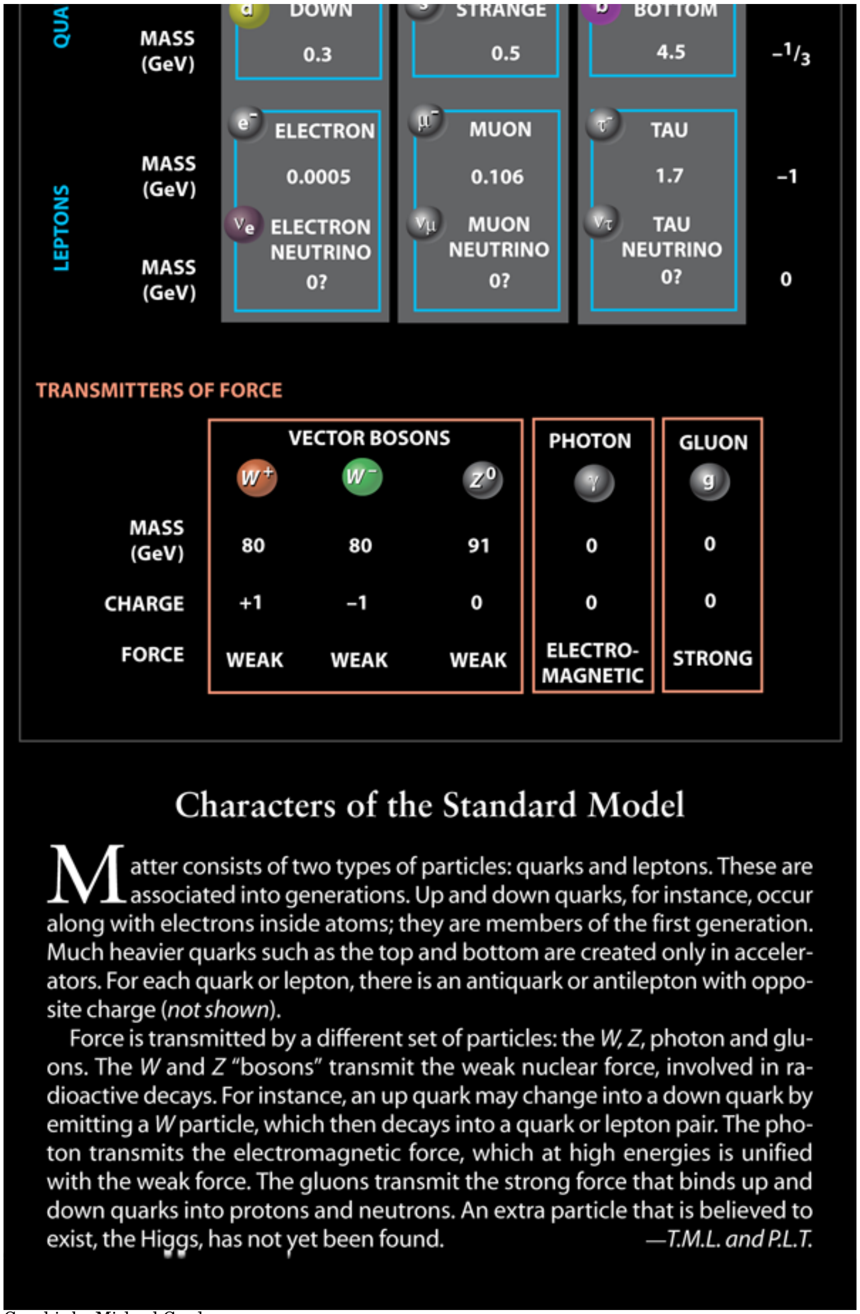
Graphic by Gabor Kiss

The three families of fundamental particles: From "The Number of Families of Matter" by Gary J. Feldman and Jack Steinberger, in *Scientific American*, February 1991. Graphic by Ian Worpole



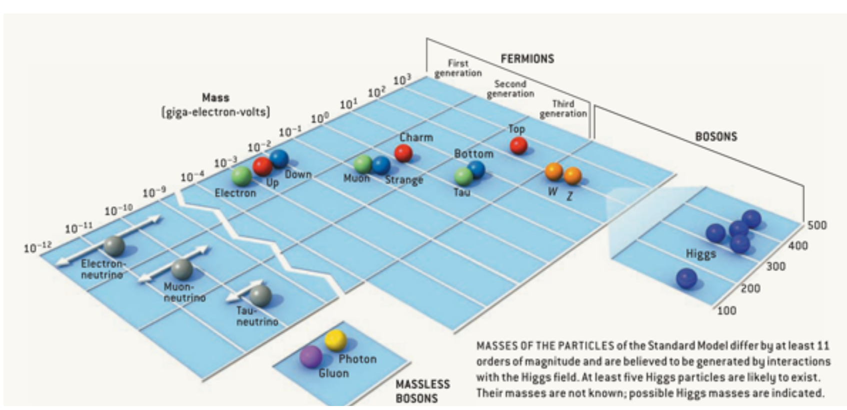
Graphic by Ian Worpole

Characters of the Standard Model: From "The Discovery of the Top Quark" by Tony M. Liss and Paul L. Tipton, in *Scientific American*, September 1997. Graphic by Michael Goodman



Graphic by Michael Goodman

Masses of the particles of the Standard Model: From ["The Mysteries of Mass"]() by Gordon Kane, in *Scientific American*, July 2005. Graphic by Bryan Christie Design



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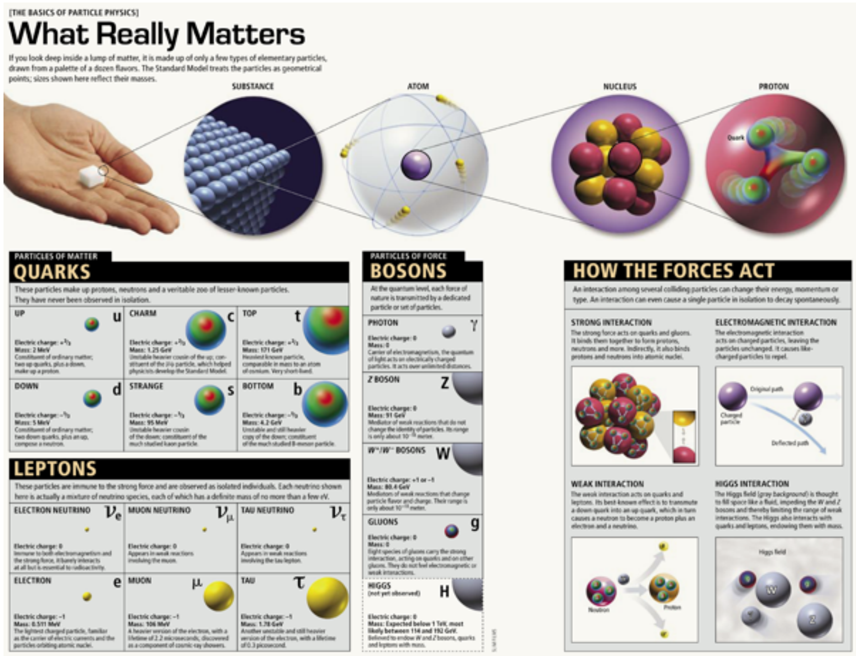
The basics of particle physics: From [“The Coming Revolutions in Particle Physics”]() by Chris Quigg, in *Scientific American*, February 2008. Graphic by SlimFilms



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To learn more about the premise and problems of the Standard Model of particle physics, see the [CERN (European Organization for Nuclear Research) website](), [“The Dawn of Physics beyond the Standard Model”]() By Gordon Kane (*Scientific American*, January 2006), and [“Could the Higgs Nobel Be the End of Particle Physics?”]() By Harry Cliff (October 2013).

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