The Standard Model

A brief (and vastly oversimplified) introduction by George Schoendorff

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The standard model of particle physics comprises all the known subatomic elementary particles regulated by the theory of quantum mechanics. It is similar in concept to the periodic table of the elements. While the periodic table arranges the order of the different atomic elements, the standard model catalogs the particles that make up these individual atoms and other exotic forms of matter. This model classifies these subatomic particles according to strangeness and spin. Wave-particle duality is a feature of quantum theory, whereby all matter exhibits properties consistent with both particles and waves. The concept of spin requires the particle to be described in terms of a wave. (Specifically, it relates to the number of times a particle's wavefuction must rotate about an axis to recover the original wavefunction.) Particles with an integer spin are called **bosons**, and those with a non-integer (or fractional) spin are **fermions**[1]**.**

The **fermions** account for the majority of the standard model. They comprise the familiar aspects of the atom and follow the Pauli exclusion principle. According to this principle, no two indistinguishable fermions may occupy the same quantum state (i.e., physical space) at the same time. This principle largely explains the constitution and behavior of matter in our universe and conveniently allows for existence as we know it!

Fermions are divided into two classes known as the quarks and the leptons. **Quarks** combine in groups of three to form the protons and neutrons found in atomic nuclei. The most common of the quarks are the *up* and *down* quarks, which have a charge of 2/3[2] and -1/3, respectively. There are other quarks, too, that are identical to the up and down quarks, except they have larger mass. These massive analogues of up and down are *charm* and *strange*. There is yet a third group of quarks that are even more massive called the *top* and *bottom* quarks[3]. Thus nature provides three versions of the fermions, each version differing only in its mass. This replication of particles into more massive successive generations is known as strangeness, and particles containing the heavier versions of the fermions are "stranger" than normal matter (consisting of only the lightest versions of the fermions).

The most familiar of the **leptons** is the *electron*. It has a -1 charge and is the basis for all chemistry and electrical applications. The other main lepton is the *electron neutrino*. It has no charge and nearly negligible mass, making its interactions the weakest in the standard model. As with the quarks, leptons also have two additional degrees of strangeness. The analogues of the electron neutrino are the *muon neutrino* and the *tau neutrino*, and the analogues of the electron are simply the *muon* and the *tau*.

The **bosons** in the standard model regulate fermion interactions and consist of force carrying particles responsible for transmitting three of the four natural forces: electromagnetism, the strong nuclear force, and the weak nuclear force. The most familiar of these is the force carrier for the electromagnetic force, the *photon*. It regulates interactions of charged particles, and the emission of this particle is the source of light. The boson associated with the strong nuclear force is the *gluon*. It is responsible for holding together the positively charged nucleus of an atom. A manifestation of the strength of this force is evident in nuclear reactions. The other two bosons in the standard model are the *W+/-* and *Z bosons*. Together, these are responsible for the most enigmatic of the forces – the weak nuclear force. This force is what regulates radioactive decay, where, for example, an up quark will change to a down quark (or vice versa). When this happens, the resulting interaction involving the W+/- boson emits an electron. The Z boson is associated with neutrino emissions.

It should be noted that there is no boson associated with the fourth and final known force, gravity. Currently, gravity is best described by Einstein's theory of relativity. Since the theories of relativity and quantum mechanics are incompatible at the subatomic level, there is no force-carrying particle for gravity.[4] There is one more boson in the standard model, but it has yet to be observed. This is the *Higgs boson* (the so-called "God particle"). It is believed to be responsible for a particle's mass. Confirmation of its existence would be the smoking gun that validates the standard model.

Thus, all matter is composed of these seventeen particles: the four force carrying bosons plus the Higgs boson (not yet observed), and the twelve fermions – six quarks and six leptons, each characterized by their charge and strangeness.

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[1] Consider the harmonic series in music for an analogy. In this case, bosons would be the recurring octaves in the series, and the fermions would be the other harmonics that produce different pitches.

[2] All charges are given in atomic units. Thus a charge of 1 is 1.6×10^{-19} Coulombs.

[3] Originally, the *top* and *bottom* quarks were known as *truth* and *beauty*, respectively.

[4] There has been extensive work to unify quantum mechanics and relativity. Einstein himself spent a large part of his life in this pursuit. It has been postulated that a graviton may exist. Unfortunately, however, the energies required to verify its existence are currently beyond the capability of the human race.