A Brief Survey of the Standard Model of Particle Physics: the Database for FRACEP

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1. Introduction

One of the most challenging activities in physics is to determine the "correct" description of the fundamental nature of matter. Today, this description is captured in the Standard Model (SM), which contains a set of fundamental particles (fermions and bosons) that are treated as point-like lumps of homogeneous stuff. Considerable evidence supports the idea that these particles may be composites of more fundamental particles. The FRACEP Model developed a description of a set of composite fermions and bosons with internal components that are consistent with the observed characteristics of the SM particles using the SM as its database. To fully appreciate the motivation for a changing view of the fundamental world, it is helpful to consider the evolution of ideas on the fundamental nature of matter over time.

When one wishes to wax eloquently about the nature of matter and physical phenomena, one invariably turns to the beginning to provide enlightenment regarding the evolving picture. We are immediately reminded of the mythological basis of man's attempts to understand his world and the universe at large. Mythologies of the ancient civilizations all, to one degree or another, personify the celestial bodies, including earth, in their gods, and attribute physical effects to the actions of those deities [1 – 5]. This mindset led inevitably to temple building (celestial observatories) and the mathematical tools that allowed accurate observation of the sun, moon and stars.

Based on astronomical analysis of temple orientation, Lockyer dates the earliest observatories in Egypt to possibly as early as 6400 BC, and some Greek temples, showing signs of Egyptian inspiration, to as early as 1500 BC [6]. According to Yoke, Chinese astronomical observations can be traced to earlier than 1500 BC, but how early is uncertain mainly because of lack of surviving documents and monuments of greater antiquity [7].

These early observatories and their accompanying mathematical tools mark the beginning of science in the human race. However, the mere acceptance of the existence of the universe, as an end to his inquiries, was not sufficient. Once the origin of all things was suitably explained (albeit in mythological terms), attention was turned to a finer look at the structure of matter. After years of exploration and philosophizing, the models of the nature of matter have developed into the chemistry [8, 9] and the physics [10 – 12] that we know and love today.

The earliest musings on the composition of nature that has directly filtered into western science (where there is definitive writing on the subject), dates back to the classic Greek philosophers. Thales, in 5th century BC, proposed the prime matter to be water because of its ability to change states from gas to liquid to solid (inspired by the Babylonians who believed that water was the origin of the cosmos). Later, Empedocles introduced the 4-element theory which stated that the four elements (fire, water, earth and air) were composed of minute, unchanging particles; and, for the first time, there were forces describing matter interaction (Love and Strife) which caused elements to combine or separate.

In the early 4th century BC, Democritus introduced the ideas of a void in which the 4 elements were in continuous, random motion, and, of shaped atoms that became entangled to produce visible substances. A competing theory by Aristotle proposed that all matter was made of the same stuff (hyle), and that the different substances were the result of varying amounts of the properties of hyle in the 4 elements. He believed that all substances were homogeneous and continuous, and that there were three types of elemental combination by which the original elements lost their basic character to produce new substances (transmutation). These early Greek ideas are a long way from the current understanding of matter but they captured the concept of fundamental lumps of stuff in the large-scale substances of nature.

The Aristotelian picture was accepted throughout the Middle Ages with little change in the notion until the 16th century when it began to be challenged. The atomist theory started to gain acceptance as the combination of experiments, coupled with mathematical abstraction, allowed the development of the advances evident in modern science. By the end of the 19th century, it was known that all matter was composed of indivisible atoms that made up a set of nearly 100 fixed elements.

In 1905, Mendeleev published his successful organization of those elements into the Periodic Table still in use today [9]. For a period of almost 40 years, he studied the elements and their properties, advancing the notion that there were simple bodies (containing a single element) and compound bodies (containing two or more elements), and identifying a phenomenon known as allotropy (that molecules of a given element can exist in several different configurations), but rejecting the notion of substructure in the atoms even in the face of rising evidence to support the idea.

This period, from the sixteenth through the nineteenth centuries, represented a time of growing complexity - from four fundamental substances that made up everything to over 100 types of fundamental stuff (each a different type of atom). We recognize today that the sheer number of elements and the periodic regularity of their properties strongly suggest sub-atomic components. This evidence of complexity (based on something more fundamental as yet undiscovered) was only beginning to be recognized in Mendeleev's time.

Shamos [10] describes the great experiments that lead to the next level of development in the understanding of nature. The first hard evidence of these smaller particles came in 1896 with the discovery of radioactive decay by Becquerel when he observed the transmutation of one element to another (Chapt.15). A second piece of evidence came in 1897 with the discovery of the electron by Thomson (Chapt.16). The modern concept of the atom began to take shape in 1919 with the experiments of Rutherford who described the atom as a dense positively charged nucleus surrounded by a negatively charged electron cloud (Chapt.19). Further, he proposed the nucleus consisted of positively charged particles (protons) and neutral particles. The neutron (Rutherford's neutral particle) was discovered in 1932 by Chadwick (Chapt.20). Thus, the field of elementary particles began to take shape.

Because of these discoveries, it became clear that there were fundamental building blocks (electron, proton and neutron) that were smaller than the atom (what had previously been thought to be fundamental). At this point, the understanding of nature began to return to simplicity – from over 100 fundamental types of matter to only three fundamental particles that combined to produce all the variety of nature.

With new experiments since the time of Chadwick, the initial family of three fundamental particles began to grow again. The positron (also called the anti-electron - an electron with positive rather than negative charge) was discovered in 1932. Then heavy particles (~ 200-300 times the mass of electron, but only about 1/3 the mass of the proton) were discovered. These heavy particles (the *Mu* meson, discovered in 1936, and the *Pi* meson in 1946) were believed to be related to the working of the nuclear force that held the atomic nucleus together and therefore must be fundamental.

In addition to experimental discoveries, the 20th century saw an entirely new picture of the world emerging in the theoretical developments of the time. Quantum Mechanics [13, 14] and Relativity [15] provided the tools to understand the smaller world of the new particles that were being discovered, accurately predicting the outcome of the ever more sophisticated scattering experiments and pointing the way to new particles that were needed to explain observations.

The experiments in the 1950's and 1960's produced evidence of so many new particles (over 100) that a reorganization of the elementary particles into groups based on their common properties was needed. The growing complexity of so many fundamental particles indicated the need to recognize the truly fundamental nature from the composite nature in the "zoo" of what had been thought to be fundamental particles. As a result, the particles were grouped into two types: 1) fundamental with no internal structure, and 2) composite with internal, smaller components.

Because of the new organization, some particles, previously believed to be fundamental (like the proton and neutron that make up the atom nuclei) were demoted to composite status. Once again, the understanding of nature was returning to a simpler configuration – from a "zoo" of fundamental particles to a few fundamental particles that combined to produce the composite particles. But is this current organization truly simple enough? FRACEP believes not.

As a primarily heuristic model (at this time), FRACEP [16a,b] demonstrates the possibility of constructing the fermions and the bosons using only two fundamental particles that build a collection of building blocks with the necessary a-priori characteristics of the SM observations. Although the SM is based on quantum mechanics, its theory is not included here, but, can be found in detail in Povh [17]. The focus here is to present the observations used to establish FRACEP, that is, a description of the fundamental particles of the SM database.

2. The Standard Model of Particle Physics

2.1 The Nature of Its Particles

According to the Standard Model of Particle Physics, the fundamental pieces of matter that make up the universe include particles known as fermions and bosons. This collection of particles (if you include the anti-fermions and anti-bosons) numbers on the order of 50 particles. The fermions include such particles as electrons, quarks and neutrinos. The bosons include photons, gluons and the Higgs among others. There are three characteristics that are considered necessary for a particle to be fundamental. These are identified as: homogeneity, uniformity, and indivisibility.

Imagine for example, a fundamental particle as a small sphere. A particle is homogeneous if everything within the sphere is the same stuff. This differs from an atom, for example, because the atom has a core of positively charged protons and zero-charge neutrons. Surrounding the core is a negatively charged electron cloud. Simply put, the core is not the same stuff as the cloud, so the atom as a whole is not a homogeneous particle. A particle is uniform if the stuff inside the sphere is not lumpy. This means that the content of the sphere is like smooth peanut butter rather than chunky peanut butter. In the atom, the core (nucleus) is like a lump in the electron cloud, so the atom is not a uniform particle. Finally, a particle is indivisible if it cannot break into pieces. For example, atoms can be split into two pieces if they are collided with fast moving small particles in accelerators. Some atoms spontaneously decay into smaller pieces because they are radioactive. So atoms are not indivisible particles.

Beginning in the early twentieth century, one-by-one the fermions and bosons were observed as experimental techniques developed. At the same time, quantum mechanics was developed and proved to provide accurate descriptions of fermion and boson interactions. Because of their size, the technology of the day did not allow probing the homogeneity or uniformity of these particles. However, a significant number of these particles were observed to spontaneously decay. This appears to violate the indivisibility requirement for a fundamental particle.

By the mid 1970's, efforts were underway to reconcile the apparent incompatibility of spontaneous decay with the requirement of indivisibility. One such effort was the development of preon models [18]. These models are quantum-mechanically based theories that assume that the fermions and bosons do have internal structure. They have had some success, but have not been accepted as the standard which still treats the fermions and bosons as fundamental.

This brings us to the FRACEP Model. Unlike the preon models, FRACEP is not based on quantum mechanics. It is a purely heuristic model (at this time). It is philosophical in nature and intended to provide a different view of the nature of matter. It is based on simple arithmetic to add the masses of components to produce mass estimates for the composite particles that agree with the observed properties of the fermions and bosons. (It is known in nuclear physics that the sum of the masses of the components of atoms equals more that the total mass of the bound atom because of binding energy. At nuclear scales this difference can be relatively small. We keep this in mind, but we do not address this issue for the FRACEP composite particles at this time.)

TABLE 1. This shows the characteristics of the fundamental particles of the Standard Model. Column 1 indicates the electromagnetic charge (q_e). Columns 2 – 4 indicate the particle and its masse with the measurement uncertainty in parentheses (in units of MeV/c^2).

Fermions: Leptons (spin 1/2)			
q_e	**Generation 1**	**Generation 2**	**Generation 3**
0	e-neutrino (ν_{e-}) <15×10^{-6}	μ-neutrino ($\nu_{\mu-}$) <0.17	τ-neutrino ($\nu_{\tau-}$) <18.2
–1	electron (e^-) 0.5109989 ($\pm 4.0 \times 10^{-8}$)	muon (μ^-) 105.65835 ($\pm 4.9 \times 10^{-8}$)	tau (τ^-) 1777.0529 ($\pm 1.6 \times 10^{-4}$)
Fermions: Quarks (spin 1/2)			
+2/3	up (u^+) 1.5 – 4.5	charm (c^+) 1100 – 1400	top (t^+) 173,700 – 182,300
–1/3	down (d^-) 5.0 – 8.0	strange (s^-) 88 – 155	bottom (b^-) 4100 – 4400
Gauge (Vector) Bosons (integer spin)			
q_e	**Particle**		
0	photon (γ) <2×10^{-22}		
+1	W^+ 80,423($\pm$39)		
–1	W^- 80,423 ($\pm$ 39)		
0	Z^0 91187.6 ($\pm$ 2.1)		
0	8 gluons (g_i) ~ 0		
Higgs (Scalar) Boson (spin 0)			
0	higgs (H) 125.3$\pm$0.4(statistical) $\pm$0.5(systematic) GeV (CMS Exp.) 126.0$\pm$0.4 $\pm$0.4 GeV (ATLAS Exp.)		

2.2 Its History

The Standard Model [19] was developed during the 1960's and 1970's to explain the experimental observations, as well as, to elucidate the fundamental nature of matter. This model is a semi-empirical model that contains a database of fundamental particles and their characteristics, a mathematical formalism based on quantum mechanics for encoding the rules for particle interactions, and, a long list of composite particles including their composition of the fundamental particles.

The SM fundamental particles are shown in Table 1. They are modeled as point-like (zero-size), with no internal structure. Their numbers include: 12 fermions, 12 gauge bosons and one Higgs boson for 25 elementary particles [20 – 23]. Each particle is associated with an anti-particle of equal mass but opposite charge and spin, giving a total of 50 fundamental particles – all with intrinsic properties like spin and charge.

Note that traditionally the three neutrinos were believed to have zero mass, but models of the sun's energy production were inconsistent with the number of measured solar neutrinos. To address this problem, the model was adjusted to include neutrino oscillation (transformation from one neutrino type to another during flight) among the three types [24-25]. The oscillation requires the neutrinos to have mass – the limits currently accepted are shown in the table.

Elgaroy et al. [26] concluded that the sum of the masses of the three neutrinos was no more than 2.2×10^{-6} MeV.

2.3 Its Fermions – One of its Fundamental Groups

The fermions have spin 1/2. There are four types each with a different electromagnetic charge. Each type has three family members within which the properties are identical except for the mass which increases with each generation over the mass of the previous one. Of the fermions, only the electron is stable. The others spontaneously decay into lighter fermions. It is not clear if the oscillation of the neutrinos (the zero charge type) represents evidence of the particles' compositeness.

Of the electron family, the muon has a single decay path ($\mu^- \rightarrow e^- + \nu_{e+} + \nu_{\mu-}$), but the tau has three paths ($\tau^- \rightarrow e^- + \nu_{e+} + \nu_{\tau-}$; $\tau^- \rightarrow \mu^- + \nu_{\mu+} + \nu_{\tau-}$; and $\tau^- \rightarrow \pi^- + \nu_{\tau-}$, where π^- is a coupled pair of quarks, d^-u^-). For the quark families, the up-quark is considered stable in the proton or neutron but the down-quark decays as: $d^- \rightarrow u^+ + e^- + \nu_{e+}$.

The heavier quarks decay in a cascade manner:

$$\begin{array}{llll} t^+ \rightarrow b^- + e^+ + \nu_{e-} & & & \\ \quad\;\; \hookrightarrow c^+ + e^- + \nu_{e+} & & & \\ \qquad\quad\;\; \hookrightarrow s^- + e^+ + \nu_{e-} & & & \\ \qquad\qquad\quad\;\; \hookrightarrow u^+ + e^- + \nu_{e+} & & & \end{array}$$

2.4 Its Bosons – the Other of its Fundamental Groups

The Bosons have integer spin. Unlike the fermions, there are no mass increasing generations for the different types. Each of the particles is associated with one of the fundamental fields. The photon is coupled to the electromagnetic field; the W^+, W^- and Z^0 are coupled to the weak field responsible for radioactive decay; and the gluons are coupled to the strong nuclear field that holds complex particles and atomic nuclei together. The higgs (H) couples to the Higgs field which, theory postulates, is responsible for the mass that all the other particles have, but this is yet to be verified. Theory cannot predict the mass of the Higgs, but experiments have narrowed the expected range to between 114 GeV and 141 GeV, or >476 GeV. Of the bosons, only the photon and the gluons are considered stable. The W's, Z^0 and H all decay.

The Z^0 (often referred to simply as the Z because of its zero charge) decays by multiple paths:

$$Z^0 \rightarrow e^+ + e^-$$
$$Z^0 \rightarrow \mu^+ + \mu^-$$
$$Z^0 \rightarrow \tau^+ + \tau^-.$$

Likewise, the W^+ and W^- decay paths include:

$$
\begin{array}{ll}
W^+ \rightarrow e^+ + \nu_{e-} & \qquad W^- \rightarrow e^- + \nu_{e+} \\
W^+ \rightarrow \mu^+ + \nu_{\mu-} & \qquad W^- \rightarrow \mu^- + \nu_{\mu+} \\
W^+ \rightarrow \tau^+ + \nu_{\tau-} & \qquad W^- \rightarrow \tau^- + \nu_{\tau+}.
\end{array}
$$

The Higgs has several cascading decay paths from pairs of particles with a total spin of zero throughout the decay process:

$$
\begin{array}{lll}
H \rightarrow \gamma + \gamma & & \\
H \rightarrow Z^0 + Z^0 & & \\
 & \rightarrow l^+ + l^- & \text{for example, } \tau^+ + \tau^- \\
 & \rightarrow q^+ + q^- & \text{for example, } b^+ + b^- \\
 & \rightarrow 2e + 2\mu & \\
 & \rightarrow 4e & \\
 & \rightarrow 4\mu & \\
 & \rightarrow l^+ + l^- + \nu & \\
H \rightarrow W^+ + W^- & & \\
 & \rightarrow e + \nu + \mu + \nu & \\
 & \rightarrow l^+ + l^- + \nu &
\end{array}
$$

The l is any lepton (neutrino or electron family member. The q is any quark (up-quark family member or down quark family member). The ν in the above decay paths has zero charge, so the final decay products maintain a sum-zero charge. Of the SM fundamental particles, only the e, μ, τ and the photon have been directly observed. All the others are indirectly observed from their decay products [27]. The gluons still have no experimentally observed evidence.

2.5 Its Hadrons – the Heavy Composites

In addition to the fundamental particles, the SM defines about 100 composite particles (the hadrons) which have two types: the baryons and the mesons. The baryons and mesons mentioned above are listed in Table 2. A more complete listing is given in Guth [28].

The Baryons are spin 1/2 particles composed of three quarks. (The only known stable baryon is the proton, the next longest lived is the neutron at 886.7 seconds; all others have lifetimes less than 10^{-7} seconds). The Mesons are integer spin particles and are composed of quark-anti-quark pairs. None are stable, and all have lifetimes less than 10^{-7} seconds. Like the fundamental particles, the composite particles are each associated with an anti-particle. The SM composite particles will not be discussed; however, more information can be found in Guth, and in Kane [19].

TABLE 2. This shows the characteristics of selected composite particles of the Standard Model [17]. Column 1 indicates the particle and its quark composition. Column 5 indicates the half-life decay time (in seconds). A more complete list of the composite particles can be found in Guth [28].

Composition	Mass (MeV/c^2)	Spin	q_e (e)	Half-life (seconds)
Baryons				
proton (p) ($u^+u^+d^-$)	938.3	1/2	+1	stable (i.e., $>10^{32}$yrs)
neutron (n) ($d^-d^-u^+$)	939.6	1/2	0	886.7
Mesons				
Pi-minus (π^-) (d^-u^-)	139.6	0	–1	$2.6 \cdot 10^{-8}$
Pi-plus (π^+) (d^+u^+)	139.6	0	+1	$2.6 \cdot 10^{-8}$

The size and energy scales of the SM particles can be compared to the scales of what was previously considered fundamental in times past as an example of how thoughts have changed with new insight.

(1) Quarks, leptons and gauge bosons are point-like (radius $<10^{-18}$m) – current SM fundamental particles.

(2) Baryons, like the proton, are $\underset{\sim}{~} 10^{-15}$m with excitation energies ~0.3GeV or more – listed among the fundamental particles in the 1920s', but currently classified as composite.

(3) Atomic nuclei (e.g., lead, ^{208}Pb) are $\underset{\sim}{~} 10^{-14}$m with excitation energies ~3MeV or more.

(4) The atom (e.g., nucleus plus electron cloud, ^{23}Na) is $\underset{\sim}{~} 10^{-10}$m with excitation energies ~3eV or more – considered fundamental in Mendeleev time (1906) though the details of the atom structure were unknown until Rutherford's model.

3. Some Final Thoughts

One final point about the SM should be addressed. Current thinking on the fundamental nature of the fermions and bosons recognizes the evidence pointing to the possible compound nature of the particles [18]. In standard quantum mechanics, each fundamental particle (e.g., the electron) is represented by a single wave function which can have more than one state, so some processes are represented by weighted sums of the multiple states. In preon theory, composite versions of the fermions and bosons are represented by multiple wave functions (each for one of the preon components in the fermion) in a quantum mechanical-like frame-work. The tacit assumption in the traditional preon model, like the traditional SM, is positive mass. It is this assumption that FRACEP [16] challenges with its two fundamental particles (one that is positive mass and one that is negative mass). As a purely heuristic model at this stage, it has a long way to go to offer an alternative to any traditional model.

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