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Preon Models in Particle Physics

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Physics
Submission date: June 2014
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NTNU

Master Thesis

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A thesis submitted in fulfillment of the requirements for the degree of Master.

Department of Physics

June 2014

NTNU

Abstract

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Master

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We summarize the standard model and grand unified theories in light of group theoretical properties. We discuss selected classic and modern preon models. Finally, a schematic preon model for all three generations of fundamental fermions in the standard model is constructed. This preon model introduces three spin 0 preons which represent the three generations, as well as two spin 1/2 preons. It incorporates handedness through the fermionic preons.

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Sammendrag

NT-fakultetet
Institutt for fysikk

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Vi oppsummerer standardmodellen og enhetlige teorier i lys av gruppeteoretiske egenskaper. Vi drøfter utvalgte klassiske og moderne preonmodeller. Til slutt blir en skjematisk preonmodell for alle tre generasjoner av fundamentale fermioner i standardmodellen konstruert. Denne preonmodellen introduserer tre spinn 0 preoner som representerer de tre generasjonene, samt to spin 1/2 preoner. Den bygger inn hendthet gjennom fermionpreonene.

Acknowledgements

Thanks to Jan Myrheim for supervising my work, Johan Hansson and John Moffat for answers to questions about preons, Dag Vidar Bauer for good and helpful advice, and to Linn Sortebech for being there for me. Thanks to Blind Guardian for musical support.

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Abbreviations and definitions

SM	the **S**tandard **M**odel of Particle Physics
GUT	**G**rand **U**nified **T**heory
SUSY	**SU**per**SY**mmetry
EM	**E**lectro**M**agnetic
CKM	**C**abibbo-**K**obayashi-**M**akawa
$\mathrm{G}_{\mathbf{c}}$	**C**olor group for some group G
$\mathrm{G}_{\mathbf{L}}$	**L**eft handed group for some group G
$\mathrm{G}_{\mathbf{hc}}$	**H**yper**c**olor group for some group G
Electron family	e, μ, τ
Neutrino family	$\nu_{\mathrm{e}}, \nu_{\mu}, \nu_{\tau}$
Up quark family	u, c, t
Down quark family	d, s, b
First generation	u, d, e, ν_{e}
Second generation	c, s, μ, ν_{μ}
Third generation	t, b, τ, ν_{τ}
Basic fermions	The quarks and leptons of the standard model
f	fermion
b	boson *or* bottom quark
l	lepton
q	quark
p	preon

Chapter 1

Introduction

1.1 The standard model

In particle physics, a collection of quantum field theories which includes models for electromagnetic, weak and strong nuclear interactions is called the Standard Model of Particle Physics (SM for short), and has been shown to yield good predictions for 42 years. The specific models in question are Feynman's quantum electrodynamics, the Glashow-Weinberg-Salam theory of electroweak processes and quantum chromodynamics [1]. SM revolves around the two families of basic fermions, quarks and leptons, and has since 1978 been the orthodox, or standard, model of particle physics.

The standard model of particle physics is known to act through the symmetry group $\mathrm{SU}(3)_\mathrm{c} \times \mathrm{SU}(2)_\mathrm{L} \times \mathrm{U}(1)_\mathrm{Y}$, with the generators being gluons and the electroweak vector bosons. The particles from the first generation are represented as (Q,u^c,d^c;L,e^c), where the raised c represents charge conjugation, and Q and L are quark and lepton doublets,

$$Q = \begin{pmatrix} u \\ d \end{pmatrix} \ , \quad L = \begin{pmatrix} \nu_\mathrm{e} \\ \mathrm{e} \end{pmatrix} \ .$$

These five transform according to Table 1.1. Representations will be given in this paper as their dimensions, as this is the number identifying the number of particles in the multiplet, where a bar implies a conjugate representation. See C.G. Wohl [2] for a quick walkthrough on calculations involving group representation theory.

	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$
Q	3	2	1/3
u^c	$\bar{3}$	1	$-4/3$
d^c	$\bar{3}$	1	2/3
L	1	2	-1
e^c	1	1	2

Table 1.1: SM representations

The generator of U_Y is the quantum number Y, the hypercharge, given as Y = B + S + C + B' + T, where the right hand terms are baryon number, strangeness, charmness, bottomness and topness. The hypercharge gauge boson is called B^0. This is connected to the third component of the weak isospin T_3 and electromagnetic charge Q_{EM} through the equation [3]

$$Q_{\mathrm{EM}} = T_3 + \frac{Y}{2} \ , \tag{1.1}$$

where T_3 is a conserved quantum number in the weak interaction. The weak isospin T is 1/2 for the doublets Q and L, and otherwise 0. The members of the doublets Q and L have respectively $T_3 = +1/2$ and $T_3 = -1/2$, while the three $\mathrm{SU}(2)_L$ singlet states have $T_3 = 0$. For the rest of this thesis, the term weak isospin will refer to T_3. The weak gauge bosons $\mathrm{W}^\pm$ carry weak isospin ± 1, while the third one, W^3 (sometimes called W^0) carries weak isospin 0. Electroweak forces are unified through the mixing of W^3 and B^0 to create the observed heavy vector boson Z^0 as well as the photon γ, through the Weinberg angle θ_{W},

$$\begin{pmatrix} \gamma \\ \mathrm{Z}^0 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\mathrm{W}} & \sin\theta_{\mathrm{W}} \\ -\sin\theta_{\mathrm{W}} & \cos\theta_{\mathrm{W}} \end{pmatrix} \begin{pmatrix} \mathrm{B}^0 \\ \mathrm{W}^3 \end{pmatrix} \ . \tag{1.2}$$

The Weinberg angle is related to the masses of the W and and Z bosons as

$$\cos\theta_W = \frac{m_{\rm W}}{m_{\rm Z}}\ . \tag{1.3}$$

What is important to note here is that only left handed particles and right handed antiparticles have weak interactions, and even more important; *all observed neutrinos are left handed, while all observed antineutrinos are right handed.* That is why this symmetry uses only the left handed weak isospin group $\mathrm{SU}(2)_L$. In this representation, the Q and L have antiparticles through time reversal which are right handed and interact weakly. The left handed u^c, d^c and e^c have antiparticles through time reversal which are right handed but have no weak interaction. Finally, the neutrino is only found as a left handed particle, and its unobserved antiparticle is the right handed antineutrino.

The gluons are the gauge bosons of the $\mathrm{SU}(3)_c$, and the endeavour to unify these with the electroweak is called Grand Unification, which will be dealt with in Section 1.3. As leptons are color singlets, they do not interact with gluons, whereas quarks do and we call interactions involving gluons strong interactions with gluons as force carriers for the strong nuclear force or color force. The colors are postulated to explain why the quarks that are only observed in nature as parts of either a meson on the form $\mathrm{q}_i\bar{\mathrm{q}}_i$ or a baryon on the form $\mathrm{q}_i\mathrm{q}_j\mathrm{q}_k$, where q is a quark and i, j, k are different colors in some permutation. The colors used have differed historically; in this paper they will be called red, blue and green (r, g, b) for color triplets, and anti-red, anti-blue and anti-green $(\bar{\mathrm{r}}, \bar{\mathrm{g}}, \bar{\mathrm{b}})$ for color anti-triplets, and we will use the notation $\bar{\mathrm{q}}_i \equiv (\bar{\mathrm{q}})_{\bar{i}}$ for simplicity. Quarks are color triplets and are found in a 3 representation of $\mathrm{SU}(3)_c$, while anti quarks are color anti-triplets and are found in a $\bar{3}$ representation. Gluons carry color and anticolor, and form a color octet; found in the 8 representation of $\mathrm{SU}(3)_c$.

1.2 Problems of the standard model

There are many issues to be had with the standard model. According to S. Raby [4], there are aesthetic problems with the standard model, as follows.

1. The Standard Model gives no reason why local gauge interactions are $SU(3)_c \times SU(2)_L \times U(1)_Y$. In other words, why do we only observe left handed neutrinos?

2. 6 quarks and 6 leptons have been observed, and these fit into a 3-generation scheme with three pairs of quarks and leptons having the same EM properties but with increasing mass. Why are there three such generations, and why such a big difference in the masses of the light and heavy fermions?

3. SM has 19 parameters which are interdependent on each other and must thus be chosen to fit the data. There are 3 arbitrary gauge coupling constants, g_3, g and g', 9 fermion masses (u, d, s, c, t, b, e, μ, τ), 3 Cabibbo-Kobayashi-Maskawa (CKM) mixing angles and one CKM phase constant, the Higgs vacuum expectation value and its mass, and the QCD phase angle θ. For massive but light Majorana neutrinos, nine more parameters must be added, three for mass, three CKM angles and three CKM phase constants. The general opinion is that there are too many arbitrary parameters for a satisfying model.

4. Charge quantization is still a mystery. Quarks have been shown to have fractional electrical charges, but we do not know why electromagnetic charges are quantized, in particular in such a way that hadrons and leptons as well as the gauge bosons have whole number discrete charges.

1.3 Grand unification

While electroweak unification has been achieved and is a part of the standard model, many physicists have tried to accomplish so called grand unification to deal with the problems described in the last section. The grand unified theories expand upon the SM group configuration $SU(3)_c \times SU(2)_L \times U_Y$ and envelop it in bigger symmetry groups.

One famous such endeavour is Jogesh Pati and Abdus Salaam's attempt to include lepton number as a fourth color [5], the $SU(4)_c \times SU(2)_L \times SU(2)_R$ gauge which will be discussed as a preon model in chapter 2. SU(4) can be broken down into SU(3)×U(1), and is used to first model leptons as the fourth quark color, and then unify with the weak force through the weak isospin. By putting the neutrino into the SU(4), there is no way of including only the left handed particles while dismissing an unobserved left handed antineutrino. Utilizing the right handed gauge group as well, Pati and Salam found a way to get around needing the abelian $U(1)_Y$ group to produce electromagnetic charge. Their Q_EM is given as $T_{3L}+T_{3R}+1/2(B\text{-}L)$, where B is the baryon number and L is the lepton number. Thus, two groups of isospin are assumed, and with them the so called sterile neutrinos. These sterile neutrinos must interact with only gravity in addition to the gauge bosons of $SU(2)_R$. The gauge bosons of $SU(2)_L$ are called W_L while the bosons of $SU(2)_R$ are called W_R, and Pati and Salam predict the mass relationship $m_{W_R} \gtrsim 3m_{W_L}$, based on the upper limit of the amplitude of right handed weak interactions as being at most of order 10% of the amplitude of left handed. The current experimental lower bound on the W_R mass is considered by the particle review group to be 715 GeV as calculated by M. Czakon et al in 1999 [6].

Another classic grand unification gauge group is the Georgi–Glashow SU(5) [4]. In SU(5), the fermions are found in two representations, [Q, u^c, e^c] is a 10 representation, while [d^c, L] is in a $\bar{5}$ representation. In this model, the Higgs boson is a doublet in a 5_H or $\bar{5}_H$, in which three colored Higgs bosons also appear, which breaks baryon and lepton number conservation. The existence of such Higgs bosons predicts the yet unobserved proton decay $p^+ \rightarrow e^+ + \pi^0 \rightarrow e^+ + 2\gamma$.

SO(10) breaks maximally into either the Pati–Salam gauge group SU(4)×SU(2)×SU(2) or the Georgi–Glashow SU(5). Here the fermions sit in a 16 dimensional spinor representation, similar to that in SU(5), where the SO(10) 16 can be broken down to the SU(5) representations [10 + $\bar{5}$ + 1]. Here, the SU(5) singlet state is the sterile left handed antineutrino. The SO(10) quantum numbers are given as spin states in Table 1.2.

	SU(5)	Y	Color	Weak
ν^c	1	0	$+++$	$++$
e^c	10	2	$+++$	$--$
u_r	10	1/3	$-++$	$+-$
d_r	10	1/3	$-++$	$-+$
u_g	10	1/3	$+-+$	$+-$
d_g	10	1/3	$+-+$	$-+$
u_b	10	1/3	$++-$	$+-$
d_b	10	1/3	$++-$	$-+$
u_r^c	10	$-4/3$	$+--$	$++$
u_g^c	10	$-4/3$	$-+-$	$++$
u_b^c	10	$-4/3$	$--+$	$++$
d_r^c	$\bar{5}$	2/3	$+--$	$--$
d_g^c	$\bar{5}$	2/3	$-+-$	$--$
d_b^c	$\bar{5}$	2/3	$--+$	$--$
ν	$\bar{5}$	-1	$---$	$+-$
e	$\bar{5}$	-1	$---$	$-+$

TABLE 1.2: SO(10) left handed fermions

In this scheme, the hypercharge is given as a funtion of numbers of weak and color spins,

$$Y = \frac{N_+^c - N_-^c}{3} - \frac{N_+^W - N_-^W}{2} \tag{1.4}$$

The $SU(2)_L$ transformations of this system flip both W-spins, one up and one down. These transformations only applies to the already established $SU(2)_L$ doublets, and it preserves Y and color. The $SU(3)_c$ transformations flip two color spins in the same fashion, one up and one down. Hence these transformations apply only to the quarks in the table, and they preserve Y and weak isospin T_3. The SU(5) transformations that are not contained in SU(3)×SU(2) flip two spins of different kinds, one c spin and one w spin, one up and one down. This transforms particles inside their SU(5) representation, and does not preserve Y. Lastly, the SO(10) transformations that are not contained in SU(5) flip two spins up or two spins down, with no restriction on which of the five spins can be flipped. This symmetry group describes only one generation, and it is assumed that the two other generations can be reproduced by replicating this SO(10). By flipping it is meant to apply raising or lowering operators to the spins, so by flip up the ladder operation $a_+ \left|-\right\rangle = \left|+\right\rangle$ is meant, and by flip down the ladder operation $a_- \left|+\right\rangle = \left|-\right\rangle$ is meant, where $a_- \left|-\right\rangle = a_+ \left|+\right\rangle = 0$.

Chapter 2

Classical Preon Models

2.1 What is a preon?

A preon is a theoretical particle which is an element of composite leptons or quarks. In other words, preon models assume there's a more fundamental kind of particle than those we have already observed. Different preon models consider different numbers and different natures of the preons, and this thesis will treat some of these models.

In their book Preons [7], which is a 1992 review of different preon models, Kalman and Souza spend a considerable amount of time pointing to problems in SM that preon models may hope to explain. Among these is point 5 in Section 1.2: The unexplained relationship between the masses of the heavy gauge bosons Z_0 and $W^{\pm}$, and they suggest that the vector bosons may be composite particles, while pointing to a similarity between the weak nuclear force and Van der Waal's intermolecular force. The higgs field is also viewed as problematic, and proposed to also be a composite particle. While the Higgs boson has now been observed at CERN, it may still be a composite particle like they suggest. Furthermore, they note that there are a lot of fundamental particles in the standard model, and effective and aesthetic preon models should effectively reduce this number by yielding fewer preons than there are quarks and leptons.

Perhaps not the strongest but at least the most commonly used argument for preons is the argument by historical induction. While atoms were thought to be fundamental and indivisible building blocks when they were discovered (thus the name atom, from greek atomos, uncuttable), history has shown this to be false. Again, when identifying the nuclei the proton and neutron, it turned out there was indeed another and deeper layer of fundamental matter, quarks. Proponents of preon models argue that since the searches for deeper layers of constituent particles have been so far successful, we should invest in the search for even more minute particles; the preons.

The dynamics of such preons will be difficult to get right and consistent, and there's no guarantee a consistent cynamical model can be made, due to the small sizes and masses of the light leptons and quarks. A constituent particle would need to be either quite heavy or light and relativistic. To get dynamics like that to work will be difficult but not impossible with heavy preons, argues Don Lincoln in his recent paper the Inner Life of Quarks [8], while Moffat on the other hand assumes in his recent preon model [9] (not further discussed in this thesis) off handedly that his preons are light and relativistic. Thus modern preon theorists must like Moffat ignore this problem as a dynamical challenge until it is solved or shown generally to be unsolvable. In this chapter, we will treat some of the most prominent classical preon models.

2.2 The haplon model

The haplon model, or the Fritzsch–Mandelbaum model [7], contains both bosonic and fermionic preons. In this model, two of each are proposed in order to describe the first generation of SM particles; the fermions α and β, and the bosons x and y. Since quarks and leptons are fermions, the simplest combinations of haplons that will yield these are di-preon systems of one boson and one fermion. There are four such combinations, and Fritzsch and Mandelbaum use them to construct the up and down quarks as well as the electron and its neutino. Combining them, we get

$$(\alpha y) \quad (\beta y) \quad (\alpha x) \quad (\beta x)\ . \tag{2.1}$$

At this point in the construction of the theory, x and y as well as α and β are interchangeable. Fritzsch and Mandelbaum argue that the bosons determine if a combination yields a quark or a lepton, and thus that one of the bosons, say y, carries lepton number, while x then carries the quark color. This splits x into three parts, $\{x_1, x_2, x_3\}$, making (x, y) effectively a quartet. Now the bosons are distinguished, but we need to separate α and β. This can be done by comparing charges. Assume that α and x gives the up quark, whereas β and x gives the down quark. The up quark has electric charge $+\frac{2}{3}$, and the down quark $-\frac{1}{3}$. None of the leptons have the factor of $\frac{1}{3}$, so this needs to be a factor in the charge of x. If we choose to have the charges of α and β opposite equal to each other, this gives

$$\mathrm{Q}_\alpha = \frac{1}{2}\ , \quad \mathrm{Q}_\beta = -\frac{1}{2}\ , \quad \mathrm{Q}_x = \frac{1}{6}\ . \tag{2.2}$$

Given the charges of ν and e^-, 0 and -1, the charge of y becomes

$$\mathrm{Q}_y = -\frac{1}{2}\ , \tag{2.3}$$

and thus

$$\nu = (\alpha y)\ , \quad \mathrm{e}^- = (\beta y)\ , \quad \mathrm{u} = (\alpha x)\ , \quad \mathrm{d} = (\beta x)\ . \tag{2.4}$$

This is the original assignment of haplons in boson-fermion pairs. There are alternatives to combining bosons and fermions, though. Kalman and Souza also associate four combinations of the fermionic haplons to the weak gauge bosons,

$$\mathrm{W}^+ = (\alpha\bar{\beta})\ , \quad \mathrm{W}^- = (\bar{\alpha}\beta)\ , \quad \mathrm{W}^3 = (\frac{\alpha\bar{\alpha} + \beta\bar{\beta}}{\sqrt{2}})\ , \quad \mathrm{B}^0 = (\frac{\alpha\bar{\alpha} - \beta\bar{\beta}}{\sqrt{2}})\ . \tag{2.5}$$

Where W^3 and B^0 are related to Z^0 and γ through the Weinberg angle θ_W as described in Section 1.1. The haplon model considers also another scheme, in which not only the x-preon carries color, but where all the preons do, in 3 and $\bar{3}$ representations of SU(3). This is the scheme contemplated by Fritzsch and Mandelbaum in their original paper on preons [10]. In this case, the color representations when combining boson and fermion preons become

$$3 \otimes \bar{3} = 1 \oplus 8 \quad , \quad \bar{3} \otimes \bar{3} = 3 \oplus \bar{6}\ . \tag{2.6}$$

So as we see, any combination of a 3 and a $\bar{3}$ will yield one color singlet, whereas a $\bar{3}$ and a $\bar{3}$ will yield a color triplet, i.e. quarks. Thus the fermion haplons are $\bar{3}$'s, as is the y-boson, whereas the x-boson becomes a 3. This gives color to all the quarks, and lets leptons remain colorless. The weak gauge bosons can still be combined as given, as an antiparticle of a $\bar{3}$ is a 3, yielding a color singlet. The 8 and $\bar{6}$ color particles are not treated here, but the $1 \oplus 8$ problem is known from before, as mesons are found as color singlets, and the diquark color octet is not observed at current energy levels. This should be similarly assumed for the dipreon systems of color $\bar{6}$.

Now there ought to be some kind of interaction keeping preons together. Kalman and Souza calls this hypercolor, analogous to the color SU(3) strong interactions, the hypercolor is proposed to be an SU(N)-interaction. Thus, haplons that form stable bound states will either go together in pairs as N and $\bar{N}$, or they will go together in N-tuplets. This hypercolor force prevents a lot of unwanted particles to be found at low energy levels, as it prevents some color 3 combinations that otherwise would have been obvious to appear at low energy levels.

	Q	SU(3)$_c$	SU(N)$_{hc}$
α	1/2	1 or $\bar{3}$	N
β	-1/2	1 or $\bar{3}$	N
x	1/6	3 or $\bar{3}$	$\bar{N}$
y	-1/2	1 or 3	$\bar{N}$

Table 2.1: Haplon model preon multiplets

For $N \neq 3$, this hypercolor effectively prevents pairs like $(\alpha\bar{x})$ at low energies, which is a color singlet and should otherwise be energetically favorable to (αx).

Although the haplon model is about the simplest possible boson-fermion preon model, and a popular basis for new preon models, it has major flaws, and is considered by Kalman and Souza a prototype preon model. First and foremost, the haplon model provides no distinction between left handedness and right handedness, and as such predicts right handed neutrinos which although they may exist in a sterile form, there is no implication of a left right asymmetry in the haplon model.

Furthermore, the two different color schemes have their own problems. In the simplest form where the x boson is the only color triplet of the model and as such the sole carrier of color, there is little room for more generations. We can repeat this scheme three times as a generation of preons, but that raises a lot of new questions, as what will happen if a generation 1 preon and a generation 3 preon combines and is as such better suited for treatment in more advanced models. One can also speculate that heavier particles such as the strange quark or the μ can be made using SU(N) multiplets of hypercolor, but as we have observed three generations of both leptons and quarks, this suggests at least one more level of complexity.

The scheme in which all the preons are color triplets is in this way a more interesting idea, as we don't have to make a lot of assumptions about the nature of the SU(N) hypercolor to recreate a rich park of particles. In this model, not only do we have the color singlets and triplets already mentioned, but there are sextets and octets as well. Souza and Kalman suggest these color octets as color carrying weak bosons, and predict several decays that should be stronger in a haplon-world than in a SM one. Among them is the decay of a color octet W_8 to two fermions and a gluon, and the Z to a quark, antiquark and a gluon. However, these sextets and octets seem not to have been observed.

In Fritsch and Mandelbaum's paper [10], the haplons are color triplets, but the authors propose an interesting solution to the problem of the generations of quarks and leptons. If the electron is a βy singlet, maybe the muon could be a strongly bound state of the βy *octet* with a gluon or some other color octet, that is $\mu = \beta y g$, and so would the tau become $\tau = \beta y g g$. Because strongly bound complexes stay inseparable up to and including the energies at LHC, such a composition of the heavier leptons can not yet be ruled out.

Lastly, if the neutrino family share preon constituents with both the electron family through y and with the up quark family through α, then if neutrino oscillations are allowed through either of these preons, we should expect to find similar patterns in either of these families.

2.3 The rishon model

Another early preon model was the rishon model, or the Harari–Shupe model or the Harari–Shupe–Seiberg model [7]. In this model, all preons (which we with the original authors will call rishons, a Hebrew name meaning "The First") are fermionic, and there are only two types, the T rishon which is charged with a third of the elementary charge, and the V rishon which is electrically neutral:

$$Q_{\mathrm{T}} = \frac{e}{3} , \quad Q_{\mathrm{V}} = 0 . \tag{2.7}$$

When any three such rishons or three antirishons go together, they form a particle in the first generation,

$$TTT = e^{+} , \quad TTV = u , \quad TVV = \bar{d} , \quad VVV = \nu_e . \tag{2.8}$$

The color and hypercolor conform to a $\mathrm{SU}(3)_{\mathrm{c}} \otimes \mathrm{SU}(3)_{\mathrm{hc}}$ group, where T is in the (3,3) representation whereas V is represented by ($\bar{3}$,3). Just looking at the color behaviour of these four leptons and quarks, as well as their antiparticles, we get the color combinations

$$3 \otimes 3 \otimes 3 , \quad 3 \otimes 3 \otimes \bar{3} , \quad 3 \otimes \bar{3} \otimes \bar{3} , \quad \bar{3} \otimes \bar{3} \otimes \bar{3} , \tag{2.9}$$

The decompositions yield the interesting low energy relevant singlets and triplets as follows,

$$
\begin{aligned}
3 \otimes 3 \otimes 3 &= 1 \oplus 8 \oplus 8 \oplus 10 \, , \\
\bar{3} \otimes \bar{3} \otimes \bar{3} &= 1 \oplus 8 \oplus 8 \oplus \overline{10} \, , \\
3 \otimes 3 \otimes \bar{3} &= 3 \oplus 3 \oplus \bar{6} \oplus 15 \, , \\
3 \otimes \bar{3} \otimes \bar{3} &= \bar{3} \oplus \bar{3} \oplus 6 \oplus \overline{15} \, .
\end{aligned}
\tag{2.10}
$$

As in the Haplon model, the leptons end up in the color singlet, while the quarks end up in a color triplet ($\bar{3}$ for the antiquarks), and Harari and Seiberg declare in their 1981 paper about rishon dynamics [11] that all color non-singlets are confined up to the energy scale Λ_{C}, which is the theoretical energy cutoff at which color stops being confined. This would then be the reason we only see quarks in their composite form, as hadrons. Furthermore, they state that the hypercolor cutoff Λ_{H} will be larger than the color cutoff Λ_{C}, and that only the hypercolor singlet states can be observed as free particles below this scale. This implies that if the rishon model is right or partly right, and if free quarks are ever observed, we haven't even seen the tip of the iceberg of the particle menagerie.

As is given in Kalman and Souza, the original versions of this model up to the work of Harari and Seiberg treated only one generation. However, Elbaz et. al. in the 1983 paper 'Lepton and quark generations in the geometrical rishon model' [12] extend it to include more generations as well as explaining the original model further than what Kalman and Souza do. Still, the main body of work on this model was done by Harari and Seiberg, writing a series of papers on the dynamics of this model [11].

2.4 Pati-Salam models

In their article "Lepton number as the fourth color" [5], Jogesh C. Pati and Abdus Salam develop several versions of an $\mathrm{SU}(4)_c$ model. This is a preon level attempt at a grand unified theory, and their $\mathrm{SU}(4)\times\mathrm{SU}(2)_L\times\mathrm{SU}(2)_R$ is still cited as one of two main basic versions of SU(N) grand unification as described in Section 1.3, the other being Georgi Glashow's SU(5) unification. This $\mathrm{SU}(2)_L\times\mathrm{SU}(2)_R$ yields non-sterile right handed neutrinos through another set of weak interactions with a more massive weak gauge boson W_R. Similarly, the classic W boson is called W_L for clarity in this model.

Pati and Salam base their paper on a simple enough idea; can quarks and leptons be unified in one extended group of strong interactions? This group would be the $\mathrm{SU}(4)_\mathrm{c}$ of color interactions of which $\mathrm{SU}(3)_c\times\mathrm{U}(1)_Y$ is a subgroup, with

$$\Psi_{\mathrm{L,R}} = \begin{bmatrix} \mathcal{P} \\ \Pi \\ \lambda \\ \chi \end{bmatrix}_{L,R} \otimes (a, b, c, d) \ . \tag{2.11}$$

Here, they use three kinds of quadruplet preons, $\mathrm{i}_{L,R}$ and α. The i $= \mathcal{P}$, Π, λ, χ is a fermionic spin 1/2 quadruplet in both left handed and right handed versions, whereas $\alpha =$ a, b, c, d is a bosonic spin 0 color quadruplet, where the 'color' d is associated with leptons. The a, b and c are used as in the original paper, where {a, b, c} are the colors {r, g, b}. Letting Ψ be symmetric under $\mathrm{SU}(4)_c\times\mathrm{SU}(4)_L\times\mathrm{SU}(4)_R$ makes Ψ_L transform like ($\bar{4}$, 4, 1) and Ψ_R like ($\bar{4}$, 1, 4) in the basic model.

These symmetries reveal a factual flaw in this model that was not so obvious at the time. It covers the fermions known at the time,

$$\Psi_{\mathrm{L,R}} = \begin{bmatrix} \mathcal{P}_{a,b,c} & \mathcal{P}_d \\ \Pi_{a,b,c} & \Pi_d \\ \lambda_{a,b,c} & \lambda_d \\ \chi_{a,b,c} & \chi_d \end{bmatrix}_{L,R} = \begin{bmatrix} \mathrm{u}_{a,b,c} & \nu_e \\ \mathrm{d}_{a,b,c} & \mathrm{e} \\ \mathrm{s}_{a,b,c} & \mu \\ \mathrm{c}_{a,b,c} & \nu_\mu \end{bmatrix}_{L,R} , \tag{2.12}$$

but the last generation of fermions (b, t, τ, ν_τ) had not been discovered with certainty at the time of writing, and as such were not included in Pati and Salam's "basic" preon model. If the last generation was to be included in the basic model, it would be an extention of $i_{L,R}$, so $SU(4)_c \times SU(6)_L \times SU(6)_R$. This is why not the $SU(4)_c \times SU(4)_L \times SU(4)_R$ but rather the one generation subgroup $SU(4)_c \times SU(2)_L \times SU(2)_R$ survived the test of time as the Pati-Salam gauge. This gauge is discussed as an "economical model" in their paper, where the generations are represented by three SU(4) color groups; $SU(2)_L \times SU(2)_R \times SU(4)_e \times SU(4)_\mu$ ($\times(SU(4)_\tau$ by extention). As the GUTs discussed in chapter one deal only with one generation of quarks and leptons, this reduces trivially to the $SU(2)_L \times SU(2)_R \times SU(4)_e$.

There are several interesting things to be said about this model. First off, the authors ascribe the elusiveness of the unobserved right handed neutrinos to a much larger mass of the gauge bosons of the right handed weak gauge group. The gauge boson $W_R^\pm$ has not been observed yet, as described in Section 1.3. Secondly, by absorbing $SU(3)_c \times U(1)_Y$ into the larger group SU(4), they get rid of the contribution of the abelian U(1) to electric charge, which they argue is key to explaining the quantized and discrete observed electrical charges of known particles.

In their so called economical model, new gluons are introduced. As the color group is doubled, so is the number of gluons. The relevant color subgroups of the $SU(4)_e$ and $SU(4)_\mu$, the normal color $SU(3)_e$ and $SU(3)_\mu$ each have their own gauge bosons, gluons. However, the physical SU(3), they argue, is identified with the direct product of $SU(3)_e$ and $SU(3)_\mu$ on the form a×a. The remaining gluons become massive with more higgs bosons required by the model, and as such are not observed.

Pati and Salam predict three new kinds of particles from this, including the W_R. One kind is the heavy exotic gauge bosons X, X^- and X^{-}' which couple same generation quarks and leptons. These couplings lead to some unobserved decays, for instance the $K^0 \to e^- + \mu^+$, and the X conserves a baryon minus lepton (B-L) quantum number rather than lepton number and baryon numbers individually. Another kind of new particle is the exotic S^0 meson, which couples every fermion with its antiparticle, and thus permits neutrinos to interact with hadrons through reactions like $\nu + \bar{\nu} \to q + \bar{q}$.

Chapter 3

Modern Preon Models

A big body of the physics community put the idea of preon models to rest after the seventies, as the big three haplon, rishon and Pati-Salam models failed to gain experimental support. The mass problem of preons was still and is still unsolved, and the experimental evidence of the electron fit the Dirac equation for a point particle better and better. However, with an elusive Higgs boson, new preon models appeared that seemingly wouldn't need one, or that would include the higgs as a composite particle. Now, the higgs particle has been observed at CERN, and the best preon modelists can hope to achieve is to predict a composite boson of energy ~ 126GeV.

3.1 Preon trinity

The preon trinity model borrows ideas from both the haplon and the rishon models [13]. In this model, Dugne, Fredriksson and Hansson suggest that by extending the haplon model to a model of three fermionic spin 1/2 preons and three bosonic spin 0 preons, we can form all known quarks and leptons while retaining simplistic symmetries. The fermionic preons are called α, β and δ, whereas the bosonic ones are called x, y and z.

What is an original addendum to this model is the inspiration from Fredriksson's work on diquarks [14], that is, systems of two bound quarks inside three quark systems. What is proposed in this model is that two preons will go together and form bosonic dipreons, which will emulate the boson from the haplon model. Also, and maybe more interestingly, these dipreons are speculated to be the supersymmetric partners of the fermionic preons. Like in the haplon model, quarks and leptons are made up by a boson and a fermion, but in this case, the fermion is a preon while the boson is a dipreon; forming a non-associative trinity of preons.

Furthermore, this model includes supersymmetry at the preon level. Supersymmetry is the idea that for each simple fundamental particle there exists a particle which contains the same quantum numbers but differs in spin by a half. So each boson has a supersymmetric fermionic partner, and each fermion has a bosonic supersymmetric partner. In the litterature, these SUSY partners are often named with an s in front of the name of the base particle, so a SUSY lepton is called a "slepton", etc. Supersymmetric extensions of SM have been popular, but the continual lack of evidence of supersymmetric partners renders it at best severely broken. However, if the supersymmetric partners are contained within a preon model, supersymmetry could be achieved without needing exotic sleptons and squarks.

Suppose, as the authors do, that the bosonic preons are really the dipreon SUSY partners of the fermionic preons. That requires them to be equal in charge and color, and it is solved as $x = (\bar{\beta}\bar{\delta})$, $y = (\bar{\alpha}\bar{\delta})$ and $z = (\bar{\alpha}\bar{\beta})$. This effectively reduces the trinity preon model to a three preon model, which has profound implications both for the transparency of the model interactions, as well as in making SUSY partners of quarks and leptons themselves, effectively imposing a SUSY that is not necessarily severely broken and where the SUSY squarks and sleptons are quarks and leptons themselves.

The trinity preons are suggested to have the charges +e/3, −2e/3 and +e/3, and every preon is in a 3 representation of $\mathrm{SU(3)_{Color}}$. This makes the antidipreons either 3 or $\bar{6}$, where the sixtet option is ruled out and assumed not found in nature by the authors. For quarks to be color triplets, they must thus consist of a preon and an antidipreon (by convention not an antipreon and a dipreon), whereas color singlet leptons must consist of a preon and a dipreon. As in the Haplon model, there is another way of making an SU(N) singlet, namely by combining a particle and an antiparticle of the same kind. As in the Haplon model, this boson combination is thought to yield the vector bosons.

charge	+e/3	−2e/3	+e/3
spin 1/2 preons	α	β	δ
spin 1 antidipreons	x = $(\bar{\beta}\bar{\delta})$	y = $(\bar{\alpha}\bar{\delta})$	z = $(\bar{\alpha}\bar{\beta})$

Table 3.1: Trinity preon charges

Here we see that to make quark charges, we need only combine these, one preon and one antidipreon. The authors here make a distinction between α and δ in that they claim δ is heavier, or makes heavier particles than α. If the preons have individual mass, and if α and δ have different mass, then we can assume this to be true without loss of generality. However, Dugne, Fredriksson and Hansson speculate that this δ preon is superheavy, whereas the dipreon containing it is not, claiming this to be because more strongly bound states have more uncertainties in their mass. Thus the quarks are assigned after the following table

	α	β	δ
x = $(\bar{\beta}\bar{\delta})$	u	s	c
y = $(\bar{\alpha}\bar{\delta})$	d	X	b
z = $(\bar{\alpha}\bar{\beta})$	t/h	g	t/h

Table 3.2: Quarks of the trinity preon model

This table does not follow the normal 3-generation scheme of quarks, and in addition to the new g (gross) and h (heavy) quarks predicts an X quark with charge of -4e/3. The authors speculate that the top quark of SM may actually be X, as at the time of writing, there was no measurement of the charge of what was believed to be the top quark, and there was an uncertainty about whether the particle measured at fermilab with m $\approx$ 170 GeV could be an exotic quark with charge -4e/3. However, with the increasingly precise Tevatron [15], Fermilab [16] and ATLAS [17] measurements, it is clear that this particle is indeed the SM top quark with charge +2/3, with the latter experiment showing this to a definitive 8σ. Thus the charge $-4e/3$ X quark may be an exotic quark, definitely heavier than the W^- boson [13] and presumably heavier than the top quark, or maybe it's not a bound state at all, as both consistuents (β and y) have charge -2e/3, and may repel each others by static electric repulsion.

The leptons are assigned according to the following table,

	α	β	δ
$\bar{\mathrm{x}} = (\beta\delta)$	ν_e	e^-	$\bar{\nu}_{\kappa 1}$
$\bar{\mathrm{y}} = (\alpha\delta)$	μ^+	$\bar{\nu}_\mu$	κ^+
$\bar{\mathrm{z}} = (\alpha\beta)$	ν_τ	τ^-	$\bar{\nu}_{\kappa 2}$

Table 3.3: Leptons of the trinity preon model

Noteworthy are the three new particles, all with the bare δ and thus probably heavy. This presents us with a very clear break of the traditional SM family structure of quarks and leptons since the τ^- and ν_τ do not map to the top and bottom quarks in these tables. It is also noteworthy that we here get two new heavy neutrinos with mass more than half that of the Z boson for consistency with the observed Z decays. As the authors note, this table invites to mixing of ν_e and $\bar{\nu}_\mu$, since these particles have the same preon content, and they speculate that this can be due to some α and δ mixing.

When constructing the heavy gauge bosons, there are more surprises. For one, at the same token as with the leptons and quarks, we get nine of these as well. Dugne, Fredriksson and Hansson creates the table in the following way

	α	β	δ
$\bar{\alpha}$	Z^0, Z'	W^-	$\bar{Z}^*$
$\bar{\beta}$	W^+	Z', Z^0	W'^+
$\bar{\delta}$	Z^*	W'^-	Z', Z"

Table 3.4: Vector bosons of the trinity model

This includes six new and unobserved heavy bosons, the Z', Z", W'^+, W'^-, Z^* and $\bar{Z}^*$ bosons. As these are not observed, they must be much heavier than the already known vector bosons. The Z boson depends on $\alpha\bar{\alpha}$ and $\beta\bar{\beta}$ through the weinberg angle like in the haplon model. This mixing of α and β in this model yields also the mixing of the e and μ neutrinos and the cabibbo mixing of the d' quark. This leads to the maybe most interesting prediction of the trinity preon model, that if the mixing of α and β is equal in the ground states of Z and d', the weinberg angle and the cabibbo angle are related through the equation

$$\frac{\cos\theta_W - \sin\theta_W}{\sqrt{2}} = \sin\theta_C \tag{3.1}$$

Using that $\sin(\theta_W)^2 = 0.23117$, this equation yields 0.28003 on the left hand side, while the $\sin\theta_C$ on the right hand side is 0.2225. Dugne, Fredriksson and Hansson consider this an interesting match considering the crude assumptions. While this provides a link between the Weinberg angle and the first cabibbo angle, the model does not yet provide an explanation to why the Weinberg angle relates Z to γ or m_Z to m_W the way it does.

3.2 The helon model

Not all preon models view preons as point particles. One of these alternative models is called the helon model, invented by the Australian physicist Sundance O. Bilson-Thompson. As a "topological toy model" [18] it takes a different approach to the preon issue by modelling certain quantum numbers as topological features, and is cited in works on loop quantum gravity. The names of the constituents are intentionally made silly (like 'quarks'), this may make sure proponents of this model won't get taken seriously until they have some hard evidence.

This model is based mostly on the Rishon model, and in the first instance yields descriptions of one generation of quarks and leptons in the model, as well as the gauge bosons and some heavier leptons and quarks, demonstrating how it can expand to other generations. The preon equivalent in this model is called a helon, and each helon consists of two tweedles. These tweedles are represented as twists in a knot theoretical ribbon through $\pm\pi$, called respectively tweedle-dum for π and tweedle-dee for $-\pi$, which shall be referred to as U and E. Thus a pair of such tweedles will have a total twist of either 0 or $\pm 2\pi$, associated with an electrical charge of 0 or $\pm e/3$. Bilson-Thompson assumes the ordering of tweedles is unimportant, and thus there are three distinct ways to combine tweedles into helons,

	UU	EU = UE	EE
Charge	+e/3	0	−e/3
Helon	H_+	H_0	H_-

Table 3.5: Preons with charge in the helon model

These helons bind together in triplets, with a mechanism that binds such thread-like entities together in both ends. Bilson-Thompson uses the image of two parallell discs, where one binds the "top" ends of the helons while the other disc binds the "bottom" ends, such that the endpoints of the threads are unable to change places. Two ribbons (tweedles) have now twisted together making a strand (helon), and three such when fastened together in respectively top and bottom ends make closed braids (quarks and leptons). The interesting topological part of this is how such fastened strands can make different configurations not only by what type of helon is where relative to the others, but also by how the three strands are braided. The trivial braids, three helons bound together without any intertwining, makes the vector bosons.

Further on, a set of rules for such triplets are presented. First off, the author wants no mixing of helons of opposite charge, meaning effectively that H_+ and H_- will never be a part of the same triplet, whereas H_0 and H_+, and H_0 and H_- are ok. Lastly, *unbraided* helon triplets will have integer net charge, that is, no mixing of helons. In short, this means that the braids appear whenever different kinds of helons are mixed. These rules are analogous to the ones from the rishon model, and the similarities become clear if we say $V = H_0$ and $T = H_+$, where $H_- = \bar{T}$, in a rishon model where $V = \bar{V}$. The important difference is that where braiding is allowed and the three helons are not the same, the order of the helons matters, and this makes quarks color triplets but leptons color singlets, see Equation (2.10).

The helon model table of basic helon triplets is

	H_+	H_0	H_-
H_+ H_+	e^-	u_b	-
H_+ H_0	u_g	$\overline{d_r}$	-
H_0 H_+	u_r	$\overline{d_g}$	-
H_0 H_0	$\overline{d_b}$	ν_e	d_b
H_0 H_-	-	d_g	$\overline{u_r}$
H_- H_0	-	$\overline{u_g}$	d_r
H_- H_-	-	$\overline{u_b}$	e^+

,

TABLE 3.6: Complex fermions in the helon model

where the helons in the left column are to the left of the one in the top row.

As we're using three helons to form a braid, we're working in the Braid group B_3. Thus we can interchange strand 1 and strand 2, T_1, or strand 2 and strand 3, T_2. B_3 covers any number of such twists on three strands, and is this infinite. As the endpoints of the braided strands are fixed, the rotational aspect of such a twist also matters. A clockwise T_{1L}, i.e. a twist where strand 2 is placed in front of strand 1 is the antitwist of the anticlockwise T_{1R}, as $T_{1R}T_{1L}$=$T_{1L}T_{1R} = 1$, the identity element. In the original article, Bilson-Thompson asserts that the basic braids of these mentioned helon combinations can be of any complexity as long as all three strands are intertwined. The simplest such are the braids with two operations, T_2T_1, and we will call the $T_{2L}T_{1R}$ the basic left handed braid.

In the Table 3.6, we have a single neutrino, and no antineutrinos. Neutrinos are left handed, so let this table be of left handed braids, $T_{2L}T_{1L}$. Now, we can construct antiparticles by simply parity transforming these, as $P(H_+)=(H_-)$ and $P(H_-)=(H_+)$ due to the nature of the tweedles in the helons. Parity transformation also transforms the braids, $P(T_{2L}T_{1R})=T_{2R}T_{1L}$ to right handed ones. Thus the parity transformed right handed electron is the left handed positron, and similarly for the other charged particles. Another way of making an antiparticle is to use charge conjugation, for which $C(H_+) = H_-$ and $C(H_-) = H_+$. There are thus four states of each charged braid, both particles and antiparticles appear in both handed states. The exception is the neutrino since charge conjugation leaves all its chargeless H_0, so a charge conjugated left handed neutrino is in all aspects indistinguishable from a normal left handed. Thus it has only two states, and a parity transformed neutrino must indeed be a right handed anti-neutrino. Thus, so far this is a model which distinguishes handedness and predicts only left handed neutrinos by virtue of the topology of the model,

Heavier leptons and quarks are modelled as more intricate braids. This property of adding more braid operations to make heavier particles makes for seemingly endless generations, as the B_3 group is infinite. The μ shares the helons and the two first braid operations with the electron, but then adds a T_2 operation. The entire second generation can be reproduced with the same features as the first with just adding this extra twist of two helons. The article shows how the μ then decays to a chargeless but otherwise equal braid and a braidless triplet of H_-s. By expanding the braid identity like $T_{2R}T_{1L}T_{1R}T_{2L}$, and then cutting it in half, with the one half containing the charge (the twist of the helons), an electron-antineutrino pair or a positron-neutrino pair is made. A quark antiquark pair may be similarly made if the charge sits unevenly in the top and bottom parts when cutting. Hence this unbraided $H_-H_-H_-$ must be the W^-.

In this model the important fundamental difference between bosons and fermions is that the boson braid permutations are identical to the identity operation. Thus, the fundamental bosons are made as this W^-, as three non intertwined strands, or any overlay that is algebraically identical. Thus to construct them, W^-'s antiparticle through both charge conjugation and parity transformation is the W^+, or the $H_+H_+H_+$. Bilson-Thompson then assigns B^0 to the unbraided chargeless $H_0H_0H_0$ triplet. The neutral vector boson W_3 is more difficult to assign, but the author claims it to be coupled charged helons and their counterhelons, and that this makes a fundament for the weinberg mixing.

Another seemingly important part of the helon model is the new quantum number Ω. Let

$$\Omega = \frac{1}{3}\beta(N(H_+) + N(H_-) - N(H_0)) \ . \tag{3.2}$$

Letting the positively charged braids have $\beta = 1$, and the negatively charged braids have $\beta = -1$, this gives for the first generation of fermions

fermion	Ω
e^+	$+1$
u	$+\frac{1}{3}$
$\bar{d}$	$-\frac{1}{3}$
ν	-1
e^-	-1
$\bar{u}$	$-\frac{1}{3}$
d	$+\frac{1}{3}$
$\bar{\nu}$	$+1$

TABLE 3.7: Distribution of helon quantum number Ω

As the value of β remain constant through more complex braids, this table will be threefold copyed into the next generations of particles. Thus Ω is $\pm\frac{1}{3}$ for quarks and antiquarks, and ∓ 1 for leptons and antileptons. Charge of complex particles in this model is trivially assigned according to the formula

$$Q = \frac{1}{3}\beta(N(\mathrm{H}_+) + N(\mathrm{H}_-)) \ , \tag{3.3}$$

but in terms of Ω this becomes

$$Q = \frac{1}{2}(\beta + \Omega) \ . \tag{3.4}$$

The author argues that this is a much nicer formula than Eq. (1.1), because Ω is more fundamental in the model and depends on less ad hoc variables than the hypercharge Y.

Chapter 4

A five preon model

At this point it is interesting to see if we can make a new preon model with different features, and see if new strengths or weaknesses occur. As there are many preon models, all having different strengths and weaknesses, but all lacking in dynamics and explicit experimental evidence, it is natural to assume that a real preon model might as well have other attributes altogether. Considering we usually don't know beforehand what mathematical and physical properties we will stumble upon, we are going to try to make a new such model here. Most of the modern models discussed in this thesis have been based on either the rishon or the haplon model of quarks. This one will be mainly based on the haplon model.

4.1 The basics

First off, let us consider different options for the number and types of preons in our model. The rishon model has two different fermionic preons, that are color and hypercolor triplets. The haplon model has both bosonic and fermionic preons, and we have seen that two of each produce the first generation of fermions, whereas three of each as in the preon trinitiy model yield all the known quarks and leptons, plus some exotic and unobserved ones. Between the four basic preons of the haplon model and the six basic preons, or three basic preons and their three basic spreons in the preon trinity model, we will consider a model of five basic preons. A five-preon haplon like model will lose the feature of the preon trinity model of absolving exotic supersymmetric partners, but might yield other interesting results.

The five-preon haplon like model can be done in different ways, in terms of number of fermionic and bosonic preons. We saw in the haplon model that the vector bosons are nicely produced by only two kinds of fermionic preons. Having three kinds of fermionic preons will give us a similar table to the one in the preon trinity model, producing five exotic vector bosons as in Table 3.4. This is not very interesting, and as such we will rather explore the alternative in this thesis.

Let there be two fermionic spin 1/2 preons, α and β, and three bosonic spin 0 preons x, y and z, as well as their antiparticles. Let these particles combine in fermion–boson pairs. This makes for six combinations, sufficient to reproduce either the known quarks or the known leptons. We do not need hypercolor yet, if we let these particles be color anti triplets, then a combination of a preon and a preon can form a color triplet, whereas a combination of a preon and an antipreon can form a color singlet. Thus we define that the quarks are $\{\alpha,\beta\}\otimes\{\mathrm{x, y, z}\}$, and leptons are $\{\bar{\alpha}, \bar{\beta}\} \otimes\{\mathrm{x, y, z}\}$.

When we assign preon combinations to the quarks and leptons, the similarities are striking. The $2\otimes3$ structure is similar to the charge distribution in both known leptons and known quarks, and for those reasons we will assume that x, y and z are similar in charge, but increasing in mass. Assuming $\mathrm{Q_x} = \mathrm{Q_y} = \mathrm{Q_z}$ gives us a preliminary assignment of quarks and leptons as given in Table 4.1. As most of the other preon models discussed in this thesis we have chosen not yet to consider chirality. This first assignment assumes that α combines with bosons to produce both charged leptons and the positively charged quarks. We will explore an alternative assignment in Section 4.4.

We are using a Cabibbo-Kobayashi-Maskawa rotation of SM [1], defining the generations of quarks by their weak isospin $\mathrm{T_3}$ doublets Q and L. Now rather than

	α	β	$\bar{\alpha}$	$\bar{\beta}$
x	u	d'	e^-	ν_e
y	c	s'	μ^-	ν_μ
z	t	b'	τ^-	ν_τ .

TABLE 4.1: First assignment of preons to basic fermions

using the mass eigenstates d, s and b, we use the weak interaction generations

$$\begin{pmatrix} \mathrm{u} \\ \mathrm{d'} \end{pmatrix} , \begin{pmatrix} \mathrm{c} \\ \mathrm{s'} \end{pmatrix} , \begin{pmatrix} \mathrm{t} \\ \mathrm{b'} \end{pmatrix} , \tag{4.1}$$

in which each weak interaction state is related to the mass eigenstates through the CKM-matrix,

$$\begin{pmatrix} \mathrm{d} \\ \mathrm{s} \\ \mathrm{b} \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} \mathrm{d'} \\ \mathrm{s'} \\ \mathrm{b'} \end{pmatrix} . \tag{4.2}$$

The V's are the coupling values of the two indexed quarks and a $\mathrm{W}^\pm$ boson, and can be simplified to 3 generalized Cabibbo angles and one phase constant. As SM provides no prediction for these parameters, the V's are thus far only experimentally determined. To find the charges of our preons we need to solve the following system of equations:

$$\begin{aligned} \mathrm{Q_x} - \mathrm{Q}_\alpha &= \mathrm{Q}_{\mathrm{e},\mu,\tau} = -1 \\ \mathrm{Q_x} - \mathrm{Q}_\beta &= \mathrm{Q}_\nu = 0 \\ \mathrm{Q_x} + \mathrm{Q}_\alpha &= \mathrm{Q}_{\mathrm{u,\ c,\ t}} = \frac{2}{3} \\ \mathrm{Q_x} + \mathrm{Q}_\beta &= \mathrm{Q}_{\mathrm{d',\ s',\ b'}} = -\frac{1}{3} . \end{aligned} \tag{4.3}$$

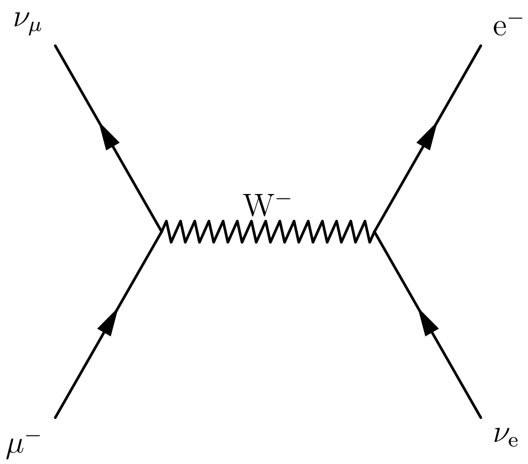
This system yields the charges

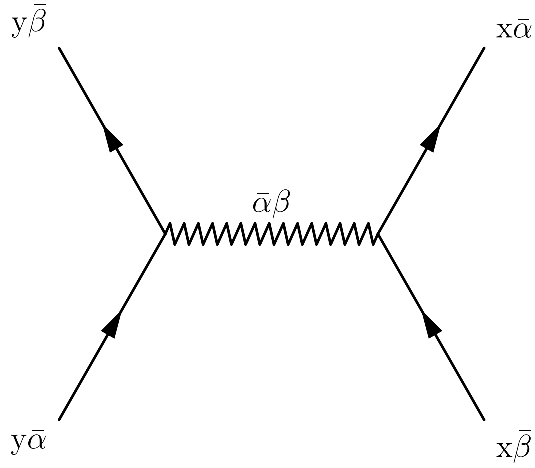
	Q	$\mathrm{SU}(3)_c$
α	$+5/6$	$\bar{3}$
β	$-1/6$	$\bar{3}$
x, y, z	$-1/6$	$\bar{3}$

TABLE 4.2: Preon charge and color, first assignment

4.2 Vector bosons

To pinpoint the weak force bosons we start by identifying the preon components of weak interactions. Let's start with muon and muon-antineutrino annihilation, $\mu^- + \bar{\nu}_\mu \to \mathrm{e}^- + \bar{\nu}_\mathrm{e}$. In terms of preon content, this becomes $\mathrm{y}\bar{\alpha} + \bar{\mathrm{y}}\beta \to \mathrm{x}\bar{\alpha} + \bar{\mathrm{x}}\beta$. We use for our Feynman diagrams the convention that the time axis goes horizontally to the right,





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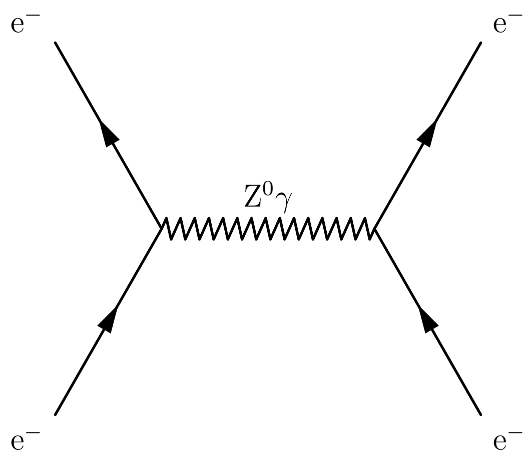
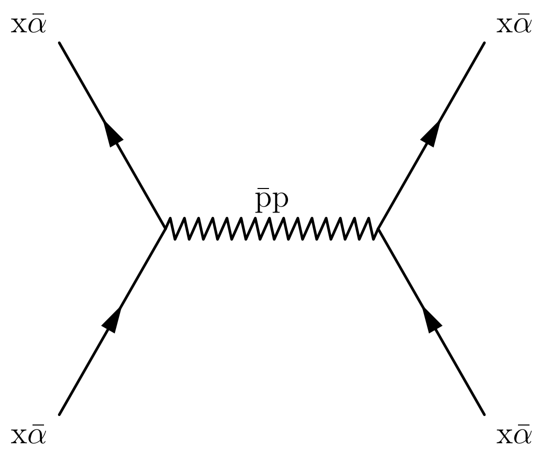
Hence, W^- is as expected identified as in the haplon model, $\mathrm{W}^- = \bar{\alpha}\beta$, and thus trivially $\mathrm{W}^+ = \alpha\bar{\beta}$. Electron pair scattering happens similarly with the Z boson or photon as force propagator, $\mathrm{e}^- + \mathrm{e}^+ \to \mathrm{e}^- + \mathrm{e}^+$, or $\mathrm{x}\bar{\alpha} + \bar{\mathrm{x}}\alpha \to \mathrm{x}\bar{\alpha} + \bar{\mathrm{x}}\alpha$,





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where $\bar{\mathrm{p}}\mathrm{p}$ is a preon-antipreon pair. To reproduce the spin 1 nature of the vector bosons, this must thus be a pair of fermionic preons. Thus again this model is like the haplon model, and we will declare

$$\mathrm{W}^3 = \frac{\alpha\bar{\alpha} + \beta\bar{\beta}}{\sqrt{2}} \,, \quad \mathrm{B}^0 = \frac{\alpha\bar{\alpha} - \beta\bar{\beta}}{\sqrt{2}} \,, \tag{4.4}$$

where W^3 and B^0 are related to Z^0 and γ through the Weinberg angle as in Equation (1.2). This makes this five-preon model effectively an extension of the haplon model into all three generations of quarks and leptons.

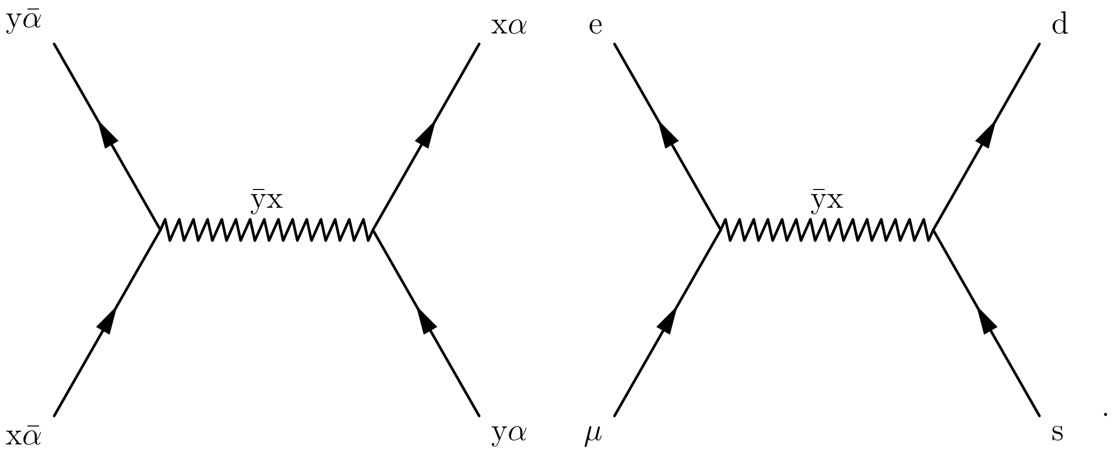
It is convenient to consider only pairs of preons. Three preon combinations like $\alpha\alpha\alpha$ and x$\alpha\beta$ will only add complexity, and we will not treat those combinations in this thesis. This is a toy model and treatment of all posibilities of preon combinations is not necessary. One way to get only pairs of preons at the observed energies is to postulate that all our preons are found in a 2 representation of hypercolor SU(2); that way they will mainly form colorless pairs, as well as colorless hadrons, of higher orders of complexity. As $\bar{2} = 2$, this would let preons and antipreons form all kinds of pairs. We will not elaborate on this in this paper.

4.3 Scalar boson complexes

Nothing so far has been said about the combinations of two bosons in this model. This is the same problem as in the haplon model, what happens to the chargeless and color $1 \oplus 8$ combinations of bosons like x$\bar{\mathrm{x}}$ and x$\bar{\mathrm{y}}$, or the charged and color $3 \oplus \bar{6}$ combinations like xx and xy?

The color singlet b$\bar{\mathrm{b}}$ where b = (x, y, z) should behave just like the known scalar or vector bosons in interactions, and as a color singlet it should be visible at energies lower than the color cutoff. Such bosons may be heavier than what we have experimentally probed so far, but we need to explain why that is. It seems that the mass differences can appear in the combinations of the preons. That is, antifermion/boson makes the lightest particles, then fermion/boson pairs are heavier, then antifermion/fermion and on top is the antiboson/boson pairs. the fermion/fermion and boson/boson pairs are so far unidentified, as they will be color triplets or antisextets we can assume these combinations do not appear until higher energies.

Still, the bare existence of the antiboson/boson pairs will yield interactions like



We will call this kind of bosons generation carriers in this paper. This interaction is similar to that of the X bosons from Pati and Salam's models, this predicts a $K^0 \to \mu^+ + e^-$ and $K^0 \to \mu^- + e^+$, which has not been observed.

The observed Higgs boson seems to be a spin 0 particle [19]. It is colorless and flavorless, and is known to appear from the annihilation of a W^- and a W^+. In our model, this reaction reads $\alpha\bar{\beta} + \bar{\alpha}\beta \to p\bar{p}$. When p is a super position of alpha and beta, we get EM radiation and/or a Z boson. However, p should also be able to be a super position of x, y and z, which must be the Higgs boson. This combination yields a color $1 \oplus 8$ as well as a flavor $1 \oplus 8$, and the singlet of both flavor and color is

$$\mathrm{H}^0 = \sum_{c=\{r,g,b\}} \frac{\mathrm{x}_c\bar{\mathrm{x}}_c + \mathrm{y}_c\bar{\mathrm{y}}_c + \mathrm{z}_c\bar{\mathrm{z}}_c}{3} \,. \tag{4.5}$$

4.4 Alternative charge scheme

In the previous section we let αb create the up quark family and $\bar{\alpha}$b create the electron family. There are two ways of assigning the fermions; we can let αb create the up quark family and $\bar{\alpha}$b create the *neutrino family*. Our table of basic fermion preon pair assignments becomes as follows

	α	β	$\bar{\alpha}$	$\bar{\beta}$
x	u	d'	ν_{e}	e^-
y	c	s'	ν_μ	μ^-
z	t	b'	ν_τ	τ^- .

TABLE 4.3: A preliminary second assignment of preons to basic fermions

Solving the charge problem, we see that an α preon making u and ν_e with x yields the equations

$$\begin{aligned} Q_x + Q_\alpha &= Q_{\mathrm{u,\,c,\,t}} = +2/3 \\ Q_x - Q_\alpha &= Q_\nu = 0 \\ \implies Q_x &= Q_\alpha = +1/3\ . \end{aligned} \tag{4.6}$$

Repeating the process for the β preon making $(\mathrm{x}\beta) = \mathrm{d}$, $(\mathrm{x}\bar{\beta}) = \mathrm{e}^-$ gives

$$Q_x + Q_\beta = Q_{\mathrm{d}} = -1/3, \quad Q_x - Q_\beta = \mathrm{e}^- = -1 \implies Q_x = -2/3 \neq +1/3\ , \tag{4.7}$$

so we need to change things. It turns out we can simply change the lepton families for their charge conjugates, and we get

	α	β	$\bar{\beta}$	$\bar{\alpha}$
x	u	d	e^+	$\bar{\nu}_{\mathrm{e}}$
y	c	s	μ^+	$\bar{\nu}_\mu$
z	t	b	τ^+	$\bar{\nu}_\tau$.

TABLE 4.4: Second assignment of preons to basic fermions

Equation (4.6) stays valid as $Q_\nu = Q_{\nu^c} = 0$ and the quark columns are unchanged. We get from the second set of equations that

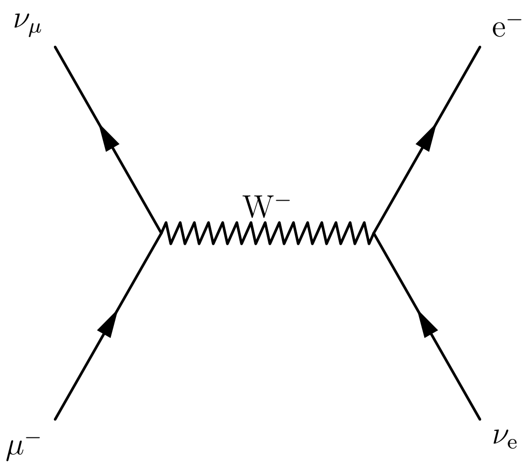
$$Q_x + Q_\beta = Q_{\mathrm{d}} = -1/3, \quad Q_x - Q_\beta = Q_{e^c} = +1 \implies Q_\beta = -2/3, \quad Q_x = 1/3\ . \tag{4.8}$$

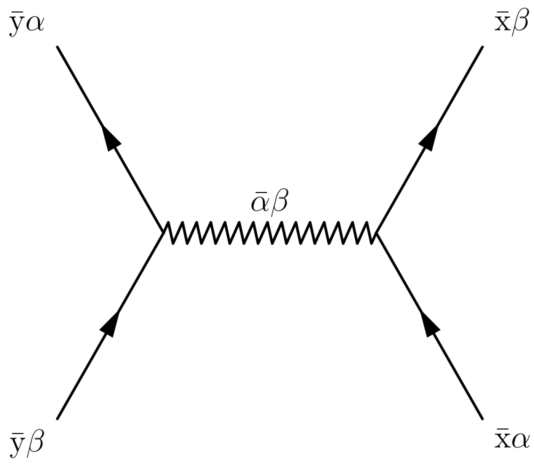
This is thus the only other legal charge assignment for our five preon model, and yields the preon charges and colors as shown in the following table,

	Q	$SU(3)_c$
α	$+1/3$	$\bar{3}$
β	$-2/3$	$\bar{3}$
x, y, z	$+1/3$	$\bar{3}$

TABLE 4.5: Preon charge and color, second assignment

From Table 4.4 we see that the x, y and z particles still define generations, and the Higgs boson is still the spin 0 colorless $\sum_c \frac{x_c\bar{x}_c+y_c\bar{y}_c+z_c\bar{z}_c}{3}$. The W^3 and B^0 bosons are trivially the same as for the other configuration as they are spin 1 bosons which carry no other quantum numbers. To see what happens with the W, we take a look at the μ–decay again





As we see, the charged weak gauge bosons are also the same as in the first assignment.

4.5 Weak isospin and hypercharge

So far, this model has not yet obtained the $SU(3)_c\times SU(2)_L\times U(1)_Y$, the problem being that it still doesn't show any distinction between right handed and left handed particles. Let us explore this further by finding what kind of weak isospin SU(2) representations our preons will sit in. Let's recreate Table 4.4, but with only the left handed basic fermions. As x, y and z are bosons, they don't exhibit handedness, and the handedness must sit in the fermionic preons. We can get only left handed fermions by changing $\bar{\alpha}$ and $\bar{\beta}$ to the left handed charge conjugates $(\alpha^c)_L$ and $(\beta^c)_L$. Now the left handed preon assignment table now becomes

	α	β	β^c	α^c
x	u	d	e^c	ν_e^c
y	c	s	μ^c	ν_μ^c
z	t	b	τ^c	ν_τ^c .

TABLE 4.6: Assignment of preons to left handed basic fermions

We will need to break this down further, so we will treat only one generation in the rest of this chapter. First off the x boson has no spin, and sits in a weak isospin singlet. The weak isospin part of any observed fermion thus depends on the isospins of α and β and their charge conjugates. Now, the Q doublet follows trivially to a P doublet, where

$$P = \begin{pmatrix} \alpha \\ \beta \end{pmatrix} . \tag{4.9}$$

To discover the spin properties of the rest, let's make a table of all sixteen left handed particles as known from Table 1.2 where u = [u_r,u_b,u_g] and similarly for d'

	α	β	β^c	α^c
x	u	d'	e^c	ν_e^c
$\bar{x}$	ν_e	e	d'^c	u^c

TABLE 4.7: Left handed basic fermions of the first generation

and their charge conjugates. We see now that α^c and β^c must be SU(2) singlets, while the P doublet actually also covers the SU(2) L doublet. Let's further take a look at the hypercharge of our preons. Hypercharge is additive, so referring to table 1.2 we get for our model

	$-1/3$	$-1/3$	$4/3$	$-2/3$
$2/3$	$1/3$	$1/3$	2	0
$-2/3$	-1	-1	$2/3$	$-4/3$

TABLE 4.8: Hypercharge of particles from Table 4.7

Now it is obvious that the observable $W^\pm$ consists of left handed αs and βs, and right handed $\bar{\alpha}$s and $\bar{\beta}$s. This is an important result, and should be investigated further. W^3 also only couples to the left handed preons and their antipreons, but B^0 does not face these restrictions, as it is the generator for the $U(1)_Y$. Thus, the

B^0 needs to be extended to a superposition of $\alpha\bar{\alpha} + \beta\bar{\beta} + \alpha^c\bar{\alpha}^c + \beta^c\bar{\beta}^c$, and so our photon and Z boson must have a more complex relationship.

Chapter 5

Conclusion

In this thesis, we have described some shortcomings of the standard model, and we have explored different preon models in light of this.

We have seen that preon models deal with the asymmetry of right and left handedness in different ways. The helon model extends the rishon model in a way that incorporates only left handed neutrinos through a topological distinction between right and left handedness in the preons. In this model, only the known fundamental fermions with their observed handedness appear. The new five preon model presented in this thesis identifies the quantum numbers of its preons and shows that by differentiating between the right and left handed fermionic preons, the choice of weak vector bosons can be limited schematically in a way that only permits the observed interactions. The Pati-Salam model also answers this question, but permits right handed neutrinos that interact weakly through a second and much heavier set of weak gauge bosons.

None of the preon models properly explain the differences in particle masses, but some statements can be made. The trinity preon model attempts to do this through dipreon composites and their δ preon which is superheavy as a single preon but not in a dipreon composition, this would explain why observed leptons in general are lighter than the heavies quarks. Although mass inside each generation is not explained by the five preon model, the generation structure is clearly shown to be grounded in the three generation bosons, and increasing masses of these bosons explains increasing masses through the generations in each family.

The parameters of SM is reduced in most preon models. The trinity model makes a connection between the first Cabibbo angle and the weinberg angle through a mixing of the α and β preons. By using composite weak gauge bosons, the number of coupling constants should be reduced, and all preon models discussed successfully reduces the number of fundamental particles, so it is reasonable to assume that successfull dynamical calculations will yield less arbitrary masses than the standard model. However, adding hypercolor like the haplon model does will add more parameters.

The Pati-Salam attempts to get rid of the fundamentally fractional charges through dismissing the $U(1)_Y$ abelian group. The helon model creates two new quantum numbers to replace weak isospin and hypercharge in terms of calculating Q. Other preon models simply extend the problem of fractional charges to the preons. Neither the helon nor the trinity model deal with photonic preon combinations. In general, the Pati-Salam models suffers from a continuous lack of evidence for the right handed weak interaction group $SU(2)_R$, as does the new five preon model's generation carriers. The preon trinity model and the five preon model looks promising, but they lack generally dynamics.

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