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An Extension of the Rishon Model

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I. INTRODUCTION

We present an extension of the Rishon Model of Harari, et. al. [1] [2] [3] In that model, the first generation leptons and quarks are each made from three rishons of two varieties, T and V as follows: $\nu_e = VVV$, $\underline{e}^+ = TTT$, $\underline{d} = TVV$, and $u = TTV$.

In addition to the original rishons and their anti-rishons $\underline{T}$ and $\underline{V}$, we introduce the dark rishon X and its anti-rishon $\underline{X}$; all have spin 1/2. The old and new rishons, their hypercolor H, color C, and charge Q are:

Rishon	H	C	Q/e
T	3	3	+1/3
V	3	$\underline{3}$	0
X	3	$\underline{3}$	0
$\underline{T}$	$\underline{3}$	$\underline{3}$	−1/3
$\underline{V}$	$\underline{3}$	3	0
$\underline{X}$	$\underline{3}$	3	0

The new rishon has no electro-weak interaction. We suggest that it may serve a dual role: First, at the elementary particle level, as a way to understand the masses of higher generations of leptons and quarks. Second, at the cosmological level, as the source of dark matter. [4]

The three rishons TTT in $\underline{e}^+$ are presumed to be in relative S-orbital states with total spin up or down. These two combinations can be in a relative S-state of total spin zero; they can form a $(6T)_{1s}$ state that can be considered a closed shell (think of the two electrons in the lowest shell in the ground state of most atoms). Of course, no such bound particle (spin 0, charge 2e, mass $2m_e$) has been observed, presumably because of Coulomb repulsion; the state only exists as a two $\underline{e}^+$ S-state.

The same statements can be made about the three rishons VVV in ν_e and the corresponding $(6V)_{1s}$ state, except with regard to the possible existence of a bound particle (spin 0, charge 0, mass $2m_\nu$) - imagine trying to detect such a particle. Of course, some type of weak repulsion could prevent such a bound state.

Similar statements can also be made about a particle made from the three rishons XXX (we call it ν_X) and the corresponding $(6X)_{1s}$ state, except that such a bound particle (spin 0, charge 0, mass $2m_\nu$) can be imagined to exist - with fear and loathing - unless there is a 'dark-weak' repulsion to prevent it. However, such an entity can conceivably attach itself to a 1st generation quark or lepton via the strong (color and hypercolor) interaction.

We assume that the mass of XXX is comparable to that of VVV, i.e. slightly less than that of TTT, which includes electromagnetic energy due to charge; also, the mass of $(6X)_{1s}$ is roughly twice the mass of XXX .

II. PRELIMINARIES:

A. Spherical Square Well Excitation Energies

Before attempting to characterize the higher generations, let's outline the crude model we will use. First, we note that a spherically symmetric potential well of depth 50 MeV has the same ordering of its energy levels above the bottom of the well as the lowest levels of a well of infinite depth - namely $1s$, $1p$, $1d$, $2s$, $1f$, $2p$, and $1g$. Furthermore, the values of the energy levels and excitation energies of the former are roughly 70% to 75% of the latter. For a deeper well the percentage would be higher and more states would be included. The excitation energies (above the 1s ground state) for the well of depth 50 MeV are 7.76, 17.22, 21.83, 28.80, 35.17, and 41.23 MeV, respectively, while those for the infinite well are 10.32, 23.34, 29.61, 38.96, 49.81, and 57.09 MeV. The bound states of the finite well of depth 50 Mev don't go beyond $1g$, while those of the well of infinite depth continue indefinitely with the order $2d$, $1h$, $3s$, $2f$, $1i$, $3p$, $1j$, $2g$, and so on.

We will use the energies of such wells as a guide to which states of the X rishon to include to get a reasonable estimate of the masses of the leptons and quarks, except in the case of the t quark. Better estimates will require calculations with more realistic spin-dependent potentials or interactions, perhaps deduced from field theoretic treatments of color and hypercolor.

B. Masses:

Masses of the higher generations are provided mainly by the total excitation energy of the Xs in higher shells. As indicated, second and third and, if needed, possibly higher generation leptons and quarks are given added mass by the filling of one or more subshells, each of which contains $6(2l+1)$ X rishons (or $\underline{X}$ rishons, but not both).

We used an energy level scheme - for the X rishons, at least - analogous to that of the 'Nuclear Shell Model', but ignoring - for now - possible spin-orbit splitting. Thus, the subshells (number of states) for each color and hypercolor of rishon, in order, are: $1s(2)$, $1p(6)$, $1d(10)$, $2s(2)$, $1f(14)$, $2p(6)$, $1g(18)$, etc. When color and hypercolor are included, the number of of Xs must be tripled to get color and hypercolor singlets in the subshell and to avoid a fermion subshell with 3 Xs. Altogether, the number of Xs needed to fill a subshell are: $1s(6)$, $1p(18)$, $1d(30)$, $2s(6)$, $1f(42)$, $2p(18)$, $1g(54)$, etc.

Using the excitation energies for the well of depth 50 Mev together with the number of X rishons in a filled subshell, we find the following total excitation energies:

Combination	Excitation Energy
$(6X)_{1s}$ [or $(6\underline{X})_{1s}$]	0 MeV
$(6X)_{1s}(18X)_{1p}$	140 MeV
$(6X)_{1s}(18X)_{1p}(30X)_{1d}$	656 MeV
$(6X)_{1s}(18X)_{1p}(30X)_{1d}(6X)_{2s}$	787 MeV
$(6X)_{1s}(18X)_{1p}(30X)_{1d}(6X)_{2s}(42X)_{1f}$	1,997 MeV
$(6X)_{1s}(18X)_{1p}(30X)_{1d}(6X)_{2s}(42X)_{1f}(18X)_{2p}$	2,630 MeV
$(6X)_{1s}(18X)_{1p}(30X)_{1d}(6X)_{2s}(42X)_{1f}(18X)_{2p}(54X)_{1g}$	4,856 MeV

which is as high as we can go with the finite well. This table gives us an idea as to how the higher generation masses could be explained; it helps explain some of the choices we make below. We have used the X rishons only in the role of filling closed subshells within higher generations, because of the relative inertness of such structures.

C. The Three Generations:

We do not believe that our selection of X subshell assignments for the higher generations of leptons and quarks - as given below - will turn out to be the final ones, when the analysis is taken beyond the crude square well potentials we have used here and without the spin-orbit interactions that are so crucial to the success of the Nuclear Shell Model. We present them here merely to show that reasonable estimates of their masses can be achieved with the introduction of the X rishon. We do believe that a more realistic and accurate treatment of the interaction can produce masses that are close to what is observed.

Each 'elemental' particle (an antiparticle is underlined - e.g., $\underline{e}^+$ is the positron, while ν_e is the electron-neutrino), the accepted value of its mass, and its possible rishon composition is listed in the following tables:

Leptons $(H,C)=(1,1)$	Mass c^2	Composition
ν_e	< 2.2 eV	VVV
$\underline{e}^+$	0.51 MeV	TTT
ν_μ	< 0.17 MeV	$VVV(6\underline{X})_{1s}$
$\underline{\mu}^+$	105 MeV	$TTT(6X)_{1s}(18X)_{1p}$
ν_τ	< 15.5 MeV	$VVV(6X)_{1s}$
$\underline{\tau}^+$	1,777 MeV	$TTT(6\underline{X})_{1s}(18\underline{X})_{1p}(30\underline{X})_{1d}(6\underline{X})_{2s}(42\underline{X})_{1f}$

and their antiparticles.

In addition to the usual leptons are some new ones:

Dark Leptons $(H,C)=(1,1)$	Mass c^2	Composition
ν_X	unknown	XXX
ν'_X	unknown	$XXX(6X)_{1s}$
et cetera	...	...

and their antiparticles.

The following table gives the accepted values for "current quark" masses ($u, \underline{d}, \underline{s}$) and "running" masses ($c, \underline{b}, t$):

Quarks (H,C)=(1,3 or $\underline{3}$)	Mass c^2	Composition
$\underline{d}$	4.1-5.8 MeV	TVV
u	1.7-3.3 MeV	TTV
$\underline{s}$	101 MeV	$TVV(6\underline{X})_{1s}(18\underline{X})_{1p}$
c	1,270 MeV	$TTV(6X)_{1s}(18X)_{1p}(30X)_{1d}(6X)_{2s}$
$\underline{b}$	4,200 MeV	$TVV(6X)_{1s}(18X)_{1p}(30X)_{1d}(6X)_{2s}(42X)_{1f}(18X)_{2p}(54X)_{1g}$
t	172,000 MeV	$TTV(6\underline{X})_{1s}(18\underline{X})_{1p}(30\underline{X}_{1d}(6\underline{X})_{2s}(42\underline{X})_{1f}(18\underline{X})_{2p}(54\underline{X})_{1g}\cdots[?(6\underline{X})_{6s}]$

and their antiparticles. Since we will be concerned only with the mass differences between particles in different generations, we suspect that the actual mass difference between the s quark and the d quark is roughly 190 MeV, as deduced from the $\Xi - N$ mass difference.

In addition to the fermions - old and new - described above, there are possible new bosons:

Dark Bosons (H,C)=(1,1)	Mass c^2	Composition
β_X	unknown	$(6X)_{1s}$
β'_X	unknown	$(6X)_{1s}(18X)_{1p}$
et cetera	...	...

One might ask why a higher generation lepton or quark in our scheme doesn't spontaneously decay into a lower one by shedding some or all of its X subshells. The only answer we can offer at present is that perhaps the energetics won't allow it; e.g., it may be that Mass$[(TTT)(6X)_{1s}(18X)_{1p}]$ < Mass$[(TTT)]$ + Mass$[(6X)_{1s}(18X)_{1p}]$.

Note that we consider the $\underline{s}$ quark to be $TVV(6\underline{X})_{1s}(18\underline{X})_{1p}$, and not $TVV(6\underline{X})_{1s}$, partly because the latter would have approximately the same mass as the $\underline{d}$ quark (TVV) and would be practically indistinguishable from it. Here we choose not to discuss the possibility of two nearly degenerate $\underline{d}$ quarks.

III. SOME OBSERVATIONS:

The extended rishon model has dark leptons and dark bosons with $(H, C = 1, 1)$ - e.g., XXX and β_X, but not dark quarks with $(H, C = 1, 3$ or $\underline{3})$ – since $XX\underline{X}$ could convert into an X. In order to have dark quarks, one could introduce a second dark rishon X' with $(H, C = 3, 3)$; recall that X has $(H, C = 3, \underline{3})$. Then we could have dark quarks such as XXX' with $(H, C = 1, \underline{3})$ and $XX'X'$ with $(H, C = 1, 3)$ - and, therefore, dark baryons made of three dark quarks. We see no need to add a fourth rishon at this time; it would be useful only if dark baryons or atoms are found to exist or are otherwise required by theory. Besides, a model based on a trio of threes - three hypercolors, three colors, and three rishons - has a certain appeal.

The list of all ten 3-rishon states, i.e. all hypercolor singlets, is:

TTT	$\underline{e}$
TTV	u
TTX	c ?
TVV	$\underline{d}$
TVX	$\underline{s}$?
TXX	$\underline{b}$?
VVV	ν_e
VVX	ν_μ ?
VXX	ν_τ ?
XXX	ν_X

The '?' indicates a possible alternative to the identification given above.

Note that while the list does include candidates for some of the 2nd and 3rd generation neutrinos and quarks, if closed X subshells are included to provide additional mass, it doesn't include $\underline{\mu}$, $\underline{\tau}$, or t.

As seen above, this alternative formulation of the 2nd and 3rd generation would incorporate VVX, and VXX for neutrinos and TTX, TVX, and TXX for quarks, which might avoid the use of the add-ons $(6X)_{1s}$ or $(6\underline{X})_{1s}$, etc. in some cases. However, this would also require a drastic revision of the weak interaction in the rishon model, which now relies on $W^+ = TTTVVV$ at its core.

IV. SOME DECAYS:

Anti-neutron decay in the original rishon model involves:

$$\underline{d} \rightarrow \underline{u} + \underline{e}^+ + \nu_e$$
$$TVV \rightarrow \underline{TTV} + TTT + VVV$$

However something different can happen in the beta decay of higher generations - dark matter can be released as 'missing mass'. In the following, terms appearing between '?' marks are intended to connote missing mass in some form.

Anti-mu decay is:

$$\underline{\mu}^+ \rightarrow \underline{e}^+ + \nu_e + \underline{\nu}_\mu$$
$$TTT(6X)_{1s}(18X)_{1p} \rightarrow TTT + VVV + \underline{VVV}(6X)_{1s} + ?(18X)_{1p}?$$

Note that '$?(18X)_{1p}?$' is more likely to be $(6X)_{1s} + (6X)_{1s} + (6X)_{1s}$.

One of the anti-tau decay modes is:

$$\underline{\tau}^+ \rightarrow \underline{e}^+ + \nu_e + \underline{\nu}_\tau$$
$$TTT(6\underline{X})_{1s}(18\underline{X})_{1p}(30\underline{X})_{1d}(6\underline{X})_{2s}(42\underline{X})_{1f} \rightarrow TTT + VVV + \underline{VVV}(6\underline{X})_{1s} + ?(18\underline{X})_{1p}(30\underline{X})_{1d}(6\underline{X})_{2s}(42\underline{X})_{1f}?$$

V. SOME POSSIBLE CONSEQUENCES OF THE X RISHON:

As noted, the original rishon model of the charged weak boson has $W^+ = TTTVVV$. Now the possibility exists that the W^+ is a superposition of states that also involve X rishons, such as $TTTVVV(6X)_{1s}(18X)_{1p}(30X)_{1d}\cdots$; this might shed some light on the W^+ mass.

An exciting possibility that emerges from this idea is the possiblity of 'beams' of dark matter coming from the decays of higher generation fermions – much in the same way as 'beams' of neutrinos are made. The result of such collisions could produce known particles via color/hypercolor interactions or another - as yet unknown - interaction of dark rishons.

[1] H. Harari, 'A Schematic Model of Quarks and Leptons', Physics Letters 86B (1979), 83-86; a brief introduction to Harari's rishons, an early paper.

[2] H. Harari and N. Seiberg, 'A Dynamical Theory for the Rishon Model', Physics Letters 98B (1981), 269-273; a more elaborate discussion of Rishons, including 'color' and 'hypercolor'.

[3] H. Harari and N. Seiberg, 'The Rishon Model', Nuclear Physics B204 (1982), 141-167; an even more elaborate discussion - including 'handedness'.

[4] The inspiration for the Rishon Model (or at least for the names of its elements) is Genesis 1.2, which begins "The earth was without form and empty," where, T (ת) stands for Tohu (תהו , without form) and V (ב) stands for Vohu (בהו , void or empty). A more complete reading is, "The earth was without form and empty, with darkness ...". Thus, similarly inspired, we introduce the dark rishon X (ח) ('Voiceless velar fricative' X) for choshech (חשך, darkness). (X as *ch* in Scots lo*ch*, or X as *ch* in German a*ch*, or X as *ch* in Hebrew *ch*oshech. In close proximity with other people, however, it may be best to just call it 'ex').