Fourth Generation fermions providing new candidates for Dark Matter and Dark Energy
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Abstract
Clifford Unification describes all known elementary fermions and their interactions, providing a useful tool in the analysis of experimental data. It also predicts the existence of a stable fourth generation (G4) of fermions, with electric charges different to their first, second and third generation counterparts. This makes neutral G4 baryon and neutral G4 lepton composites possible, respectively providing candidates for Dark Matter and Dark Energy, which are examined in the light of experimental evidence.

§1. Introduction
Clifford Unification [1] has been shown to describe the properties of all three known generations (G1-G3) of fermions. It also predicts the existence of a currently unobserved, fourth generation (G4), which carry electronic charges that are all different to those of the corresponding G1-G3 fermions. However, the very existence another generation of fermions has long been rejected by particle physicists because of the lack of experimental evidence.

At the same time, there is considerable astrophysical evidence for the existence of very large amounts of ‘Dark Matter’ (DM) and ‘Dark Energy’ (DE) in galactic and inter-galactic space. To date, DM has only been observed through its gravitational effects, which shows it to consist of stable, electrically neutral particles. It has not been possible to positively identify either DM or DE with composites of G1-G3 fermions, or with any other particles described in the Standard Model of particle physics. Many attempts, based on sophisticated mathematical models, have been made to identify other candidates, but experimental evidence favouring any particular candidate has yet to be obtained [2-5]. It therefore remains possible that stable neutral composites of G4 fermions could provide candidates for DM and DE.

Considerable effort has been made to obtain the properties of DM and DE particles using earthbound experiments. Belyaev et al [6] interpreted disappearing tracks at LHC as absorption of particles by heavy DM, consistent with collisions with very heavy stable particles, but this interpretation has yet to be confirmed. Foot [7] suggested in 2013 that experimental data available at that time could be explained in terms of DM with two or more components. However, a 2021 analysis of the COSINE-100 experiments [8] has thrown doubt on this suggestion. Current attempts to observe DM, for example [9,10], are based on the assumption of specific properties that distinguish it from ordinary matter. So far no statistically significant results have been obtained.

§2 of this work contrasts the predicted properties of fourth generation fermions with the established properties of G1-G3 fermions. §3 examines the arguments for the non-existence of G4 fermions. §4 and §5 examine the properties of neutral stable G4 composites, and §6 estimates the numbers and masses of G4 fermions. §7 examines relationships between G4 fermion composites and existing experimental data concerning DM and DE. §8 summarizes the results of this work, its possible impact on the analysis and design of experiments, and the cosmological significance of Clifford Unification.
§2. Properties of the predicted fourth generation fermions

It was shown in [1] that all elementary fermions in the three known generations (G1-G3) are specified by seven primary quantum numbers, here labelled $A, B, C, D, E, F, G$, each taking the values $\pm 1$. Each quantum number is identified with the binary eigenvalues of one of seven commuting elements of the Clifford algebra $Cl_{7,7}$. All fermions have $B = 1$, and the anti-fermion corresponding to a specific fermion is described by reversing the signs of all seven quantum numbers. Elements of $Cl_{7,7}$ were also shown to describe all the known gauge field interactions between the fermions. Magnitudes of the charges on all G1-G3 fermions were shown in [1] to be given by $Qe$, where $e$ is the electronic charge, and

$$Q = \frac{1}{6}(D + E + X) - \frac{1}{2}(F + G + H),$$

(2.1)

where the $X = -DEB$ and $H = -FGC$.

The seven quantum number description of the G1-G3 fermions in [1] also describes two leptons and six quarks in the currently unobserved fourth (G4) generation. The table below (extracted from Tables 7.1, 8.1 and 8.2 of [1]), compares the primary quantum numbers of G1 and G4 fermions, showing that (2.1) predicts them to have very different charges. In particular, G4 leptons carry either two negative charges or a single positive charge: there are no G4 neutrinos.

| D + E + X | F | G | H | C | Q | Generation | Fermion |
|-----------|---|---|---|---|---|-----------|---------|
| -3        | -1| -1| -1| 1 | +1| G4        | l(1)    |
| -3        | 1 | 1 | -1| 1 | -1| G1        | $e^-$   |
| -3        | -1| 1 | 1 | -1| -2| G4        | l(-2)   |
| -3        | -1| 1 | -1| 1 | 0 | G1        | $\nu_e$ |
| 1         | 1 | 1 | 1 | -1| -4/3| G4      | q(-4/3) |
| 1         | -1| -1| 1 | -1| 2/3| G1       | u       |
| 1         | -1| -1| -1| 1 | 5/3| G4       | q(5/3)  |
| 1         | 1 | 1 | -1| 1 | -1/3| G1      | d       |

Neutrons (n) and protons (p) have the G1 quark structures $n \simeq uudd$ and $p \simeq uudd$, forming a doublet with the same electroweak interactions as the electron/neutrino doublet. The analogous G4 baryons $b(2), b(-1)$ are

$$n(0) = u(2/3)d(-1/3)d(-1/3) \leftrightarrow b(2) = q(-4/3)q(5/3)q(5/3),$$

$$p(1) = u(2/3)u(2/3)d(-1/3) \leftrightarrow b(-1) = q(5/3)q(-4/3)q(-4/3).$$

(2.2)

Hence there are no neutral G4 baryons analogous to G1 neutrons. The quantum numbers $D, E, B$ describing strong interaction gluons are the same for all four generations, suggesting that the gluon bonding of G4 quarks is similar to that for the G1-G3 quarks. However, in contrast to neutrons and protons, the G4 baryons $b(2)$ and $b(-1)$ are both subject to internal electrostatic bonding. Taking the mean inter-quark distance to be $r_0$, this can be estimated as $e^2[2(5/3)/(4/3) - (4/3)^2]/r_0 = (8/3)e^2/r_0$ for $b(2)$ and $e^2[2(5/3)/(4/3) - (5/3)^2]/r_0 = (5/3)e^2/r_0$ for $b(-1)$. This predicts $b(-1)$ and $b(2)$ to be more strongly bound than protons, adding to their stability, and making $b(2)$ more stable than $b(-1)$.

The charge difference between the components of G1-G3 fermion, quark and baryon doublets is a single electronic charge, whereas the corresponding charge difference between the components of G4 lepton, quark and baryon doublets is three electronic charges. It follows that the G4 weak interaction bosons ($W^\pm$) carry three electronic charges.
3. Why have no G4 fermions been observed?

The existence of G4 fermions is doubted by most particle physicists because of the clear experimental evidence provided in [11], p.36, Fig.1.13, that only three generations of neutrinos exist. However, this result was based on the assumption that G4 fermions would necessarily include neutrinos, and that the weak interaction has the same form for all four generations. As neither of these assumptions is correct for the G4 fermions predicted in [1], this is not relevant to their existence. Other evidence for the absence of G4 fermions has been based on estimates of G4 masses by extrapolating the known masses of G1-G3 fermions [12,13]. The fact that G4 fermions have different charges, and are predicted in [1] to be stable, makes it unlikely that such extrapolations are valid. There remains, of course, the question why they have not been observed, inevitably suggesting that they might be constituents of DM and DE.

4. G4 atoms and molecules.

G1 fermions form stable atoms, in which a central nucleus composed of protons and neutrons has its positive charge compensated by a surrounding cloud of electrons. Molecules, comprising many atoms with shared electrons, are also stable. Neutral G4 analogues of atoms and molecules could exist. For example, the hydrogen atom, consisting of a single electron \( e^- \) bound to proton (uud) nucleus has two G4 analogues:

1. a positively charged \( l(1) \) lepton bound to a negatively charged \( q(-4/3)q(-4/3)q(5/3) baryon nucleus and
2. a \( l(-2) \) lepton bound to a \( q(-4/3)q(5/3)q(5/3) baryon nucleus, which carries two positive charges.

The tightly bound G4 baryons are expected to be smaller than G1 baryons, which would make these G4 analogues more stable than hydrogen atoms. These and heavier G4 atoms, and their molecular structures, might well be stable, but would have observable spectra, making them unlikely candidates for DM.

5. Neutral G4 composites

The fact that both G4 baryons carry charges makes it possible for neutral G4 baryon composites to exist, with both electromagnetic and gravitational bonding making them far more stable than any atomic or molecular structure. These composites would be similar in size to G1 baryons, and have structures of the form \( x(b(2) + 2b(−1)) \), where \( x \) is any positive integer. Given that all baryons have spin 1/2, composites with odd values of \( x \) could be spin 1/2 fermions, while composites with even values \( x \) would be bosons with integral spins.

The \( x = 1 \) baryon composites have three components, which would have minimum energy as a linear chain, with the structure [\( b(−1) − b(2) − b(−1) \)]. This would have two high frequency stretching modes and a single, doubly degenerate, bending mode at much lower frequency. One, two and three dimensional \( x \gg 1 \) neutral baryon composites can be formed from combinations of the \( x = 1 \) composites. For example, a linear chain can be formed in which each \( x = 1 \) component is linked to another \( x = 1 \) component on either side. Larger composites would, of course, allow other vibrational modes. Three dimensional condensations with very high values of \( x \) could form (possibly crystalline) solids.

Neutral \( x[2l(1) + l(−2)] \) lepton composites, analogous to the baryon composites described above, might also be possible, but would be far larger and have weaker binding than their baryon counterparts. They would also have very low masses and be unlikely to bond strongly enough to form structures with \( x > 1 \).
§6. Spatial confinement of G1-G3 fermions.

Comparison of Tables 7.1, 8.1 and 8.2 of [1] shows that the algebraic relationship between fermions in the first three generations, and fermions in the fourth generation, is isomorphic with the relationship between quarks and leptons. Single quarks have never been observed outside nuclear matter, in accord with the finding in [1] that G1-G3 quarks are confined to nuclear spatial regions, called hadronic in [1]. Atomic matter, formed from G1 hadrons and electrons, occupies the whole of the leptonic regions of space. The isomorphism suggests that G1-G3 fermions are confined to spatial regions analogous with hadronic space, while G4 fermions occupy the whole of observable space.

The number of fermions in a finite universe must be fixed. Ordinary G1 atomic matter contains equal numbers of protons and electrons, so that there are three times as many quarks as there are electrons. This is consistent with the hypothesis, based on Table 7.1 of [1], that, in the absence of anti-fermions, there is a charge balance with equal numbers (say N) of $e^-, \nu, u$ and $d$ fermions giving $4N$ ordinary matter (G1-G3) fermions in all. Given the algebraic isomorphism described above, this argument can be extended to give a total number of G4 fermions equal to the sum of G1-G3 fermions. At sufficiently low temperatures these fermions will mostly be G1. It follows that there are $4N$ G4 fermions in all.

§7. Neutral G4 composites as Dark Matter and Dark Energy candidates

Galaxy halos [14] apparently contain considerable amounts of Dark Matter (DM), suggesting that they could be a gas of $x = 1$ G4 baryon composites, containing the observed solar systems and neutron stars within many small G1-G3 subregions. This would be a Fermi gas which, at the very low temperature of the cosmic microwave background, would have the special stability properties produced by Pauli blocking [15], making them difficult to observe. Nevertheless, it might be possible that the observed baryon acoustic oscillations [16,17] are produced by the low frequency internal vibrations of the G4 baryon composites described in §4.

It is difficult to understand the observed properties of black holes, especially the super-massive black holes [18], with masses of more than $10^6$ solar masses, that are thought to form galaxy nuclei. The overall DM to ordinary matter (OM) mass ratio estimated from astrophysical observations is thought to be about $m_{\text{DM}}/m_{\text{OM}} = 5$, suggesting that dark matter fermions have a similar size and approximately five times the mass their G1 counterparts. This gives an estimate of the masses of the $x = 1$ neutral baryon composites as $3 \times 5 = 15$ proton masses. It is therefore to be expected that even small clusters would form black holes. It also suggests a relatively simple process for the accretion of halo material by galaxy cores compared with current models [19-22].

Just as high energy electrons sometimes penetrate nuclei, it should also be possible for G4 fermion and boson composites to penetrate regions that are predominantly composed of observable matter. If the neutral bosonic particles have the $x = 1$ structure described above it would, in principle, be possible to separate them into their baryon components in collisions with G1 particles with sufficiently high energies. Such events might be observable as one of the G4 baryons carries two positive electronic charges.

At the present time there appears to be no direct experimental evidence relating to the properties of Dark Energy. However, the G4 lepton composite with $x = 1$, described in §5, suggests that it might interact with G1-G3 neutrinos, but this possibility has yet to be explored.

§8. Conclusions

At the present time there does not appear to be clear experimental evidence for, or against, the identification of DM or DE with the G4 candidates proposed in this work. However, experimental results are being obtained and analysed at an ever increasing rate, so it is hoped that reliable assessments of the new candidates proposed in this work can be made within the next few years. It is, of course, important to have clearly defined candidates to make focussed analyses of experimental data possible.

If the proposed G4 candidates are viable, this will validate the conceptual framework developed in [1], which is centred on the idea that fermion properties are determined by the substrate in which they are confined. This will make it necessary to consider the cosmological significance of Clifford Unification. In this context it is worth noting that [1] shows the positive time direction ($B = 1$) to be correlated with an expanding substrate. Anti-fermions have a negative proper time ($B = -1$), and a contracting substrate. This suggests that fermions and anti-fermions occupy different regions of space-time, so that large agglomerates of anti-fermions cannot occur in the observable universe.
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