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Lowest Energy State Mesons Made Up Of u and d Quarks Suggested As Dark Matter Particles

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Abstract: *The universe contains by mass ~ 5 % normal matter and ~ 24 % dark matter. The normal matter has approximately ~ 69.1 % nuclides of* H^1 *and ~ 30.9 % nuclides of He, which are made up of u and d quarks and were formed when the universe had cooled to approximately* 10^{12} *K. We propose that during this period u and d quarks,*$\bar{u}$ *and* $\bar{d}$ *antiquarks,and gluons combined to form three light mesons* $(u\bar{u})$, $(d\bar{d})$ *and* $(u\bar{u} + d\bar{d})/\surd 2$ *in most stable lowest energy quantum state (LES) with angular momentum* $l = 0$, *charge* $Q = 0$ *and spin* $s = 0$ *and isospin* $\boldsymbol{I} = 0$. *These light mesons* $(u\bar{u})$ *and* $(d\bar{d})$ *were formed by direct interaction among free, unconfined quarks, antiquarks and gluons in the quark – gluon plasma which filled a vast volume and lasted for a considerable time in the early universe. We suggest that these light mesons are the much sought after dark matter particles in universe. These light mesons* $(u\bar{u})$ *and* $(d\bar{d})$ *are not formed in a confined plasma of the size of a nucleus having volume ~* $1fm^3$ *because the quark composition in such cases is determined by the symmetry group of the system in accordance with the standard model of particle physics.*

***Key word** - Cosmology, Dark matter, Meson*

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I. Introduction

The term dark matter refers to a material in form of small particles which interact with one another and with the visible matter in the universe only via gravity. Many experimental studies on celestial objects since 1930 - such as the measurements of velocity of rotation of galaxies, rotational velocity of stars in the galaxies, gravitational lensing of background galaxies, computer simulations on formation of galaxies and galactic structure have led to the conclusion that the universe is filled with a large amount of dark matter. Dark matter is an important topic in cosmology and so many high sensitivity experiments have been set up, often under deep mines or ice, for detection of the dark matter particle (DMP). Some of the experiments which have been running for several years use, for example, crystals of Ge, Si, NaI(Tl) or liquid noble gas but none have so far found the DMPs. The particle collider experiments which make detailed analysis of the emitted radiation and charged particles have also not found the DMPs.

The dark matter is usually assumed to be some form of elementary particle. Candidatesfor non-baryonic dark matter are hypothetical particles such as axions, weakly interacting massive particles (WIMPs) and super-symmetric particles and some other particles. Neutrinos and primordial black holes (PBH) have also been suggested as candidates for DMPs. However, neutrinos because of their individual tiny masses can account for only a small fraction of dark matter. The observations on PBHs indicate that the PBHs are insufficient to account for the observed dark matter. Vast volume of experimental and theoretical work on the dark matter and related topics has been summarized by Tanabashi et al. [1-3]. These publications not only provide an up-to-date catalog of the ‘particle physics data’, but also have comprehensive articles on dark matter, mesons, standard model etc.

Quantitate estimate of different elements in the universe obtained by various techniques has been summarized by Weinberg [4]. Since 1998, the contribution of the baryonic matter, dark energy and dark matter in the universe has been deduced from the analysis of the cosmic microwave background radiation (CMB) and the line shift data on distant galaxies. The latest Planck collaboration CMB data [5] indicates that the universe has ~ 5 mass % baryonic matter, ~ 24 mass % dark matter and ~ 70 mass % dark energy, and that the neutrinos and radiation make very little contribution to it.

II. The early universe

We shall review some features of the quark gluon plasma produced after the cosmic big bang[6-8]. All models of cosmic inflation indicate that during the big bang the there is a large n e^n fold expansion of the space dimensions from initial size, say, 10^{-30} cm (which is $> l_{PL} = 10^{-33}$ cm) to about 1 meter. The big bang ends after ~ 10^{-36} s. During this expansion the temperature of the universe decreased from the singularity temperature ~

10^{30} K (which is < $T_{PL}10^{32}$ K) to, say, 10^{28} K. When the universe cooled from this temperature (10^{28} K) and expanded, the quark gluon plasma was formed in the temperature range 10^{15} to 10^{12} K, and the mesons and baryons were created in the range 10^{12} to 10^{9} K.

We use eqs. (15.11.3) and (15.11.4) from Weinberg [4] for an approximate estimate of R(T), the radius of the universe, and t(T), the time measured from the start of the big bang, as a function temperature T . These equations can be rewritten as

$R_2 = R_1(T_1/T_2)$ and $t_2 = t_1 (T_1/T_2)^2$.

We take the values at the start of the expansion of the universe (after the big bang) as $t_1 = 10^{-36}$s , R_1 = 1m and $T_1 = 10^{28}$ K. From the above equations one finds that for $T_2 = 10^{12}$ K, $R_2 = 10^{16}$ m and $t_2 = 10^{-4}$ s. Similarly, for $T_2 = 10^{9}$ K, one gets $R_2 = 10^{19}$ m and $t_2 = 10^{2}$ s. In this temperature range 10^{12} to 10^{9} K, large number of elementary particles, photons, quarks, antiquarks and gluons were created and occupied the universe. The mesons and baryons are formed from unconfined quarks and gluons in the plasma which occupied volume from 10^{48} – 10^{57} m^3 and lasted for several 100 sec.

The symmetry group constraints of the standard model of the particle physics apply to quark gluon plasma which is confined to a volume of ~ 1 fm^3. However these constraints do not apply to free, *unconfined* quarks and gluons. These plasma conditions made possible formation of mesons and baryons by direct interaction among the quarks, antiquarks and gluons in the early universe. Some mesons, which are the proposed dark matter particles are formed *only* in unconfined plasma.

Quarks and gluons in confined and unconfined plasmas

Strong interactions confine the quarks and gluons in mesons and baryons to asmall volume ~ 1 fm^3 . The standard model of particle physics which takes into consideration the symmetry group of the meson or baryon is applicable to such *confined* plasmas. This model gives the quark composition of the meson or baryon. In contrast to this, the quarks and gluons in the plasma of the early universe were *unconfined* and freely moved in the vast volume of the universe at that time. The quarks and gluons, in this plasma, when they were in close proximity also formed the mesons and baryons that are created in the confined plasma. Some additional the mesons and baryons were formed by direct interaction among the unconfined quarks, antiquarks and gluons. The restrictions of the standard model of particle physics are not applicable to unconfined quarks and gluons in plasma of the early universe which had volume many times 100m^3 which is >> ~ 1 fm^3, the volume of the confined plasma. Light meson ($u\bar{u}$) and ($d\bar{d}$) in their lowest energy quantum state (which are not allowed by symmetry considerations in a confined plasma) were formed in the unconfined plasma.

The process described above can be explained using an analogy. Consider large volume plasma comprising of protons and electrons. When this plasma cools, both hydrogen atoms and hydrogen molecules will be formed. Free protons will take up electron to form hydrogen atoms. In addition, hydrogen molecules will be formed when the electron orbitals of close adjacent hydrogen atoms overlap. Lowest energy state light mesons ($u\bar{u}$)and ($d\bar{d}$) are the analogs of the hydrogen atomwith electron in 1s orbital, while the meson of composition ($u\bar{u} + d\bar{d}$)/√ 2 is the analog of the hydrogen molecule.

III. Mesons as dark matter particles (DMP)

Dark matter is mostly in the form of particles which have no electrical charge (Q =0) and no magnetic spin (s = 0) but respond to gravity. This is corroborated by the failure to detect them in outgoing stream of particles produced in the particle collider experiments at CERN, Fermi Labs etc. Standard model of particle physics [2] provides a good understanding of the constituents of matter. According to the standard model, the matter is composed of leptons, mesons and baryons. The mesons and baryons are the confined states of quarks bound by gluons. The six quarks are u (0.0022), d (0.0047), c (1.275), s (0.095), t (173) and b (4.18). Approximate masses of these quarks in GeV/c^2 are given in parenthesis. Quarks u, c and t have charge + (2/3)e while d, s and b quarks have charge – (1/3)e. Here e is the charge of the electron. All the quarks have spin ½. There are six antiquarks $\bar{u}$, $\bar{d}$, $\bar{c}$, $\bar{s}$, $\bar{t}$ and $\bar{b}$which have same mass as that of the corresponding quark but have opposite sign for the charge and spin.

When, following the big bang, the universe cooled and the temperature was ~>10^{12} K, it was filled with quark gluon plasma containing many different quarks, antiquarks, radiations and gluons. As mentioned above, the quarks, antiquarks and gluons combined to form mesons and baryons. It is seen from the Particle Physics Tables [1] that the mesons and baryons which contain c, s, t or b quark are unstable. Due to this reason, no mesons and baryons remained which had any c, s, t or b quarks. At ~10^{12} K, u and d quarks formed, in nearly equal numbers, stable protons and neutrons which have quark composition (uud) and (udd) respectively. Though the proton to neutron ration increased steadily with decrease in temperature, ~ 10^{9} K sufficient number of neutrons and protons combined to form helium and other light nuclei [4].

The u and d quarks have charge – (2/3)e and (1/3)e respectively, and both have spin ½. The quarks and antiquarks u, d, $\bar{u}$ and $\bar{d}$in the early universe can combine to form mesons which are bound states of one quark and one antiquark, and have additive l = 0, charge Q = 0 and spin s = 0, which is the requirement for a DMP. The baryons cannot be DMPs because they contain three quarks each with spin ½ and their additive spin $s \neq 0$.

A $(q\overline{q'})$ meson is characterized not only by its quark content but also by its quantum state J^{PC} and isospin **I** [1]. The quantum flavors of quarks, namely, the angular momentum l, spin s, isospin **I** and charge conjugation $C = (-1)^{l+s}$ are additive. If the orbital momentum of the meson $(q\overline{q'})$ is l, then by definition, parity $P = (-1)^{l+1}$and so for l =0, P = -1 and for l =1, P = +1; and spin s = 0 for parallel spins and s = +1 for parallel spins. The meson spin J is $|l - s| < J < |l+s|$. Hence it follows that for the state with orbital momentum l =0 and s = 0, the flavors are J = 0, P = -1 and C = +1. Hence this state can be designated as $J^{PC} = 0^{-+}$.

We consider next light unflavored mesons having l = 0, s = 0 and **I** = 0 in and quantum state $J^{PC} = 0^{-+}$ formed by quarks and antiquarks u, $\bar{u}$, d and$\bar{d}$. The quarks and antiquarks u, $\bar{u}$, d and$\bar{d}$ also form, for instance, π mesons, ρ mesonsand ω^0 mesons that have higher quantum number, energy and mass. These mesons are unstable[1] - they decay into lighter mesons, elementary particles and radiation - and therefore are not suitable as candidates for DMPs. From the perspective of the DMPs we are interested only in highly stable mesons having l = 0, s = 0 and **I** = 0 in the lowest energy quantum state (LES)and are likely to be as stable as protons which were formed in the early universe.

We shall restrict discussion to two cases - isospin **I** =1 and **I** =0 Griffiths [9]. For **I** = +1, the z-component of isospin $\mathbf{I}_Z$ can take values be +1, 0 or -1. For confined quark gluon plasma, the application of SU(2) symmetry to (u, d) isomer pairleads to three meson states[9,10]. The first case with$\mathbf{I}_Z$ = +1 leads to π^+meson with quark content $(u\bar{d})$. It has charge Q = +1 and mean life is $(2.6)10^{-8}$ sec. The second case $\mathbf{I}_Z$ = 0 leads to π^0 meson which has Q = 0, quark composition $(d\bar{d} - u\bar{u} /\sqrt{2})$, rest mass ~ 139 MeV/$c^2$ and mean life of $(8.52)10^{-17}$ sec. The third case $\mathbf{I}_Z$ = -1, leads to the π^- meson which has Q = -1 and quark composition $(\bar{u}d)$; its mean life is $(2.6)10^{-8}$ sec. These mesons don't fulfill the requirements of the DM particles because of their short mean life time. Moreover, the charge Q of mesons π^+ and π^- is $\neq 0$.

In the second case, $J^{PC} = 0^{-+}$, **I** = 0 (and $\mathbf{I}_Z$ = 0) because isospins of the quark and antiquark are antiparallel. This leads to three mesons which are different from the π mesons, in particular from neutral π^0 meson, which have isospin **I** = 1. For confined quark gluon plasma, the application of SU(2) symmetryto (u, d) isomer pairfor **I** = 0 (and $\mathbf{I}_Z$ = 0)leads to one meson with quark composition $(u\bar{u} + d\bar{d})/\sqrt{2}$ [9,10]. This meson may also be formed in particle collider experiments wherein the quark gluon plasma is confined to a volume of ~ 1 fm^3 .We can term this meson as dark matter particle DMP 1. The other two mesons $(u\bar{u})$,DMP2, and $(d\bar{d})$ DMP3,with $J^{PC} = 0^{-+}$, **I** = 0 (and $\mathbf{I}_Z$ = 0), were formed by direct interaction among the respective free, *unconfined quarks and antiquarks and gluons in the early universe*. The properties of the quark gluon plasma of the early universe have been summarized in Section 2. These mesons $(u\bar{u})$ and $(d\bar{d})$ with$J^{PC} = 0^{-+}$, **I** = 0 (and $\mathbf{I}_Z$ = 0) will not be formed if the quark gluons and confined to a small volume of ~ 1 fm^3because of mixing of the u and d quark states. Consequently, DMP 2 and DMP3 will not be formed in the particle collider experiments.

When the temperature of the universe was ~ 10^{12} K, very large number of quarks and gluons, were in the quark gluon plasma. The u and $\bar{u}$ quarks, which were in large numbers in the plasma, had considerable time to interact with one-another and with gluons to form the $(u\bar{u})$ mesons in lowest quantum state $J^{PC} = 0^{-+}$ and I = 0. This process created large number of LES $(u\bar{u})$ mesons. A similar process also created large number of LES $(d\bar{d})$ mesonswith $J^{PC} = 0^{-+}$ and I = 0. The mixing of u and d quark under SU(2) symmetry for **I** = 0 made up LESmeson having quark combination ~ $(u\bar{u} + d\bar{d})/\sqrt{2}$. The u,$\bar{u}$, d and $\bar{d}$quarks and antiquarks also formed π mesons, ρ mesons and ω^0 mesons but these high energy state mesons in the early universe, being unstable, like many other mesons ad baryons, decayed and disappeared [3]. During this period, the unconfined plasma also produced from u and d quarks all the protons and neutrons that filled the universe. Hence when the universe cooled down, it had in addition to protons and neutrons, large number of LES $(u\bar{u})$, $(d\bar{d})$ and $(u\bar{u} + d\bar{d})/\sqrt{2}$ mesons in quantum state $J^{PC} = 0^{-+}$ and I = 0 , which have relevance as DMPs.

The fact that stands out is that, besides electrons, nearly all the 5 wt. % of matter in the universe contains protons and neutrons which are the bound states of u and d quarks when the temperature of universe decreased from ~10^{12} K to 10^9 K. We have suggested that that the dark matter particle mesons DMPs were also formed from quarks and antiquarks u, d, $\bar{u}$ and $\bar{d}$ along with the protons and neutrons and light nuclei. The dark matter particles are considered to contribute ~ 24% mass to the universe. It may be noted that since both protons and neutrons, and DMPs were formed in same environment out of u and d quarks and antiquarks, their mass contribution to the universe are comparable.

Light mesons, made up of u and d quarks show an increase in mass with increase in J and / or **I**. Their rest masses are as follows. π mesons with $J^{PC} = 0^{-+}$, I = 1 have mass ~ 139 MeV/c^2 ; ρ mesons with $J^{PC} = 1^{--}$ **I** = 1 have mass ~ 775 MeV/c^2, and ω^0 meson $J^{PC} = 1^{--}$, I =0 has mass ~ 782 MeV/c^2. If this trend continues, then the mesons in the LES with $J^{PC} = 0^{-+}$, **I** = 0, suggested here as the DMPs, would have mass < 139 $\mathrm{MeV/c^2}$, the mass of π^0 meson.

IV. Conclusion

We have mentioned that light mesons ($u\bar{u}$), ($d\bar{d}$) and ($u\bar{u} + d\bar{d}$)/√2 in LES state 0^{-+}, **I** = 0are expected to have mass < 139 $\mathrm{MeV/c^2}$. In some cases, the d quark decays into u quark. This transition, which is mediated by weak interaction, is responsible for the transformation of a neutron to proton. The weak interaction may transform meson ($d\bar{d}$) to a lighter meson ($u\bar{u}$) – a transformation which also conserves the baryon number. There can be other transformation channels as well. For the same reason, the stability of meson ($u\bar{u} + d\bar{d}$)/√ 2 is also not certain. Since the u quark is the lightest among all the quarks and it cannot transform to a meson of lower mass, LES meson ($u\bar{u}$) is likely to be as stable as proton. Therefore it may also be the most abundant DMP in the universe. These three mesons are not listed in the catalog of (experimentally) observed mesons [1,3]. The three proposed DMP mesons have not been detected in any experiment so far.

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