New Four-Element Theory of Nature

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This paper reviews the new four-element theory of nature, developed by the author for classically unifying all fundamental interactions of nature. Based on this theory, nature consists of only four fundamental elements, which are radiation (γ), mass (M), electric charge (Q), and color charge (C). Any known matter or particle observed in the universe and discovered in labs is a combination of one or more of the four fundamental elements, such as light is radiation only, neutron has mass only, Weyl fermion has electric charge only, gluon has color charge only, proton is a combination of mass and electric charge, and quark — a combination of mass, electric charge, and color charge. Fundamental interactions in nature are interactions among these fundamental elements. Radiation and mass are two forms of real energy as Einstein formulated. Electric and color charges are considered as two forms of imaginary energy. All the fundamental interactions are unified into a single interaction between complex energies. Interaction between real energies is the gravitational field force with three categories: mass-mass, mass-radiation, and radiation-radiation interactions. Interaction between imaginary energies is the gauge field force with also three categories: the electromagnetic force between electric charges, the strong force between color charges, and the weak force between electric and color charges. Interactions between real and imaginary energies are imaginary force, which have no observational support but may explain why charges are usually adhered on mass. As the weak force is an interaction between electric and color charges, it occurs effectively inside quark and causes quark excitation and decay. This leads the author to develop a new two-flavor multi-excitation quark model. This review gives details in various aspects and implications of the new four-element theory.

1 Introduction

Traditional four-element theory of nature, which was originated from Greek philosophy, posited that earth, air, fire, and water are the fundamental building blocks of all matter in nature. From the view of modern sciences, what are the fundamental elements of nature? It is well known that scientists have discovered one hundred and eighteen chemical elements in nature and from laboratory experiments, and listed them in the Mendeleev periodic table according to their chemical properties [1]. All the chemical elements can be also categorized into four groups: metals, nonmetals, metalloids, and noble gases or more specifically into eight groups by classifying metals into three types and separating the 113$^{\text{th}}$ though 118th elements as unknowns and the 7$^{\text{th}}$, 17$^{\text{th}}$, 35$^{\text{th}}$, 63$^{\text{rd}}$, and 85$^{\text{th}}$ elements as halogens. Elements, compounds, and mixtures are three typical types of matter in chemistry. Solids, liquids, and gases are three fundamental states of matter in physics. Ionized gases are usually called plasmas, the fourth state of matter. Almost all the normal or ordinary matter in the universe is in the plasma state.

Particle physicists have discovered over three hundred particle in nature and from laboratory experiments, and usually categorized them into hadrons and leptons according to whether they participate in the strong interaction or not, or into fermions and bosons according to whether they have half-integer spins or not [2, 3]. Hadrons are composed of quarks with six flavors, usually being grouped into three generations or families along with the six leptons [4,5]. The six quarks are up (u), down (d), charm (c), strange (s), top (t), and bottom (b). The six leptons are electron (e), muon (μ), and tau (τ) and their corresponding neutrinos (ν_e, ν_μ, ν_τ). In the standard model of particle physics, the twelve spin-1/2 fermions (i.e., six quarks and six leptons) are building blocks of matter, the four spin-1 bosons (γ, g, W and Z) are gauge force carriers, and the spin-0 Higgs boson is the particle mass giver. Including gravitons (the carriers of gravitational force) and all antiparticles, physicists have found or predicted fifty-seven fundamental particles and listed them in the particle table [6].

Both chemical elements and physical elementary particles are not fundamental elements of nature because they still have common properties. Nuclei of different chemical elements consist of different numbers of nucleons (protons and neutrons). Nucleons are combinations of quarks. Quarks are combinations of mass, electric charge, and color charge. Leptons and weak bosons have mass and/or electric charge. Gamma bosons are massless radiation, and gluon bosons are color charges. Considering these facts, the author proposed and developed a new four-element theory of nature [7, 8]. From the fundamental elements of nature to reveal a new quantum world of quarks, the author has recently proposed and developed a new quark model called two-flavor multi-

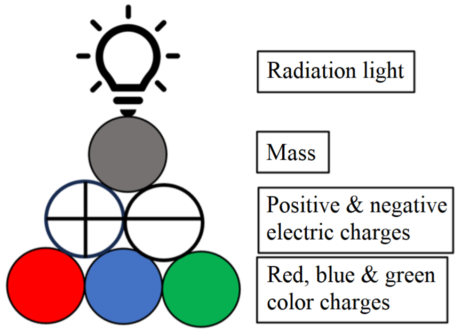

Fig. 1: Four fundamental elements of nature [7, 8]. They are radiation (γ), mass (M), electric charge (Q), and color charge (C). Radiation and mass are two forms of real energies. Electric and color charges are two forms of imaginary energies.

Table 1: Fundamental elements of nature. A particle is a combination of one or more of the four fundamental elements: mass (M), radiation (γ), electric charge (Q), and color charge (C).

Particles	γ	M	Q	C
Photon	✓			
Neutron		✓		
Weyl Fermion			✓	
Gluon				✓
Proton		✓	✓	
Massless Meson			✓	✓
Quark		✓	✓	✓

excitation quark model [9, 10], which has potential to solve both mysteries of why the present universe is significantly missing antimatter but fully filling with dark matter. This paper gives a sufficient review on this author's newly developed four-element theory of nature.

2 Fundamental elements of nature

The new four-element theory of nature suggests that nature consists of only four fundamental elements [7, 8], which are radiation (γ), mass (M), electric charge (Q), and color charges (C) as shown in Fig. 1. Any known matter or particle observed in nature or generated in labs is a combination of one or more of the four fundamental elements. For instances, as shown in Table 1, photon is radiation only; neutron has mass only; Weyl fermion has electric charge only; gluon has color charge only; proton is a combination of mass and electric charge; massless meson is a combination of electric and color charges; and quark is a combination of mass, electric charge, and color charge.

The author further categorized the four fundamental elements into two types of energies. Radiation and mass are two forms of real energy as Einstein formulated to be proportional to radiation frequency and mass, respectively, while electric and color charges are two forms of imaginary energy as the author formulated to be proportional to electric and color charges, respectively. Radiation energy is the energy of electromagnetic waves, propagating at the speed of light. Mass energy is the nuclear energy of an object or particle at rest or in motion. Real energy can do work in the real world and is measurable. A pure electric charge such as a Weyl fermion [11], as it is a form of imaginary energy, cannot be directly observed in nature, but its flow or current in semimetals has been detected [12]. A pure color charge such as a gluon [13], as it is a form of imaginary energy, cannot be directly observed in nature, but its behavior or existence has been detected in quark-gluon plasmas or jet events [14].

2.1 Mass — a form of real energy

Mass is a fundamental property of matter, which directly determines the gravitational interaction via Newton's law of gravitation [15]. Mass of an object is the quantity or amount of matter that the object contains. It is a measure of its inertia of motion in accordance with Newton's laws of motion. A body experiences an inertial force when it accelerates relative to the center of mass of the entire universe as Mach's principle indicates. In short, mass there affects inertia here. From Einstein's energy-mass expression (or Einstein's first law), mass is also understood as a form of real energy. A particle at rest with mass M has real energy given by [16]

$$E_M = Mc^2\,, \tag{1}$$

where c is the speed of light in the free space. A particle in motion, has mass to be the Lorentz factor of the rest mass, $\gamma_L M$, where $\gamma_L = (1 - v^2/c^2)^{1/2}$ and v the speed of the particle. This real energy is always positive and directly measurable. It cannot be destroyed or created but can be converted from one form to another. In nuclear fission and fusion processes, a small amount of missing mass converts into a huge amount of nuclear energy. Newton's second law of motion states that acceleration of an object is proportional to the net force on the object and inversely proportional to the mass of the object.

2.2 Radiation — a form of real energy

Radiation γ refers to the electromagnetic radiation (or light), consisting of varying electric and magnetic fields, and can travel through vacuum by itself at the speed of light, about 300 million meters per second. Light looks like a ray as it travels straightly. Isaac Newton believed light to be particle because of its reflection and refraction. Thomas Young suggested light to be wave because of its interference and diffraction. James Clerk Maxwell recognized light to be electromagnetic waves because they travel at the same speed. In quantum physics, radiation is described as photons, which are massless quanta of real energy. The energy of a photon is given by [17]

$$E_\gamma = h\nu\,, \tag{2}$$

where h is the Planck constant and ν is the radiation frequency. Radiation quanta or photons of light explain blackbody radiation spectra [18], atomic emission and absorption spectra [19], Compton photon-electron scattering [20], and photoelectric effects [17]. Therefore, we can say in general that radiation is also a form of real energy and always positive. An atom, when it changes its state from energy E_2 to energy E_1, emits a photon with frequency or energy given or determined by the energy difference, $h\nu = E_2 - E_1$.

According to the increasing order of frequency or the decreasing order of wavelength, physicists usually categorize electromagnetic waves into radio wave, microwave, infrared, visible light, ultraviolet, X-ray, and gamma ray. Oscillations of electrons and nuclei including protons produce radio waves and microwaves; thermal motions of electrons and ions produce infrared light; Orbital or energy changes of electrons in atoms emit visible light and ultraviolet. Sudden stops of high-speed electrons on targets produce X-rays; and nuclear reactions and decays produce gamma rays.

Annihilations between particles and antiparticles including quarks and antiquarks produce pairs of gamma rays. In a pair production process, a gamma ray materializes into a pair of particle and antiparticle with non-zero masses. Annihilation and pair production indicate that the two forms of real energies (i.e. mass and radiation) can convert from one to another, so that they are not independent. If we define an equivalent mass for radiation to be $m_\gamma = h\nu/c^2$, we may consider nature to be composed of three fundamental elements: mass, electric charge, and color charge, rather than fours, so that reduce the four-element theory of nature to a three-element theory of nature.

2.3 Electric charge — a form of imaginary energy

Electric charge is another fundamental or intrinsic property of matter or some particles, which directly determines the electromagnetic interaction via Coulomb's law of electric force [27]. Electric charge has two varieties of either positive or negative. It appears or is observed always in association with mass to form positive or negative electrically charged particles with different masses such as electron and proton. The interaction between electric charges, however, is completely independent of their masses. Positive and negative charges can annihilate or cancel out each other and produce in pair with total electric charges conserved. Weyl fermion is a massless electron, which was predicted a century ago and recently measured in semimetals but not individually [11, 12].

A pure or individual electric charge should have its own meaning of physics. Zhang [7] first hypothesized or considered electric charge Q to be a form of imaginary energy. The amount of imaginary energy is defined to be proportional to the charge as

$$E_Q = \frac{Q}{\sqrt{G}}\,c^2\,, \tag{3}$$

where G is the gravitational constant. This allows us to unify Newton's law of gravitation with Coulomb's law of electric force into a single expression between complex energy of electrically charged particles [7]. The imaginary energy has the same sign as the electric charge. Then, for an electrically charged particle, the total energy is

$$E = E_M + iE_Q = (1 + i\alpha)Mc^2\,, \tag{4}$$

where i is the imaginary number and α is the charge-mass ratio of the particle, defined by

$$\alpha = \frac{E_Q}{E_M} = \frac{Q}{\sqrt{G}M}\,, \tag{5}$$

in the cgs electrostatic unit system. The complex conjugate of the energy of a charged particle such as an electron gives the energy of its corresponding antiparticle such as a positron [21, 22].

Including electric charge, Zhang [7] has modified Einstein's first law (1) into (4), in which electric charge is expressed as imaginary mass or energy. For an electrically charged particle, the absolute value of α is a big number. This implies that an electrically charged particle contains much more imaginary energy than its real energy (e.g., $\alpha = 10^{18}$ for proton and $\alpha = -2\times10^{21}$ for electron). A neutral particle such as a neutron, photon, or neutrino has only real energy. Weinberg [23] suggested that electric charges come from the fifth-dimensional space, which is a small and compact circle space in the Kaluza-Klein (KK) theory [24–26]. Zhang has developed a five-dimensional fully covariant KK-theory with a scalar field [28] and shown that electric charge can affect light (i.e., electric redshift) and gravity (i.e., gravitational shielding) [29, 30].

As the energy of an antiparticle is simply obtained by conjugating the energy of the corresponding particle, a particle and its antiparticle have same real energy but imaginary energy with opposite sign. In a particle-antiparticle annihilation process, their real energies completely convert into radiation photon energies and their imaginary energies annihilate or cancel out. Since there are no masses to adhere with, the electric charges come together due to the electric attraction and cancel out, or form a positive-negative electric charge pair $(+,-)$. In a particle-antiparticle pair production process, the radiation photon energies transfer to rest energies with a pair of imaginary energies, which combine with the rest energies to form a particle and an antiparticle.

Real energy is continuous, while imaginary energy is quantized. Each electric charge quantum e (which is also proton's charge) has imaginary energy about $iE_e = iec^2/\sqrt{G} \sim i10^{27}$ eV about 10^{18} times greater than proton's real energy ($\sim$ 931 MeV). This ratio is about the ratio between the radius of proton and the radius of the circular fifth dimensional space.

Table 2: Properties of six quarks: name, symbol, and electric charge.

Name	Symbol	Mass	Electric Charges
up	u	2.4 MeV	$2e/3$
down	d	4.8 MeV	$-e/3$
charm	c	1.27 GeV	$2e/3$
strange	s	104 MeV	$-e/3$
top	t	171.2 GeV	$2e/3$
bottom	b	4.2 GeV	$-e/3$

Table 3: Color combinations between red, blue, green and their anti-colors.

Color	r	b	g	$\bar{r}$	$\bar{b}$	$\bar{g}$
r	$2r$	$\bar{g}$	$\bar{b}$	0	$r_{\bar{b}}$	$r_{\bar{g}}$
b	$\bar{g}$	$2b$	$\bar{r}$	$b_{\bar{r}}$	0	$b_{\bar{g}}$
g	$\bar{b}$	$\bar{r}$	$2g$	$g_{\bar{r}}$	$g_{\bar{b}}$	0
$\bar{r}$	0	$\bar{r}_b$	$\bar{r}_g$	$2\bar{r}$	g	b
$\bar{b}$	$\bar{b}_r$	0	$\bar{b}_g$	g	$2\bar{b}$	r
$\bar{g}$	$\bar{g}_r$	$\bar{g}_b$	0	b	r	$2\bar{g}$

2.4 Color charge — a form of imaginary energy

Color charge C is a fundamental property of quarks and gluons [36], which has analogies with the notion of electric charge of particles. The basic properties (mass and electric charge) of the six quarks are shown in Table 2. There are three varieties of color charges: red, blue, and green. An antiquark's color is anti-red, anti-blue, or anti-green. Quarks and antiquarks also hold electric charges but the numbers of electric charges to be fractional such as $\pm e/3$ or $\pm 2e/3$. An elementary particle is usually composed of two or more quarks or antiquarks and colorless with electric charge to be a multiple of e or neutral. For instances, a proton is composed of two up quarks and one down quark (uud); a neutron is composed of one up quark and two down quarks (udd); a pion meson π^+ is composed of one up quark and one down antiquark ($u\bar{d}$); a charmed sigma Σ^{++} is composed by two up quarks and one charm quark (uuc); and so on.

Similar to electric charge Q, the author has hypothesized or considered the color charge C to be another form of imaginary energy. The amount of imaginary energy in a color charge can be defined by

$$E_C = \frac{C}{\sqrt{G}}\, c^2\,, \tag{6}$$

in analogy to the electric charge for the grand unification of all fundamental interactions into a single interaction between complex energies [8]. Then, for a quark with mass M, electric charge Q, and color charge C, the total energy of the quark is

$$E = E_M + iE_Q + iE_C = (1 + i\alpha + i\beta)Mc^2\,, \tag{7}$$

where β is defined by

$$\beta = \frac{E_C}{E_M} = \frac{C}{\sqrt{G}M}\,. \tag{8}$$

The total energy of an antiquark is obtained by conjugating the total energy of its corresponding quark. A quark and its antiquark have the same real energy and equal amount of imaginary energy, but their signs are opposite. The opposites of red, blue, and green charges are anti-red, anti-blue, and anti-green charges.

2.5 Color neutrality and quark confinement

In particle physics, color is a fundamental property of quarks and gluons, related to the strong forces. It is not the visible color but a type of charge. A neutral or white color (i.e., zero color charge) is formed when (1) a color and its anticolor combine $C + \bar{C} = 0$), (2) red, blue, and green colors combine ($r + b + g = 0$), and (3) anti-red, anti-blue, and anti-green colors combine ($\bar{r} + \bar{b} + \bar{g} = 0$). Table 3 lists the colors formed when any two colors combine, such as red and red colors combine to form double red color, red and blue combine to form anti-green color, red and green colors combine to form anti-blue color, red and anti-red colors combine to form white color, red and anti-blue colors combine to form red-anti-blue color, and red and anti-green colors combine to form red-anti-green color, and so on. Color neutrality refers to that only color-neutral particles can exist in isolation or independently. Color confinement refers to that particles with colors or anticolors cannot be observed alone.

2.6 Energy space of particles

Both real and imaginary energies are conserved, respectively. Being only positive, a real energy cannot be created or destroyed but can be converted from one to another. In electron-positron annihilation process, mass is converted into radiation. In the pair production of a gamma ray, radiation is converted or materialized into mass. Being both negative and positive for electric charges and both color and anti-color for color charges, an imaginary energy can be canceled out or neutralized. Net charges in an isolated system remain the same. As mentioned in subsection 2.1 above, the two forms of real energies (mass and radiation) can be converted from one to another and thus not independent. Here, we believe, the two forms of imaginary energies (electric charge and color charge) are independent, but they can interact via the weak force.

Fig. 2 constructs a three-dimensional (3D) energy space for particles based on the three independent fundamental elements or energy components (mass, electric charge, and color charge). Any particle has a position or can be located in this 3D energy space with coordinates (M, Q, C) with $M > 0$. For instances, a neutral particle such as neutron and neutrino, in-

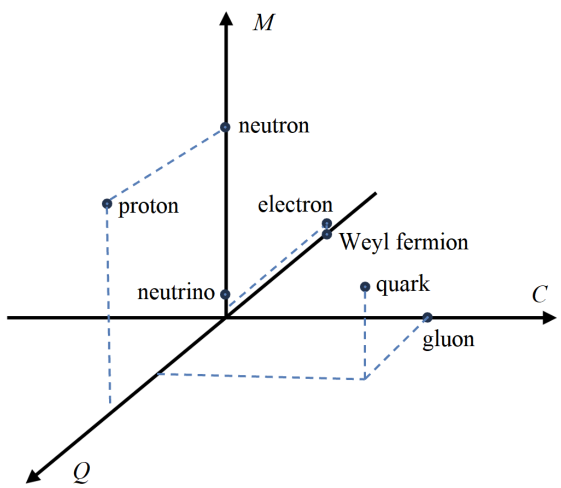

Fig. 2: 3D particle energy space. A neutral particle such as neutron or neutrino including radiation is found on the M-axis, a Weyl fermion is found on the Q-axis, a gluon is found on the C-axis, an electrically charged particle such as proton or electron is found in the $M-Q$ plane, and a quark is found in the 3D space with non-zero coordinates.

cluding radiation when it is equivalent to mass, has a coordinate $(M, 0, 0)$, located on the M-axis; an electrically charged particle such as proton and electron, located in the M-Q plane with a coordinate $(M, Q, 0)$; and a quark has a position in the 3D space with non-zero coordinates. Weyl fermions are on the Q-axis and gluons are on the C-axis. And so on for many other particles, including antiparticles, we can locate each of them with a unique set of coordinates in this 3D energy space of particles.

3 Fundamental interactions and unification

3.1 Fundamental interactions in nature

Fundamental interactions in nature are interactions among fundamental elements of nature. Among the four fundamental elements, there are ten fundamental interactions (Table 4). The three real forces ($\vec{F}_{MM}$, $\vec{F}_{\gamma\gamma}$, and $\vec{F}_{M\gamma}$) are interactions between two forms of real energies (γ and M) and belong to the gravitational forces. Another three real forces ($\vec{F}_{QQ}$, $\vec{F}_{QC}$, and $\vec{F}_{CC}$) are interactions between two forms of imaginary energies (Q and C) and belong to the gauge field forces, named, respectively, the electromagnetic, weak, and strong forces. The four imaginary forces ($i\vec{F}_{\gamma Q}$, $i\vec{F}_{\gamma C}$, $i\vec{F}_{MQ}$, and $i\vec{F}_{MC}$) are interactions between real and imaginary energies and have no direct measurements. Although these imaginary forces are not directly observational, they may play key roles in explaining why charges are always attached along with masses and absorb/emit radiation photons, and why gluons are adhesive. In physics, the fundamental interactions found in nature conventionally refer to the following fours: gravitational, electromagnetic, weak, and strong forces.

Table 4: Fundamental interactions among the four fundamental elements.

Name	γ	M	iQ	iC
γ	$\vec{F}_{\gamma\gamma}$	$\vec{F}_{\gamma M}$	$i\vec{F}_{\gamma Q}$	$i\vec{F}_{\gamma C}$
M		$\vec{F}_{MM}$	$i\vec{F}_{MQ}$	$i\vec{F}_{MC}$
iQ			$\vec{F}_{QQ}$	$\vec{F}_{QC}$
iC				$\vec{F}_{CC}$

3.2 Unification of all fundamental interactions

All the ten fundamental interactions among the four fundamental elements (two real energies and two imaginary energies) can be unified as a single interaction between complex energies as given by the following equation or shown by Fig. 3 [8]

$$\vec{F}_{E_1E_2} = -G\,\frac{E_1E_2}{c^4r^2}\,\hat{r}\,, \tag{9}$$

where G is the gravitational constant, E_1 and E_2 are complex energies of the two objects or particles, and r is the distance between the two objects or particles. This expression (9) may be called a generalized Newtonian gravitational law. Considering the complex energy of a general object or particle that has two real parts and two imaginary parts (i.e., $E_1 = E_{1\gamma}+E_{1M}+iE_{1Q}+iE_{1C}$ and $E_2 = E_{2\gamma}+E_{2M}+iE_{2Q}+iE_{2C}$), we can expand the single complex force into six real and four imaginary forces,

$$\begin{aligned}
\vec{F}_{E_1E_2} = & -G\,\frac{M_1M_2}{r^2}\,\hat{r} - G\,\frac{M_1h\nu_2 + M_2h\nu_1}{c^2r^2}\,\hat{r} - G\,\frac{h\nu_1h\nu_2}{c^4r^2}\,\hat{r} \\
& + \frac{Q_1Q_2}{r^2}\,\hat{r} + \frac{Q_1C_2 + Q_2C_1}{r^2}\,\hat{r} + \frac{C_1C_2}{r^2}\,\hat{r} \\
& - i\sqrt{G}\,\frac{h\nu_1Q_2 + h\nu_2Q_1}{c^2r^2}\,\hat{r} - i\sqrt{G}\,\frac{h\nu_1C_2 + h\nu_2C_1}{c^2r^2}\,\hat{r} \\
& - i\sqrt{G}\,\frac{M_1Q_2 + M_2Q_1}{r^2}\,\hat{r} - i\sqrt{G}\,\frac{M_1C_2 + M_2C_1}{r^2}\,\hat{r} \\
& = \vec{F}_{MM} + \vec{F}_{\gamma M} + \vec{F}_{\gamma\gamma} + \vec{F}_{QQ} + \vec{F}_{QC} + \vec{F}_{CC} \\
& + i\vec{F}_{\gamma Q} + i\vec{F}_{\gamma C} + i\vec{F}_{MQ} + i\vec{F}_{MC} \\
& = \vec{F}_{RR} + \vec{F}_{II} + i\vec{F}_{RI}\,.
\end{aligned} \tag{10}$$

Here, we have used (1–3) and (6) for the two real and two imaginary energy expressions. The symbol $\hat{r}$ is the unit vector along the direction of radial distance.

3.3 Gravitational force — interaction between real energy

The force $\vec{F}_{MM}$ represents Newton's law for the gravitational interaction between two masses. This force governs the orbital motion of astrophysical objects including the solar system. The force $\vec{F}_{\gamma M}$ is the gravitational interaction between mass and radiation and the force $\vec{F}_{\gamma\gamma}$ is the gravitational interaction between radiation and radiation. These three types

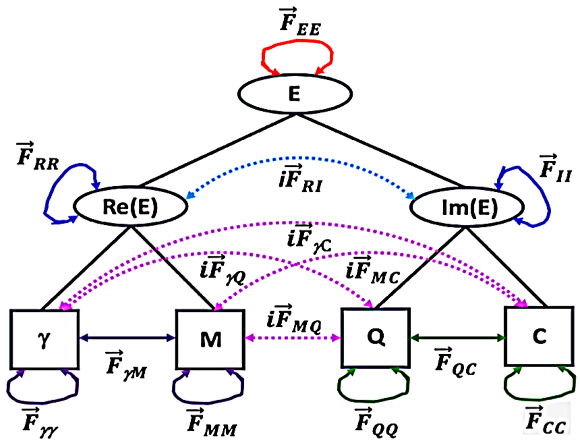

Fig. 3: Fundamental interactions among the four fundamental elements of nature: radiation, mass, electric charge and color charge. Mass and radiation are real energies, while electric and color charges are imaginary energies. Nature is a system of complex energy, and all the fundamental interactions of nature are classically unified into a single interaction between complex energies. There are six real and four imaginary interactions among the four fundamental elements.

of gravitational interactions are categorized as the interaction between real energies (Fig. 4a). Defining the radiation equivalent mass, we have a single gravitational force between masses.

When a photon of light travels relative to an object (e.g. the Sun) from $\vec{r}$ to $\vec{r}+d\vec{r}$, it changes its frequency from ν to $\nu+d\nu$. Calculating the work done by this mass-radiation force on a photon to be the energy change of the photon,

$$h d\nu = \vec{F}_{\gamma M} \cdot d\vec{r} = -G\,\frac{h\nu M}{c^2 r^2}\,dr\,, \tag{11}$$

the author derived Einstein's gravitational redshift without using the Schwarzschild solution of Einstein's general relativity [8, 37, 38]. First, dividing (11) by the photon energy $h\nu$ for variable separation and then integrating the radial distance from the object radius R to infinity ∞ and the photon frequency from the emission frequency ν_e to the observation frequency ν_o, we have

$$\int_{\nu_e}^{\nu_o} \frac{d\nu}{\nu} = -\int_R^\infty \frac{GM}{c^2 r^2}\,dr\,. \tag{12}$$

Completing this definite integration, we obtain

$$\ln\frac{\nu_o}{\nu_e} = -\frac{GM}{c^2 R}\,, \quad \text{or} \quad \frac{\nu_e}{\nu_o} = \exp\left(\frac{GM}{c^2 R}\right). \tag{13}$$

Then, the gravitational redshift can be derived as

$$Z_G = \frac{\lambda_o - \lambda_e}{\lambda_e} = \frac{\nu_e - \nu_o}{\nu_o} = \exp\left(\frac{GM}{c^2 R}\right) - 1\,. \tag{14}$$

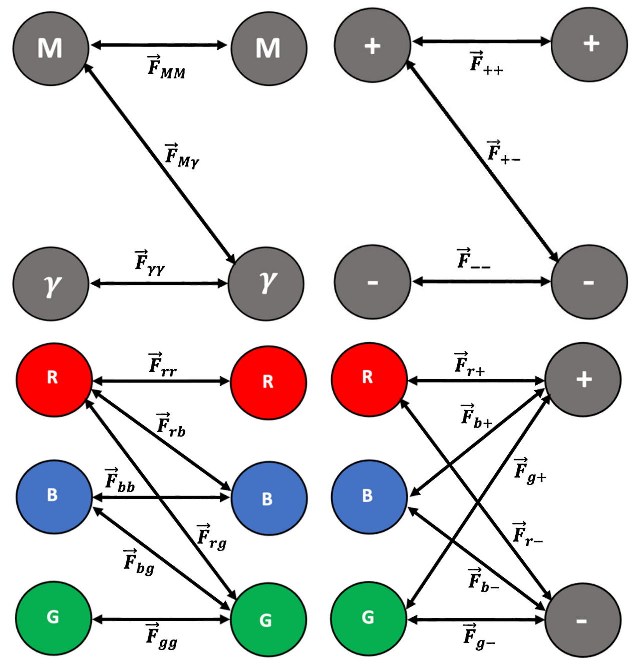

Fig. 4: (a) Top left panel shows the three types of gravitational interaction between real energies. They are the mass-mass, mass-radiation, and radiation-radiation interactions. (b) Top right panel shows the three types of electromagnetic force between electric charges. They are the positive-positive, positive-negative, and negative-negative interactions. (c) Bottom left panel shows the six types of strong interactions between color charges. They are the red-red, red-blue, red-green, blue-blue, blue-green, and green-green interactions. (d) Bottom right panel shows the six types of weak interactions between electric and color charges. They red-positive, red-negative, blue-positive, blue-negative, green-positive, and green-negative interactions.

In the weak field approximation, it reduces to

$$Z_G = \frac{GM}{c^2 R}\,. \tag{15}$$

Similarly, calculating the work done on a photon from an object by the radiation-radiation gravitation, the author further obtained a radiation redshift, which is proportional to the fourth power of temperature of the radiation. For the light from the Sun, the radiation redshift is about 10^{-13}, around seventh order lower in magnitude than the gravitational redshift [8], and hence negligible. For an extremely hot object, the radiation redshift will be significant and may be detectable.

3.4 Electromagnetic force — interaction between electric charges

The force $\vec{F}_{QQ}$ represents Coulomb's law for the electromagnetic interaction between two electric charges. This force governs the orbital motion of atomic electrons around nuclei. Electric charges have two varieties and thus three types of in-

Table 5: Gauge field interactions between different types of charges. These include the six strong field interactions between three types of color charges (coded as red), the six weak field interactions between three types of color charges and two types of electric charges (coded as blue), and the three types of electromagnetic field interactions between two types of electric charges (coded as green).

Charge	r	b	g	$+$	$-$
r	$\vec{F}_{rr}$	$\vec{F}_{rb}$	$\vec{F}_{rg}$	$\vec{F}_{r+}$	$\vec{F}_{r-}$
b		$\vec{F}_{bb}$	$\vec{F}_{bg}$	$\vec{F}_{b+}$	$\vec{F}_{b-}$
g			$\vec{F}_{gg}$	$\vec{F}_{g+}$	$\vec{F}_{g-}$
$+$				$\vec{F}_{++}$	$\vec{F}_{+-}$
$-$					$\vec{F}_{--}$

teractions (Fig. 4b, see also Table 5):

1) repelling between positive electric charges $\vec{F}_{++}$,
2) repelling between negative electric charges $\vec{F}_{--}$, and
3) attracting between positive and negative electric charges $\vec{F}_{+-}$.

Like charges repel one another and unlike charges attract one another. In the standard model of particle physics, the electromagnetic force between electric charges is described by the group $U(1)$.

3.5 Strong Force — interaction between color charges

The force $\vec{F}_{CC}$ is the strong interaction between color charges. Color charges have three varieties: red, blue, and green and thus have six types of interactions (Fig. 4c, see also Table 5):

1) the red-red interaction $\vec{F}_{rr}$,
2) the blue-blue interaction $\vec{F}_{bb}$,
3) the green-green interaction $\vec{F}_{gg}$,
4) the red-blue interaction $\vec{F}_{rb}$,
5) the red-green interaction $\vec{F}_{rg}$, and
6) the blue-green interaction $\vec{F}_{bg}$.

Fig. 4c shows these six types of color interactions or strong forces. With anticolors, there are 21 types of strong force between color charges. In the standard model of particle physics, the strong forces between color charges are described by the group SU(3).

The strong interaction is the only one that can change color of quarks in a hadron particle. A typical strong interaction is the proton-neutron scattering. This is an interaction between the color charge of one up quark in proton and the color charge of one down quark in neutron via exchanging a π^+-meson between the proton and neutron. In other words, during this proton-neutron scattering an up quark in the proton changes into a down quark by emitting a π^+, meanwhile a down quark in the neutron changes into an up quark by absorbing the π^+. Another typical strong interaction is delta decay, $\Delta^0 \to p + \pi^-$. This is an interaction between the color charge of one down quark and the color charges of the other two quarks. In this interaction, a down quark emits a π^- and then becomes an up quark, $d \to u + \pi^-$.

It should be noted here that the strong force carriers between nucleons (not quarks) are the pion mesons ($\pi^\pm$, π^0), which are the lightest hadrons, composed of one first-generation quark and one first-generation antiquark, and bind nucleons to form nuclei [33]. Gluons are the particles that mediate the strong forces that bind quarks together to form hadrons including nucleons [34]. Including antiparticles and gravitons (or gravitational force carriers), we have more fundamental particles [35]. We may categorize the strong force into two categories: (1) the nuclear force between nucleons to bind nucleons to form a nucleus and (2) the color charge interaction or force between quarks to bind quarks into hadrons.

3.6 Weak force — interaction between electric charge and color charge

The force $\vec{F}_{QC}$ is the weak interaction between electric and color charges. Considering electric charges with two varieties and color charges with three varieties, we have also six types of weak interactions (Fig. 4d, see also Table 5):

1) the positive-red interaction $\vec{F}_{+r}$,
2) the positive-blue interaction $\vec{F}_{+b}$,
3) the positive-green interaction $\vec{F}_{+g}$,
4) the negative-red interaction $\vec{F}_{-r}$,
5) the negative-blue interaction $\vec{F}_{-b}$, and
6) the negative-green interaction $\vec{F}_{-g}$.

With anticolors, there are 12 types of weak between electric and color charges. In the standard model of particle physics, the weak forces are described by the group SU(2) and carried by the W and Z bosons. The weak interaction is the only one that can change flavors of quarks in a hadron particle, which causes atoms to change from one element to another. A typical weak interaction occurs when neutron decays into proton with emissions of an electron and an electron-type antineutrino. In this process, a down quark in the neutron changes into an up quark by emitting a W-boson, which lives about 10^{-25} seconds and then breaks into a high-energy electron and an electron-type antineutrino.

3.7 Interaction between two electrically charged particles

The interaction between two electrically charged particles such as the interaction between two protons in a nucleus or the interaction between proton and electron in a hydrogen atom is given by

$$\begin{aligned}\vec{F}_{E_1E_2} &= -G\,\frac{(E_{1M} + iE_{1Q})(E_{2M} + iE_{2Q})}{c^4 r^2}\,\hat{r}\\ &= -G\,\frac{M_1M_2}{r^2}\,\hat{r} + \frac{Q_1Q_2}{r^2}\,\hat{r} - i\sqrt{G}\,\frac{M_1Q_2 + M_2Q_1}{r^2}\,\hat{r}\\ &= \vec{F}_{MM} + \vec{F}_{QQ} + i\vec{F}_{MQ}\,, \end{aligned} \tag{16}$$

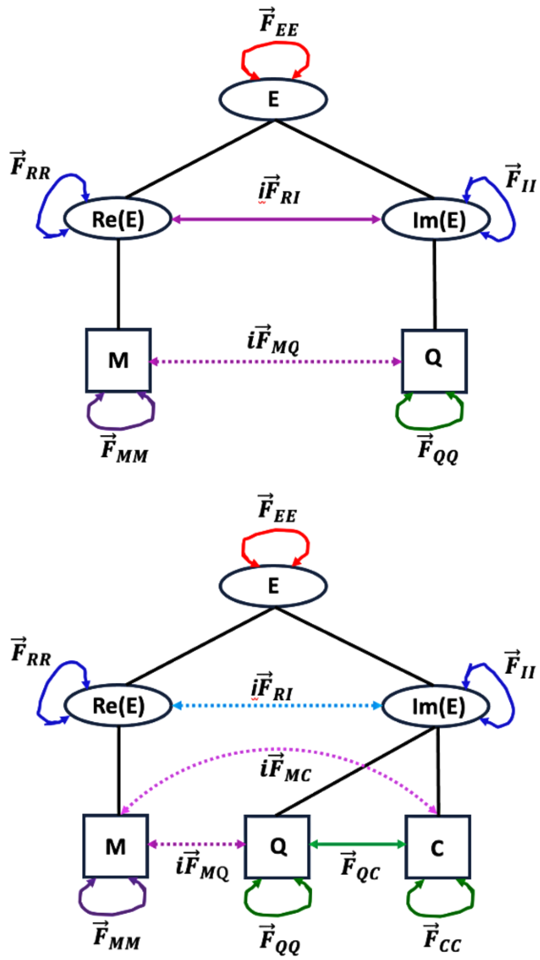

Fig. 5: (a) Top panel shows interaction between two electrically charged particles. It splits into three fundamental interactions: (1) a real force between masses $\vec{F}_{MM}$, the gravitational force governed by Newton's gravitational law, (2) a real force between electric charges $\vec{F}_{QQ}$, the electromagnetic force governed by Coulomb's law, and (3) an imaginary force between mass and electric charges $i\vec{F}_{MQ}$, which plays the role in sticking and adhering the electric charge on the mass to form electrically charged particles. (b) Bottom panel shows interaction between two quarks. It splits into six fundamental forces: (1) a real force between masses (gravitational) $\vec{F}_{MM}$, (2) a real force between electric charges (electromagnetic) $\vec{F}_{QQ}$, (3) a real force between color charges (strong) $\vec{F}_{CC}$, (4) a real force between electric and color charges (weak) $\vec{F}_{QC}$, (5) an imaginary force between mass and electric charge $i\vec{F}_{MQ}$, and (6) an imaginary force between mass and color charge $i\vec{F}_{MC}$.

or shown in Fig. 5a. It is split into two real forces and one imaginary force. The two real forces are $\vec{F}_{MM}$ and $\vec{F}_{QQ}$, governed by Newton's law of gravitation and Coulomb's law of electromagnetism, respectively. The one imaginary force is $i\vec{F}_{QC}$, which can occur inside of a particle to glue its electric charge on its mass or between two particles.

3.8 Interaction between two quarks

The interaction between two quarks in a hadron or in a quark-gluon plasma is given by

$$\begin{aligned}\vec{F}_{E_1E_2} &= -G\,\frac{(E_{1M}+iE_{1Q}+iE_{1C})(E_{2M}+iE_{2Q}+iE_{2C})}{c^4r^2}\,\hat{r}\\ &= -G\,\frac{M_1M_2}{r^2}\,\hat{r}+\frac{Q_1Q_2}{r^2}\,\hat{r}+\frac{Q_1C_2+Q_2C_1}{r^2}\,\hat{r}+\frac{C_1C_2}{r^2}\,\hat{r}\\ &\quad -i\sqrt{G}\,\frac{M_1Q_2+M_2Q_1}{r^2}\,\hat{r}- -i\sqrt{G}\,\frac{M_1C_2+M_2C_1}{r^2}\,\hat{r}\\ &= \vec{F}_{MM}+\vec{F}_{QQ}+\vec{F}_{QC}+\vec{F}_{CC}+i\vec{F}_{MQ}+i\vec{F}_{MC}\,. \end{aligned} \tag{17}$$

or shown in Fig. 5b. It is split into four real and two imaginary forces. The four real forces are $\vec{F}_{MM}$, $\vec{F}_{QQ}$, $\vec{F}_{QC}$ and $\vec{F}_{CC}$, called by the gravitational, electromagnetic, weak and strong interactions, respectively. The two imaginary forces are $i\vec{F}_{MQ}$ and $i\vec{F}_{MC}$, gluing electric and color charges on mass.

Considering the strong interaction to be asymptotically free within a typical hadron [39], we can replace the color charge by

$$C \longrightarrow \frac{r}{r_0}\,C\,, \tag{18}$$

where r is the radial distance and $r_0 \sim 10^{-15}$ m is the radius of the typical hadron. This assumption represents that color charge becomes less colorful if it is closer to each other, i.e., asymptotically colorless. Then, the strong interaction between color charges of two quarks can be rewritten by

$$\vec{F}_{C_1C_2} = \frac{C_1C_2}{r_0^2}\,\hat{r}\,, \tag{19}$$

which is independent of the radial distance and consistent with measurements, and the weak force between electric charge of one quark and color charge of another quark becomes

$$\vec{F}_{Q_1C_2} = \frac{Q_1C_2}{r_0 r}\,\hat{r}\,, \tag{20}$$

which is inversely proportional to the distance and consistent with measurements. The electromagnetic force between electric charges of two quarks is given by

$$\vec{F}_{Q_1Q_2} = \frac{Q_1Q_2}{r^2}\,\hat{r}\,. \tag{21}$$

Within a typical hadron (i.e., $r \sim r_0$) such as a proton or a neutron, the strong force can be 100 times stronger than the electromagnetic force in strength. This leads to the color-electric charge ratio of a quark to be $C/Q \sim 10$. The ratio between strong force and weak force will be about $\sim rC/(r_0Q)$. Since the weak force between electric charge and color charge has a shorter range of interaction ($r \sim 10^{-18}$ m or $r/r_0 \sim 10^{-3}$) such as within a typical quark, we have that the weak force between electric and color charge within a typical quark can be 100 times greater than the strong force between color charges of two quarks within a typical hadron. Therefore, the weak force that occurs inside a quark and causes the quark decay is not actually weak.

4 Discussions and conclusions

The new four-element theory suggests the weak force to be an interaction between electric and color charges, in analogy to the electromagnetic force to be an interaction between electric charges and the strong force to be an interaction between color charges. It occurs effectively inside a quark between its electric and color charges, so that is responsible for the excitation and decay of quarks. Considering an atom to be composed of a nucleus and electrons, a nucleus to be composed of nucleons, and a nucleon to be composed of quarks, we see radioactive decay of atoms to result from the decay of quarks that are triggered by the weak interaction between the quark's electric and color charges. This new scenario of weak interaction beyond the standard model of particle physics has important implications to the quark model, particle physics, and cosmology. Based on the new four-element theory of nature, we have developed a new quark model called two-flavor multi-excitation quark model [9, 40].

The new four-element theory of nature addresses only the ordinary matter of the universe. Based on the big bang standard model of cosmology, our universe dominates by dark matter and dark energy over 95%. The ordinary matter only takes 5%. The possible candidates of dark matter are weakly interacting massive particles (WIMPs), axions, sterile neutrinos, and primordial black holes. For the dark energy, the most favored explanation is the cosmological constant. The author proposed and developed a black hole model of the universe, which does not need dark energy [41–44]. On the other hand, the reason why distant supernovae appear dimmer than expected may be due to the redshift-luminosity relation that is conventionally applied is only an approximate expression for nearby objects [45]. If the spacetime is dynamic, our universe does not need to be accelerating and even expanding [46, 47].

As consequences of this review work, we have comprehensively reviewed the new four-element theory of nature, that was proposed and developed previously by the author to classically unify all fundamental interactions into a single interaction between complex energies. The new four-element theory of nature suggests that nature consists of four fundamental elements, which are radiation, mass, electric charge, and color charge. Any known matter or particle observed in nature or discovered in labs is a combination of one or more of the four fundamental elements. Fundamental interactions in nature are interactions among these fundamental elements. Radiation and mass are two forms of real energy. Electric and color charges are two forms of imaginary energy. All fundamental interactions are unified into a single interaction between complex energies. Interactions between real energies are gravitational field forces with three categories: mass-mass, mass-radiation, and radiation-radiation interactions. Interactions between imaginary energies are gauge field forces with also three categories: electric-electric charge (or electromagnetic), electric-color charge (or weak), and color-color charge (or strong) interactions. Interactions between real and imaginary energies are imaginary forces, which do not have observational support but may explain why electric and color charges are usually adhered on mass, rather than independently exist. The significant result obtained from the new four-element theory of nature such that the weak force is an interaction between electric and color charges would have essential implications to the quark and particle theories beyond the standard model as well as cosmology.

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