

On a possible cause of negative sign of gravitational interaction between matter and antimatter

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Most of the fundamental ideas of science are essentially simple, and may, as a rule, be expressed in a language comprehensible to everyone. [...] If you can't explain it simply, you don't understand it well enough.

— Albert Einstein

ABSTRACT

Based on the mass-energy equivalence from special theory of relativity, we conjecture simple and clear framework for the purpose of conceptualizing atomic mass generation mechanism for a single hydrogen atom. We then apply it to see if it would offer conclusive clarification of the issue of the sign of gravitational interaction between the Earth and antihydrogen atoms at CERN. Our testable prediction is that the interaction will be conclusively repulsive, i.e. of equal and opposite magnitude as compared to the attractive one. We are confident that, if experimentally verified, our conjecture has sufficient potential to result in a theoretical basis of the first experimentally testable quantum gravity hypothesis.

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1. INTRODUCTION

The principle of universality of free fall, or Weak Equivalence Principle (WEP) states that all bodies fall with the same acceleration, independent of their mass and composition. WEP has been tested with very high precision for matter, but never directly for antimatter. The principal goal of ALPHA-g, AEGIS, and GBAR experiments is to test WEP with antihydrogen atoms at CERN. Experiments with charged antiparticles have been considered hopeless by now, given the extreme weakness of gravity in comparison with the other forces.

Magnetism is not electricity, however, there isn't any such magnetism to be found in hydrogen atom that would be independent of electric charge and its behavior. And vice versa, there isn't any such electric charge to be found in hydrogen atom that would exist in the absence of magnetic field.

Hydrogen atom happens to be a piece of matter. Matter has mass, and mass is considered to result in gravity. There isn't any such gravity produced by hydrogen atom that would be independent of atom's mass, and there isn't any such mass to be found in hydrogen atom that would exist in the absence of atom's gravity. Mass and gravity are neither electricity, magnetism, nor electromagnetism.

CONJECTURE 1.

- **There aren't any such mass and gravity to be found in hydrogen atom that would be independent of atom's electricity, magnetism, associated angular momenta (and whatever other forms of energy we could possibly find in the atom), and such that could exist in their absence, because each energy present in hydrogen atom is, in principle, equivalent of some portion of its mass.**

2. THE MASS-ENERGY EQUIVALENCE

Albert Einstein explains his famous formula, as recorded in the soundtrack of the 1948 film [1], *Atomic Physics*:

It followed from the special theory of relativity that mass and energy are both but different manifestations of the same thing — a somewhat unfamiliar conception for the average mind. Furthermore, the equation E is equal to $m c$ -squared, in which energy is put equal to mass, multiplied by the square of the velocity of light, showed that very small amounts of mass may be converted into a very large amount of energy and vice versa. The mass and energy were in fact equivalent, according to the formula mentioned above. This was demonstrated by Cockcroft and Walton in 1932, experimentally.

ASSUMPTION 1.

- **When hydrogen atom absorbs, or emits, a low-energy photon (thermal radiation), then it respectively gains, or loses, a portion of its mass equivalent of photon's energy.**

This assumption is, in principle, in agreement with Einstein's mass-energy equivalence. The mass-energy equivalence is unconditional in a sense of being valid for photons of any energy, and not for high-energy ones only.

Direct implication of this assumption is that atomic mass could undergo limited fluctuations. This implication receives theoretical support from the peer-reviewed, published theoretical research of Woodward J.F. [2] on transient mass fluctuations based on the Mach's Principle, and from its preliminary experimental verification [3]. Further experimental testing of transient mass fluctuations and their potential application to space propulsion will be conducted by NASA.

Another theoretical, soon to be experimentally testable, possibility of transforming energy of photons into particles of matter [4] is described by the theory of Breit-Wheeler process that is based on QED theory, and on the mass-energy equivalence.

According to Einstein's special theory of relativity, mass of a material body depends on its velocity. Even though for non-relativistic velocities this dependence is negligible in practice, it still nonetheless holds true in theory. By analogy, atomic mass fluctuations due to absorption, or emission, of low-energy photons are also negligible in practice. Similarly, it is only the low-energy neutron that is absorbed by fissile uranium's nucleus, and not the high-energy one, in the process of converting mass into energy.

Another indirect evidence that might be suggestive of mass fluctuations are higher than expected observed fluctuations of the gravity constant.

In view of the above, it seems reasonable to conclude that ASSUMPTION 1 is plausible enough.

3. HYDROGEN'S MASS GENERATION MECHANISM

As per ASSUMPTION 1, when hydrogen atom absorbs, or emits, a photon, then the distance between electron and proton increases, or decreases, respectively. This change of the distance reflects the corresponding change of value of the electric dipole moment between electron and proton.

When absorption of a photon by hydrogen atom results in equivalent increase of its mass, then this mass increase is reflected in the corresponding increase of the electric dipole moment value. Direct implication of it becomes our

CONJECTURE 2.

- **Hydrogen atom's electric dipole moment, being energy of electric potential, constitutes a measure of its mass. A measure of atomic mass so defined is a vector that represents energy.**

In addition to CONJECTURE 2, we recall CONJECTURE 1, which states that, in our view, there aren't any such mass and gravity to be found in hydrogen atom that would be independent of atom's electricity, magnetism, associated angular momenta (and whatever other forms of energy we could possibly find in the atom), and such that could exist in their absence, because each energy present in hydrogen atom is, in principle, equivalent of some portion of its mass.

We can convert electric dipole's energy to its equivalent mass, but let us notice that hydrogen atom's electric dipole spins due to electron's rotation around the proton. We already know the value of hydrogen atom's inertial mass. Let's convert it to its equivalent energy. Let's calculate the value of hydrogen atom's electric dipole energy. If the latter is smaller than then the former, the difference should be found as energy related to magnetic moments.

4. WILL ANTIHYDROGEN ATOMS BE GRAVITATIONALLY REPELLED BY THE EARTH?

Attractive gravity of the Earth can be conceptualized as lines directed inward, towards the center of its mass. This agrees with hydrogen atom's inwardly directed vector of electric dipole moment. This, in turn, reflects the natural fact that hydrogen atom's mass gives rise to attractive gravity. In this sense, it also reflects the fact that two material bodies composed of atoms which have their electric dipole moment vectors directed inward will gravitationally attract each other. On the other hand, antihydrogen atom's electric dipole moment vector is directed outward.

TESTABLE PREDICTION

- **Antihydrogen atoms at CERN will be conclusively gravitationally repelled by atoms of matter, i.e. with equal and opposite magnitude as compared to hydrogen atoms.**

SECONDARY PREDICTION

- **We expect the gravitational interaction among atoms of antimatter to also be repulsive.**

Direct implication of our secondary prediction is that antimatter atoms would not be able to form massive bodies in the Universe that could be easily detected by astronomical observations.

This, in turn, would imply that we could expect vast regions of atomic antimatter dust to be present in the intergalactic space, thus solving the mystery of the missing antimatter. Similar scenario was hypothesized by Bars and James [5]. Such vast regions of antimatter dust would power not only cosmological inflation, but would also power antimatter regions' self-expansion, which would further accelerate the inflation. Antimatter and its antigravity would naturally eliminate the need for dark matter and dark energy.

The existence of antimatter was first predicted theoretically. Later it was also directly detected experimentally, and even produced artificially. However, the existence of dark matter has neither been directly detected experimentally, nor has dark matter been predicted theoretically. It is even worse. While the existence of matter is naturally accompanied by antimatter, then shouldn't we also expect the existence of dark antimatter?

GAMMA-RAY BURSTS

Avalanches of relativistic runaway electrons, which develop in electric fields within thunderclouds, emit gamma rays. Bursts of gamma rays from lightning, called Terrestrial Gamma-ray Flashes (TGF) were first detected in 1992 by NASA's Compton Gamma-ray Observatory. Four detectors installed by Kyoto University in the city of Kashiwazaki picked up a large gamma ray reading immediately after a nearby lightning strike. When data was analyzed, it revealed three distinct bursts, each one lasting longer than the one before. The first burst was from the lightning strike. Both of the later signals were caused by photonuclear reactions [6]. The gamma rays emitted in lightning have enough energy to knock a neutron out of atmospheric nitrogen, and it was the reabsorption of this neutron by particles in the atmosphere that produced the gamma-ray afterglow. The final, prolonged emission was from the breakdown of now neutron-poor and unstable nitrogen atoms. These released positrons, which subsequently collided with electrons in annihilation events releasing gamma rays.

In gamma-ray astronomy, gamma-ray bursts (GRBs) are the brightest electromagnetic events known to occur in the universe. Bursts can last from ten milliseconds to several hours. After an initial flash of gamma rays, a longer-lived "afterglow" is usually emitted at longer wavelengths. The means by which gamma-ray bursts convert energy into radiation remains poorly understood, and there is no generally accepted model of how this process occurs. Any successful model of GRB emission must explain the physical process for generating gamma-ray emission that matches the observed diversity of light curves, spectra, and other characteristics. Particularly difficult to explain are very high efficiencies that are inferred from some explosions. We suppose that GRBs are due to asteroids penetrating regions of antimatter dust.

ATOMIC STRUCTURE STABILITY

Most of naturally occurring atoms are stable, and do not decay. For an atom to be stable, there has to be balance of forces present in it.

In a hydrogen atom, there is an electric attraction between electron and proton, and this attraction must be balanced by some repulsion. According to our understanding, electron produces gravity, and proton produces antigravity. This constitutes the required repulsion. Electron cloud is subject to both, electric repulsion and gravitational attraction. In this view, quantum gravity is a factor that contributes to atomic structure stability.

5. COULD ANTIMATTER HAVE NEGATIVE MASS?

Yes, but only in a sense of the letter “m” being preceded by mathematical minus “-” sign in equations.

What would the notion of physically real **negative** mass specifically refer to in physical reality? One of the things it could refer to is “**negative wave**”, and the other is “*wave of negative energy*” :

- What would be the essential difference between a wave of negative energy and a wave of positive energy?
- How could “negative wave” possibly look like?
- The notion of negative energy goes hand-in-hand with the notion of **negative radiation**.

Therefore, such vague notion as “*physically real negative mass*” is not sound enough to be taken seriously as an explanation of antihydrogen atoms antigravitating.

However, in view of our conjecture, it can be validly said that antihydrogen atom has antimass in virtue of its electric dipole moment vector being directed in the opposite way to that of hydrogen atom. This is precisely what the otherwise impossible notion of physically real negative mass refers to in subatomic physical reality.

6. THE NOTION OF MASS AND THE GRAVITATIONAL INTERACTION

Let's recall that our above proposed concept of mass is a vector representing energy. If mass gives rise to gravity, then our mass, as a vector, should give rise to the force of gravity also represented as a vector.

In physics, a mass generation mechanism is a theory which attempts to explain the origin of mass from the most fundamental laws of physics. To date, a number of different models have been proposed which advocate different views of the origin of mass. The problem is complicated by the fact that the notion of mass is inseparably related to the gravitational interaction, but a theory of the latter has not been reconciled with the Standard Model of particle physics yet.

The concept of mass, with the concept of gravitational mass identified with the concept of inertial mass, is quantified and defined by gravitational phenomenology. Therefore, on purely logical grounds, the concept of mass so defined cannot then be used in the theories of physics as an explanation of the very phenomenology used to define and quantify it, because otherwise it would become a classical instance of meaningless, circular reasoning; meaningless, because not all circular reasonings are created equal.

To address the above issue, let us suppose that hydrogen atom's electric dipole moment vector can be viewed and interpreted from three closely related perspectives.

The electric dipole moment as a vector representing energy can be understood as validly representing hydrogen atom's inertial mass, because energy is equivalent of mass, also when hydrogen atom absorbs a single low-energy photon (thermal radiation).

It could, however, also be understood as validly representing hydrogen atom's gravitational mass. Which mass, then, it should represent? Inertial or gravitational? Perhaps it should represent the gravitational mass, because the electric dipole moment is a vector, therefore gravitational mass so understood is conceptually compatible with the vector of gravity force that it is supposed to give rise to.

If we decide that the electric dipole moment represents gravitational mass, then where is the inertial mass to be found inside the hydrogen atom? Since both masses are considered to be of equal value, then perhaps they are merely two different ways of looking at the same thing, at hydrogen atom's electric dipole moment?

It seems that mass, inertial or gravitational, should naturally be a scalar value, because mass is considered to be inert. Yet, we discovered it to be a vector. If this seems to be counter-intuitive, then we need to explain how a scalar mass could physically result in a vector of gravity force? This seems to be a mystery in its own right. In addition to mass generation mechanism, we clearly need gravity generation mechanism, too. The third way of looking at hydrogen atom's electric dipole moment vector is to understand it as representing gravitational potential.

Let's consider one single hydrogen atom in completely empty outer space. Its mass is the energy of its electric dipole (in combination with its magnetic energy and all energies of its associated angular momenta). This mass is the potential energy of the electric dipole. This potential energy represents gravitational potential, and the inward direction of electric dipole moment vector indicates that it is an attractive gravitational potential.

Let's put the second hydrogen atom next to the first one. Now, the gravitational potentials of the two atoms give rise to forces of their gravitational interaction. We know it from experience that matter-matter gravitational interaction is attractive, which clarifies that two inwardly directed electric dipole moment vectors result in attractive gravity. The potential energy of the two electric dipoles (in combination with all energies of associated angular momenta, and magnetic field energies) will result in the forces of gravitational interaction. How would such gravity force propagate? In general, the physical medium are magnetic fields, and specifically, gravitational interaction will make use of magnetic vortex tubes, which also involves angular momentum. Because the notion of mass is inseparably related to the gravitational interaction, it is impossible to experimentally detect the physical existence of inertial or gravitational mass as something separate from the gravitational interaction, even in principle. This should give us a pause for reflection. Quoting Chang D.C. from his paper [7], section 10, *Interpretation of Newton's gravitational law from the perspective of the wave view of mass* (page 24),

*Mass can have two meanings in classical mechanics. One is inertial mass and the other one is gravitational mass. In the above discussion, we showed that the concept of **inertial mass could be an illusion**. This so called "inertial mass" is actually a measure of particle's energy, as per mass-energy equivalence in the special theory of relativity.*

According to our conjecture, inertial mass is merely an unfalsifiable metaphysical assumption, which physical existence could never be experimentally verified, even in principle. On the other hand, gravitational interaction is an obvious testable empirical fact.

The above could mean that the reason that inertial and gravitational mass are of equal value is that they are one and the same thing viewed from two different perspectives. Similarly, the reason that even in principle we cannot experimentally detect the physical existence of inertial or gravitational mass as something separate from the gravitational

interaction, is that they are one and the same thing (the electric dipole moment) viewed from two different perspectives.

Therefore, it would seem that notions of inertial mass, gravitational mass, and gravitational potential are in reality one and the same thing (the electric dipole moment) viewed, understood and interpreted from three different perspectives in three different contexts.

With every new context there will be new notion of mass, like for example, passive mass, active mass, effective mass, inertial mass, gravitational mass, relativistic mass, and quantum mass. How many more kinds of mass are there to be discovered, or rather invented, yet?

7. WHAT, SPECIFICALLY, DOES THE NOTION OF MASS REFER TO IN SUBATOMIC PHYSICAL REALITY?

Gravitomagnetism is produced by stars and planets when they spin. It's similar in form to the magnetic field produced by a spinning ball of charge. Replace charge with mass, and magnetism becomes gravitomagnetism.

Written out in full glory, the equations of general theory of relativity are complex. Indeed, they have been solved in only a few special cases. One of them is the case of weak gravity, like we experience on Earth. In the weak field limit, Einstein's equations reduce to a form remarkably like Maxwell's equations of electromagnetism. Terms appear that are analogous to electric field, and to magnetic field. The electric terms correspond to the gravity that keeps our feet on the ground. The magnetic terms are wholly unfamiliar; we don't sense them in everyday life.

It needs to be emphasized that our conjecture of hydrogen atom's electric dipole moment being a measure of its mass should not be misunderstood as if it were to exist in absence of everything else. In so far as we conjecture hydrogen atom's electric dipole moment to be a measure of its mass, it is only on condition of being encapsulated in everything else that hydrogen atom provides, like magnetic fields, all associated angular momenta, and whatever other forms of energy we could possibly find in the atom, forms of energy that, in principle, are equivalent of some portion of its mass.

Our hydrogen atom's mass generation mechanism is a dynamic process. Hydrogen atom's mass is produced by fluctuating electric dipole moment, due to combination of electric charges, their magnetic fields, and all associated angular momenta. All energies in the atom combine to produce its mass, because each energy present in hydrogen atom is, in principle, equivalent of some portion of its mass.

This resembles gravitomagnetism in a sense that when we use GTR's equations in the weak field limit to describe gravity of spinning stars, or planets, terms appear that are analogous to electric field, and to magnetic field.

If the electric terms correspond to the gravity that keeps our feet on the ground, then it could be due to hydrogen atom's electric dipole moment being a measure of its mass as the cause of gravity.

In regard to the magnetic terms being wholly unfamiliar, because we don't sense them in everyday life, we think that this is due to magnetic fields being gravity's propagation medium. We suppose that gravity interactions make use of magnetic vortex tubes. It implies that gravity is a very complex phenomenon, much more so than magnetism, and not a fundamental force with its associated carrier particle.

We believe that the above validates our supposition that notions of inertial mass, gravitational mass, and gravitational force are one and the same thing (the electric dipole moment) viewed, understood and interpreted from three different perspectives in three different contexts.

This finally allows us to always be able to answer the following fundamental question: What, specifically, does the notion of inertial mass, gravitational mass, or gravitational force, refer to in subatomic physical reality?

Each of them, depending on each particular context, refers to the electric dipole moment, but only as this moment is embedded in an atom, as per our CONJECTURE 1,

that there aren't any such mass and gravity to be found in hydrogen atom that would be independent of atom's electricity, magnetism, all associated angular momenta (and whatever other forms of energy we could possibly find in the atom), and such that could exist in their absence, because each energy present in hydrogen atom is, in principle, equivalent of some portion of its mass.

The above shows direct correspondence between our concept of vector-mass as the cause of gravity force (vector), and the gravity as gravitomagnetism in the weak field limit equations of Einstein's general theory of relativity. What a remarkable correspondence it is, indeed.

Could our quantum gravity conjecture constitute a basis for unifying quantum mechanics with general theory of relativity in the weak field limit?

8. ELECTRON'S MASS

Macroscopic phenomenon of gravitomagnetism is described by three factors: spin of a massive body, or system of bodies, electric terms, and magnetic terms. If we take a look at electron it is clear that the gravitomagnetic generation mechanism applies. Therefore, we suppose that this properly oriented combination of angular momentum, electric dipole moment, and magnetic moment, could be scale-invariant, and applies to all structures, from atoms and planets to solar systems and galaxies [8].

However, electron is an electric monopole. Nevertheless, electron may also have its electric dipole moment [9]. Because electron's electric dipole moment may not be a permanent property, let's assume electron to be strictly an electric monopole.

If we take a conceptual look at a hydrogen atom from outside, all we will see is an electron cloud. If we take a conceptual look at a single electron from outside, we could also see electron as a smaller cloud (uncertainty principle).

For the sake of argument, let's assume that because electron has a negative charge, angular momentum (spin), and magnetic moment, it generates gravity.

Specifically, it generates attractive gravity, because its outer "shell" is negatively charged, like in case of atoms of matter. Of course, being a monopole, it does not have any inner positively charged "nucleus", but effectively, from outside, it looks similar enough to an electron "cloud" of a hydrogen atom.

By analogy, proton would also generate gravity, albeit the repulsive one, in virtue of having its "outer" shell charged positively, like in case of atoms of antimatter.

Antiproton would generate attractive gravity. That would explain results of antiproton gravitational experiments at CERN. The expectation was that antiproton would antigravitate. And it did not. We suppose that on the assumption that protons should naturally gravitate, like regular matter, there was no experiments to observe that they might have not.

According to our conjecture, as opposed to antiprotons, protons would actually antigravitate. This is another **testable prediction** stemming from our conjecture that could be experimentally verified at CERN.

9. CONCLUDING REMARKS

Hypotheses non fingo (Latin for “I feign no hypotheses”) is a phrase used by Isaac Newton in an essay, “*General Scholium*”, which in 1713 was appended to the second edition of his *Principia*. The following is a modern translation [10] of the passage containing this famous remark:

I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction.

We are confident that, finally, the time has come when we discovered the reason for properties of gravity derived from subatomic phenomena. We proposed atomic mass generation mechanism. We conceptualize atomic mass to be a vector representing energy of electric potential (electric dipole moment) in conjunction with energy of magnetic moment, and angular momenta. Atomic mass defined as a vector suggests that our mass generation mechanism can also be understood as gravity generation mechanism due to direct correspondence between our mechanism and the gravitomagnetic generation mechanism from Einstein’s general theory of relativity. That is precisely how mass results in gravity.

When we apply our mass/gravity generation mechanism to atoms of matter and antimatter, we notice that the electric dipole moment constitutes a directional factor. Because atoms of matter gravitationally attract one another while having their electric dipole moment vectors directed inward, this would indicate that antihydrogen atoms should be gravitationally repelled by matter at CERN in virtue of having their electric dipole moment vectors directed outward. This is precisely what the otherwise impossible notion of “physically real negative mass” refers to in subatomic physical reality.

Because in our view gravity is a very complex phenomenon, much more so than magnetism, and not a fundamental force with its associated carrier particle, this would suggest magnetic fields being gravity's propagation medium. In our opinion, gravity interactions would specifically make use of magnetic vortex tubes.

Even though general theory of relativity conceives gravity to be spacetime's curvature, it does not explain in virtue of what specific mechanism mass is supposed to interact with spacetime in a way resulting in it being curved. In order to be in a position to propose such mechanism, first we would need to know what exactly constitutes mass, and what exactly spacetime is made of.

Considering this direct correspondence between principles of our quantum mass/gravity generation mechanism and the principles of gravitomagnetic generation mechanism from Einstein's general theory of relativity, we are optimistic that this direct correspondence could constitute a basis for unifying quantum mechanics with general theory of relativity in the weak field limit, if only in a sense of the properly oriented combination of angular momentum, electric dipole moment, and magnetic moment, being scale-invariant and thus applicable to all structures, from atoms and planets to solar systems and galaxies.

Quoting Chang D.C. from his paper [11], *As we pointed out above, Einstein's 1905 paper did not predict the correct velocity-dependence of mass. But today, we are taught that STR gave the right prediction. What is the justification for that? After the correct formula for the velocity-dependence of mass became known from experiments, physicists gave up Einstein's original argument from 1905 and used different ways to derive velocity-dependence of mass, like for example in a widely used textbook, Special Relativity by A.P. French, which is part of the MIT Introductory Physics Series. The idea that radiation and matter behave similarly was a very interesting assumption. According to the Special Relativity textbook, this assumption was following the spirit of Einstein's work. Indeed, in many papers written by Einstein, he frequently implied that the energy*

involved in radiation and the mass of matter are conceptually convertible. One may say that, in Einstein's mind, mass is some sort of energy. Hence, although Einstein had published many papers on the derivation of non-Newtonian relations of mass, most of his derivations were not based on the principle of relativity. Instead, his theoretical arguments were based on various hypothetical thought experiments which frequently implied that radiation and matter behave similarly. Furthermore, some of these derivations were not free of flaws. One may conclude that general acceptance of these "non-Newtonian relations" was not based on the soundness of theoretical arguments. Instead, as pointed out by A.P. French, "its real vindication is based on experimentally observed behavior of particles."

CERN experiments, ALPHA-g, AEGIS, and GBAR, will measure the sign of gravitational interaction between matter and antimatter in the next few years. Should the above presented arguments underlying our quantum gravity conjecture, and its two predictions, are not considered to be sound enough, we can only hope that, surprising as it may be at first, they will not be rejected offhand in favor of something else that, like a seductively looking distant mirage, does not exist, and that our quantum gravity conjecture would receive the benefit of the doubt until such time when official announcement of results from antihydrogen experiments at CERN is finally made.

We close by quoting Nobel Prize Laureate, Albert Szent-Gyorgyi:

Scientific discovery consists of seeing what everybody has seen, and thinking what nobody else has thought. Scientific discovery must be, by definition, at variance with existing knowledge. During my lifetime, I made two. Both were rejected offhand by Popes of my field of science.

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