

Quantum Tunneling Diffusion of Hydrogen

Now in a new study, scientists from Hokkaido University in Japan have reported the first evidence of quantum tunneling as a mechanism for the surface diffusion of hydrogen atoms on the surface of ice, although quantum tunneling has previously been observed for hydrogen atoms on the surface of some metals. In quantum tunneling, the hydrogen atoms can move through barriers that they otherwise could not pass through using only classical mechanisms, such as thermal hopping. [10]

An international team of scientists studying ultrafast physics have solved a mystery of quantum mechanics, and found that quantum tunneling is an instantaneous process. The new theory could lead to faster and smaller electronic components, for which quantum tunneling is a significant factor. It will also lead to a better understanding of diverse areas such as electron microscopy, nuclear fusion and DNA mutations. [9]

Taking into account the Planck Distribution Law of the electromagnetic oscillators, we can explain the electron/proton mass ratio and the Weak and Strong Interactions. Lattice QCD gives the same results as the diffraction patterns of the electromagnetic oscillators, explaining the color confinement and the asymptotic freedom of the Strong Interactions.

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Preface

The diffraction patterns of the electromagnetic oscillators give the explanation of the Electroweak and Electro-Strong interactions. [2] Lattice QCD gives the same results as the diffraction patterns which explain the color confinement and the asymptotic freedom.

The hadronization is the diffraction pattern of the baryons giving the jet of the color – neutral particles!

First observation made of quantum-tunneling diffusion of hydrogen atoms on ice

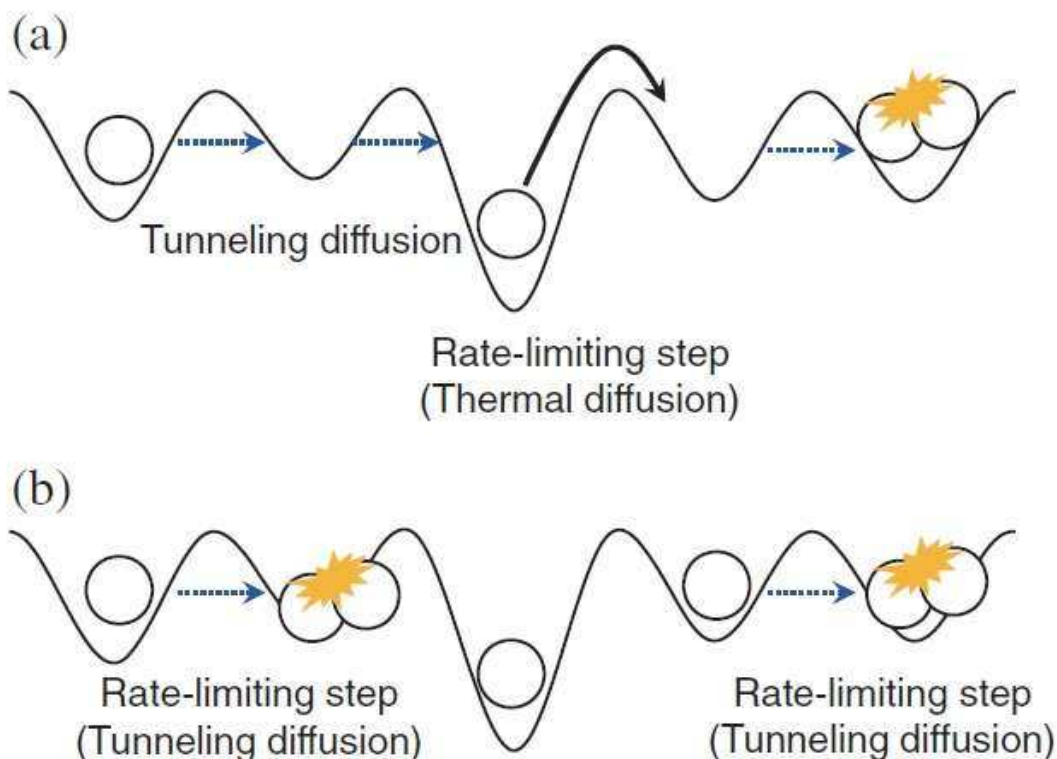


Illustration of surface diffusion of atoms, with the blue arrows showing quantum-tunneling diffusion (through classical barriers) and the black arrow showing thermal hopping. The figure shows how the diffusion mechanisms differ for (a) low atomic flux (dominated by thermal hopping) and (b) high atomic flux (dominated by quantum tunneling). Credit: Kuwahata, et al. ©2015 American Physical Society

As long as the temperature is above absolute zero, gas molecules are always in constant random motion. They may diffuse—or spread out—through three-dimensional space or, in a process called "surface diffusion," along the two-dimensional surface of a solid. The most well-known mechanism to explain surface diffusion is a classical mechanism called thermal hopping, in which gas molecules jump from one adsorption site (the place where the gas molecules attach to the surface) to another at a temperature-dependent rate. So far, thermal hopping is the only mechanism known to explain the surface diffusion of hydrogen atoms on the surface of ice.

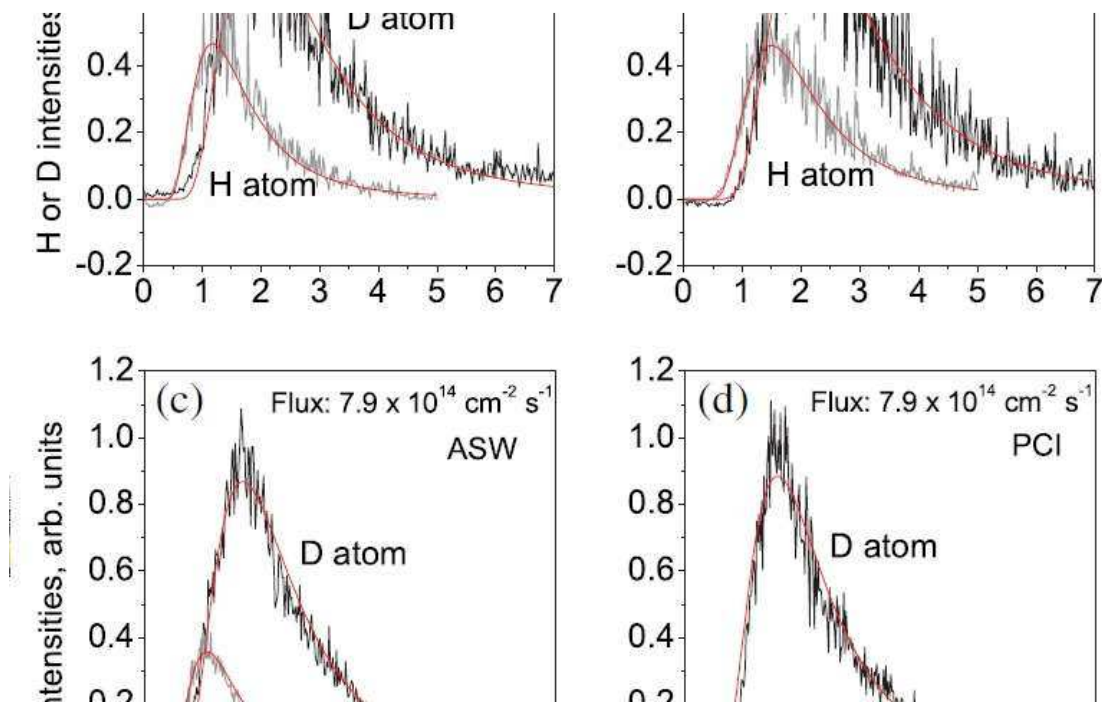
Now in a new study, scientists from Hokkaido University in Japan have reported the first evidence of quantum tunneling as a mechanism for the surface diffusion of hydrogen atoms on the surface of ice, although quantum tunneling has previously been observed for hydrogen atoms on the surface of some metals. In quantum tunneling, the hydrogen atoms can move through barriers that they otherwise could not pass through using only classical mechanisms, such as thermal hopping.

"This is the first observation of hydrogen-atom tunneling diffusion on an ice surface," coauthor Naoki Watanabe, Professor at Hokkaido University, told Phys.org.

The new finding means that surface diffusion in this situation may work differently than previously thought. This may have implications for understanding the formation of H₂ molecules in interstellar clouds, as the same hydrogen-on-ice surface diffusion process occurs on the surface of cosmic ice just before two hydrogen atoms combine to form an H₂ molecule.

Since quantum tunneling cannot be observed directly, the scientists had to detect its presence using a creative approach and some high-tech, laser-based analytical tools. In the previous studies on metal surfaces, quantum-tunneling diffusion was detected by taking advantage of the fact that, unlike thermal hopping, quantum tunneling is temperature-independent. Unfortunately, in the ice regime that the scientists investigated here, the temperatures are so low (below 20 K) that the temperature window in which diffusion occurs is too narrow to measure temperature dependence.

Instead, the scientists took advantage of an isotope effect. Based on previous experimental data and calculations on thermal hopping and the kinetic energies of gases, the scientists predicted that, at 10 K, hydrogen atoms (which have one proton and one electron) should diffuse at a rate that is 4.5 times faster than that of deuterium atoms (which have one proton, one electron, and one neutron). If the rate difference between the two isotopes were to significantly differ from 4.5 in experiments on ice, then the difference could not be explained by thermal hopping, and would be clear evidence of quantum-tunneling diffusion.



Larger-than-expected isotope effect: The PSD-REMPI ion intensities of the deuterium atoms are approximately twice as strong as those of the hydrogen atoms for (a) amorphous solid water and (b) polycrystalline ice at low atomic fluxes. However, the D/H ratio increases with increasing atomic flux by a small amount for (c) amorphous solid water and a larger amount for (d) polycrystalline ice. This large difference in (d) indicates that hydrogen atoms diffuse much faster than deuterium atoms, strongly suggesting that surface diffusion occurs due to quantum tunneling in this ice at higher fluxes. Credit: Kuwahata, et al. ©2015 American Physical Society

As it turned out, the new experimental results showed that, at 10 K, hydrogen atoms diffuse 100 times faster than deuterium ions on a highly ordered type of ice called polycrystalline ice. The researchers concluded that this larger-than-expected kinetic isotope effect can only be explained by quantum tunneling.

The researchers also found that, on a less-ordered type of ice called amorphous solid water, the rate difference is about 16, which is only somewhat higher than expected. The scientists believe that this small increase suggests that quantum tunneling may play a role in the surface diffusion on this type of ice, but thermal hopping is likely still the dominant mechanism. The reason why quantum tunneling may be suppressed on amorphous solid water may have to do with its nonperiodic structure, whereas polycrystalline ice has a periodic structure.

Another interesting part of the study is the way that the researchers determined the rates—not by direct measurement, but by using two laser techniques called photostimulated desorption (PSD) and resonance-enhanced multiphoton ionization (REMPI). The PSD laser beam first desorbs/detaches the adsorbed gas atoms on the ice surface, and then the REMPI laser ionizes the desorbed atoms. The researchers then measured the ion intensities, which are proportional to the number of desorbed atoms. By comparing the ion intensities of the desorbed hydrogen and deuterium atoms, the scientists could determine the ratio of their concentrations, which in turn could be used to find the ratio of their diffusion rates.

As the scientists explained, the results could lead to a better understanding of the astrochemical H₂ formation process, and they plan to pursue this area more in the future.

"The diffusion mechanism—whether tunneling or thermal hopping—strongly depends on the morphology of the ice surface," Watanabe said. "Cosmic ice has various ranges of morphology. This work demonstrates how H atoms on cosmic ice diffuse toward H₂ formation. The H atoms alternate between tunneling diffusion and thermal hopping until encountering a reaction partner of another H atom. In the future, we would like to continue with similar experiments on heavier atoms such as oxygen and radicals, which also exist on cosmic ice and contribute to the formation of molecules on the cosmic ice." [10]

Physicists solve quantum tunneling mystery

At very small scales quantum physics shows that particles such as electrons have wave-like properties – their exact position is not well defined. This means they can occasionally sneak through apparently impenetrable barriers, a phenomenon called quantum tunneling.

Quantum tunneling plays a role in a number of phenomena, such as nuclear fusion in the sun, scanning tunneling microscopy, and flash memory for computers.

However, the leakage of particles also limits the miniaturisation of electronic components.

Professor Kheifets and Dr. Igor Ivanov, from the ANU Research School of Physics and Engineering, are members of a team which studied ultrafast experiments at the attosecond scale (10⁻¹⁸ seconds), a field that has developed in the last 15 years.

Until their work, a number of attosecond phenomena could not be adequately explained, such as the time delay when a photon ionised an atom.

“At that timescale the time an electron takes to quantum tunnel out of an atom was thought to be significant. But the mathematics says the time during tunneling is imaginary – a complex number – which we realised meant it must be an instantaneous process,” said Professor Kheifets.

“A very interesting paradox arises, because electron velocity during tunneling may become greater than the speed of light. However, this does not contradict the special theory of relativity, as the tunneling velocity is also imaginary” said Dr Ivanov, who recently took up a position at the Center for Relativistic Laser Science in Korea.

The team’s calculations, which were made using the Raijin supercomputer, revealed that the delay in photoionisation originates not from quantum tunneling but from the electric field of the nucleus attracting the escaping electron.

The results give an accurate calibration for future attosecond-scale research, said Professor Kheifets.

“It’s a good reference point for future experiments, such as studying proteins unfolding, or speeding up electrons in microchips,” he said. [9]

Asymmetry in the interference occurrences of oscillators

The asymmetrical configurations are stable objects of the real physical world, because they cannot annihilate. One of the most obvious asymmetry is the proton – electron mass rate $M_p = 1840 M_e$ while they have equal charge. We explain this fact by the strong interaction of the proton, but how remember it his strong interaction ability for example in the H – atom where are only electromagnetic interactions among proton and electron.

This gives us the idea to origin the mass of proton from the electromagnetic interactions by the way interference occurrences of oscillators. The uncertainty relation of Heisenberg makes sure that the particles are oscillating.

The resultant intensity due to n equally spaced oscillators, all of equal amplitude but different from one another in phase, either because they are driven differently in phase or because we are looking at them an angle such that there is a difference in time delay:

$$(1) I = I_0 \sin^2 n \phi/2 / \sin^2 \phi/2$$

If ϕ is infinitesimal so that $\sin\phi = \phi$, than

$$(2) I = n^2 I_0$$

This gives us the idea of

$$(3) M_p = n^2 M_e$$

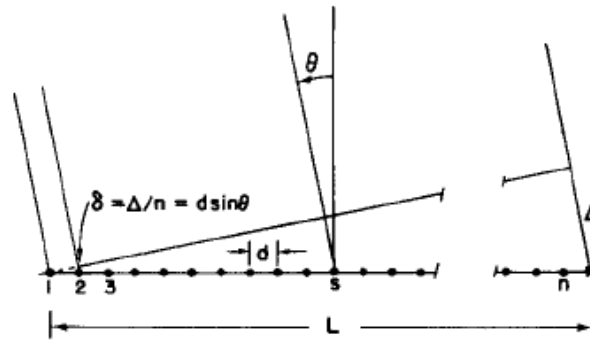


Fig. 30-3. A linear array of n equal oscillators, driven with phases $\alpha_s = s\alpha$.

Figure 1.) A linear array of n equal oscillators

There is an important feature about formula (1) which is that if the angle ϕ is increased by the multiple of 2π , it makes no difference to the formula.

So

$$(4) \quad d \sin \theta = m \lambda$$

and we get m -order beam if λ less than d . [6]

If d less than λ we get only zero-order one centered at $\theta = 0$. Of course, there is also a beam in the opposite direction. The right chooses of d and λ we can ensure the conservation of charge.

For example

$$(5) \quad 2(m+1) = n$$

Where $2(m+1) = N_p$ number of protons and $n = N_e$ number of electrons.

In this way we can see the H_2 molecules so that $2n$ electrons of n radiate to $4(m+1)$ protons, because $d_e > \lambda_e$ for electrons, while the two protons of one H_2 molecule radiate to two electrons of them, because of $d_p < \lambda_e$ for this two protons.

To support this idea we can turn to the Planck distribution law, that is equal with the Bose – Einstein statistics.

Spontaneously broken symmetry in the Planck distribution law

The Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms molecules, crystals, dark matter and energy.

Max Planck found for the black body radiation

As a function of wavelength (λ), Planck's law is written as:

$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}.$$

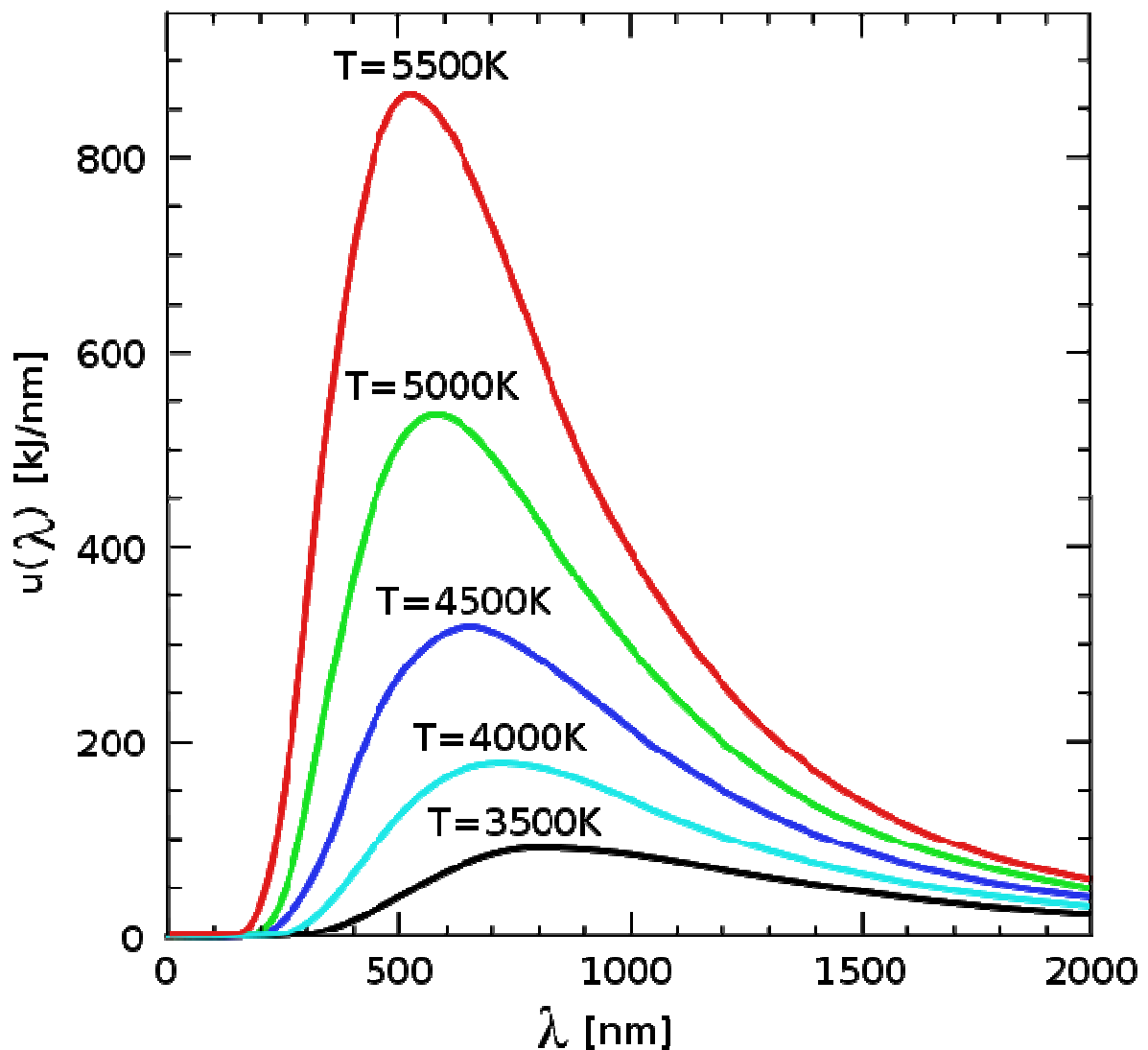


Figure 2. The distribution law for different T temperatures

We see there are two different λ_1 and λ_2 for each T and intensity, so we can find between them a d so that $\lambda_1 < d < \lambda_2$.

We have many possibilities for such asymmetrical reflections, so we have many stable oscillator configurations for any T temperature with equal exchange of intensity by radiation. All of these configurations can exist together. At the λ_{\max} is the annihilation point where the configurations are symmetrical. The λ_{\max} is changing by the Wien's displacement law in many textbooks.

$$(7) \quad \lambda_{\max} = \frac{b}{T}$$

where λ_{\max} is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's displacement constant*, equal to $2.8977685(51) \times 10^{-3} \text{ m} \cdot \text{K}$ (2002 CODATA recommended value).

By the changing of T the asymmetrical configurations are changing too.

The structure of the proton

We must move to the higher T temperature if we want look into the nucleus or nucleon arrive to $d < 10^{-13} \text{ cm}$. [2] If an electron with $\lambda_e < d$ move across the proton then by (5) $2(m+1) = n$ with $m = 0$ we get $n = 2$ so we need two particles with negative and two particles with positive charges. If the proton can fraction to three parts, two with positive and one with negative charges, then the reflection of oscillators are right. Because this very strange reflection where one part of the proton with the electron together on the same side of the reflection, the all parts of the proton must be quasi lepton so $d > \lambda_q$. One way dividing the proton to three parts is, dividing his oscillation by the three direction of the space. We can order $1/3 e$ charge to each coordinates and $2/3 e$ charge to one plane oscillation, because the charge is scalar. In this way the proton has two $+2/3 e$ plane oscillation and one linear oscillation with $-1/3 e$ charge. The colors of quarks are coming from the three directions of coordinates and the proton is colorless. The flavors of quarks are the possible oscillations differently by energy and if they are plane or linear oscillations. We know there is no possible reflecting two oscillations to each other which are completely orthogonal, so the quarks never can be free, however there is asymptotic freedom while their energy are increasing to turn them to orthogonal. If they will be completely orthogonal then they lose this reflection and take new partners from the vacuum. Keeping the symmetry of the vacuum the new oscillations are keeping all the conservation laws, like charge, number of baryons and leptons. The all features of gluons are coming from this model. The mathematics of reflecting oscillators show Fermi statistics.

Important to mention that in the Deuteron there are 3 quarks of $+2/3$ and $-1/3$ charge, that is three u and d quarks making the complete symmetry and because this its high stability.

The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

Another important issue of the quark model is when one quark changes its flavor such that a linear oscillation transforms into plane oscillation or vice versa, changing the charge value with 1 or -1. This kind of change in the oscillation mode requires not only parity change, but also charge and time changes (CPT symmetry) resulting a right handed anti-neutrino or a left handed neutrino.

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse, because they are different geometrical constructions, the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

The neutrino is a 1/2 spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with $\frac{1}{2}$ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The limit of the velocity of particles as the speed of light appropriate only for electrical charged particles, since the accelerated charges are self maintaining locally the accelerating electric force. The neutrinos are CP symmetry breaking particles compensated by time in the CPT symmetry, that is the time coordinate not works as in the electromagnetic interactions, consequently the speed of neutrinos is not limited by the speed of light.

The weak interaction T-asymmetry is in conjunction with the T-asymmetry of the second law of thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes the weak interaction, for example the Hydrogen fusion.

Probably because it is a spin creating movement changing linear oscillation to 2 dimensional oscillation by changing d to u quark and creating anti neutrino going back in time relative to the proton and electron created from the neutron, it seems that the anti neutrino fastest then the velocity of the photons created also in this weak interaction?

A quark flavor changing shows that it is a reflection changes movement and the CP- and T- symmetry breaking. This flavor changing oscillation could prove that it could be also on higher level such as atoms, molecules, probably big biological significant molecules and responsible on the aging of the life.

Important to mention that the weak interaction is always contains particles and antiparticles, where the neutrinos (antineutrinos) present the opposite side. It means by Feynman's interpretation that these particles present the backward time and probably because this they seem to move faster than the speed of light in the reference frame of the other side.

Finally since the weak interaction is an electric dipole change with $\frac{1}{2}$ spin creating, it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The Strong Interaction - QCD

Confinement and Asymptotic Freedom

For any theory to provide a successful description of strong interactions it should simultaneously exhibit the phenomena of confinement at large distances and asymptotic freedom at short distances. Lattice calculations support the hypothesis that for non-abelian gauge theories the two domains are analytically connected, and confinement and asymptotic freedom coexist. Similarly, one way to show that QCD is the correct theory of strong interactions is that the coupling extracted at various scales (using experimental data or lattice simulations) is unique in the sense that its variation with scale is given by the renormalization group. The data for α_s is reviewed in Section 19. In this section I will discuss what these statements mean and imply. [4]

Lattice QCD

Lattice QCD is a well-established non-perturbative approach to solving the quantum chromodynamics (QCD) theory of quarks and gluons. It is a lattice gauge theory formulated on a grid or lattice of points in space and time. When the size of the lattice is taken infinitely large and its sites infinitesimally close to each other, the continuum QCD is recovered. [6]

Analytic or perturbative solutions in low-energy QCD are hard or impossible due to the highly nonlinear nature of the strong force. This formulation of QCD in discrete rather than continuous space-time naturally introduces a momentum cut-off at the order $1/a$, where a is the lattice spacing, which regularizes the theory. As a result, lattice QCD is mathematically well-defined. Most importantly, lattice QCD provides a framework for investigation of non-perturbative phenomena such as confinement and quark-gluon plasma formation, which are intractable by means of analytic field theories.

In lattice QCD, fields representing quarks are defined at lattice sites (which leads to fermion doubling), while the gluon fields are defined on the links connecting neighboring sites.

QCD

QCD enjoys two peculiar properties:

- **Confinement**, which means that the force between quarks does not diminish as they are separated. Because of this, it would take an infinite amount of energy to separate two quarks; they are forever bound into hadrons such as the proton and the neutron. Although analytically unproven, confinement is widely believed to be true because it explains the consistent failure of free quark searches, and it is easy to demonstrate in lattice QCD.

- **Asymptotic freedom**, which means that in very high-energy reactions, quarks and gluons interact very weakly. This prediction of QCD was first discovered in the early 1970s by David Politzer and by Frank Wilczek and David Gross. For this work they were awarded the 2004 Nobel Prize in Physics.

There is no known phase-transition line separating these two properties; confinement is dominant in low-energy scales but, as energy increases, asymptotic freedom becomes dominant. [5]

Color Confinement

When two quarks become separated, as happens in particle accelerator collisions, at some point it is more energetically favorable for a new quark-antiquark pair to spontaneously appear, than to allow the tube to extend further. As a result of this, when quarks are produced in particle accelerators, instead of seeing the individual quarks in detectors, scientists see "jets" of many color-neutral particles (mesons and baryons), clustered together. This process is called hadronization, fragmentation, or string breaking, and is one of the least understood processes in particle physics. [3]

Electromagnetic inertia and mass

Electromagnetic Induction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass. [1]

The frequency dependence of mass

Since $E = h\nu$ and $E = mc^2$, $m = h\nu / c^2$ that is the m depends only on the ν frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_0 inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

Electron - Proton mass rate

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! Also since the particles are diffraction patterns they have some closeness to each other. [2]

There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of

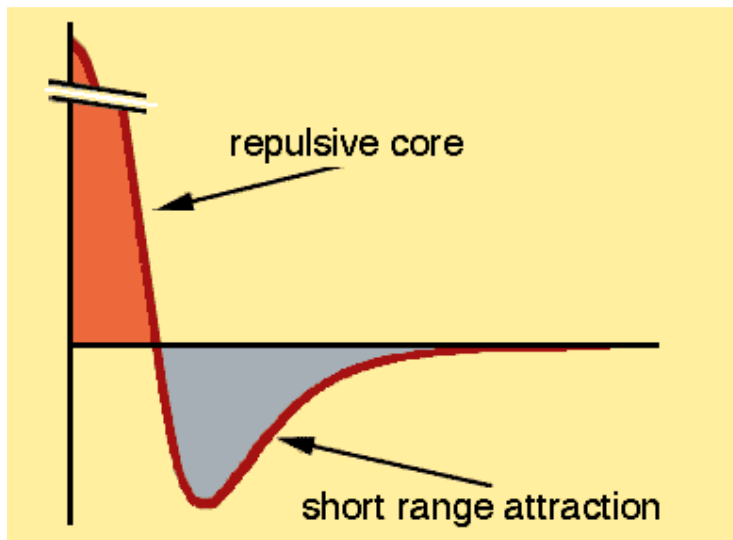
these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

The potential of the diffraction pattern

The force that holds protons and neutrons together is extremely strong. It has to be strong to overcome the electric repulsion between the positively charged protons. It is also of very short range, acting only when two particles are within 1 or 2 fm of each other.

1 fm (femto meter) = 10^{-15} m = 10^{-15} m = 0.000000000000001 meters.

The qualitative features of the nucleon-nucleon force are shown below.



There is an extremely **strong short-range repulsion** that pushes protons and neutrons apart before they can get close enough to touch. (This is shown in orange.) This repulsion can be understood to arise because the quarks in individual nucleons are forbidden to be in the same area by the Pauli Exclusion Principle.

There is a **medium-range attraction** (pulling the neutrons and protons together) that is strongest for separations of about 1 fm. (This is shown in gray.) This attraction can be understood to arise from the exchange of quarks between the nucleons, something that looks a lot like the exchange of a pion when the separation is large.

The density of nuclei is limited by the short range repulsion. The maximum size of nuclei is limited by the fact that the attractive force dies away extremely quickly (exponentially) when nucleons are more than a few fm apart.

Elements beyond uranium (which has 92 protons), particularly the trans-fermium elements (with more than 100 protons), tend to be unstable to fission or alpha decay because the Coulomb repulsion between protons falls off much more slowly than the nuclear attraction. This means that each proton sees repulsion from every other proton but only feels an attractive force from the few neutrons and protons that are nearby -- even if there is a large excess of neutrons.

Some "super heavy nuclei" (new elements with about 114 protons) might turn out to be stable as a result of the same kind of quantum mechanical shell-closure that makes noble gases very stable chemically. [7]

Conclusions

Lattice QCD gives the same results as the diffraction theory of the electromagnetic oscillators, which is the explanation of the strong force and the quark confinement. [8]

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