

ALPHA Antihydrogen Breakthrough

New research by a team from Aarhus, Swansea, and Purdue Universities has enabled recent experiments to make the first measurement of the 1S – 2S atomic state transition in antihydrogen. [12]

The LHCb experiment has found hints of what could be a new piece of the jigsaw puzzle of the missing antimatter in our universe. [11]

In a stringent test of a fundamental property of the standard model of particle physics, known as CPT symmetry, researchers from the RIKEN-led BASE collaboration at CERN have made the most precise measurements so far of the charge-to-mass ratio of protons and their antimatter counterparts, antiprotons. [10]

The puzzle comes from experiments that aimed to determine how quarks, the building blocks of the proton, are arranged inside that particle. That information is locked inside a quantity that scientists refer to as the proton's electric form factor. The electric form factor describes the spatial distribution of the quarks inside the proton by mapping the charge that the quarks carry. [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.

Contents

Preface.....	2
Paper reveals the theory behind ALPHA antihydrogen breakthrough.....	2
New source of asymmetry between matter and antimatter	3
Protons and antiprotons appear to be true mirror images.....	4
Scientists Mix Matter and Anti-Matter to Resolve Decade-Old Proton Puzzle	5
Asymmetry in the interference occurrences of oscillators	7
Spontaneously broken symmetry in the Planck distribution law.....	9
The structure of the proton	10
The weak interaction	11
The Strong Interaction - QCD	12

Confinement and Asymptotic Freedom	12
Lattice QCD.....	12
QCD	12
Color Confinement	13
Electromagnetic inertia and mass.....	13
Electromagnetic Induction	13
The frequency dependence of mass	13
Electron – Proton mass rate	13
The potential of the diffraction pattern	14
Conclusions	15
References	15

Author: George Rajna

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!

Paper reveals the theory behind ALPHA antihydrogen breakthrough

New research by a team from Aarhus, Swansea, and Purdue Universities has enabled recent experiments to make the first measurement of the 1S – 2S atomic state transition in antihydrogen.

In the paper, published in the Journal of Physics B: Atomic, Molecular and Optical Physics, a theoretical approach is developed for the ALPHA experiment at CERN, and provides the insight needed to make high precision spectroscopic measurements of the transition energy between the 1S and 2S energy levels.

As a result, successful measurements have now been made to a precision of better than one part in a billion.

According to lead author Dr Chris Rasmussen: "The calculations presented here enabled the first observation of the 1S-2S transition in antihydrogen by the ALPHA collaboration, which has been a long sought goal of the antimatter community."

The research presented by Dr Rasmussen, Professor Niels Madsen, and Professor Francis Robicheaux, also points the way forward to even higher precision measurements of the properties of antihydrogen.

The physical arrangement for the experiments is highly complex, and so far only a handful of antiatoms can be trapped at a time – typically fewer than 20. This means careful consideration needs to be given to the conditions of any measurement, to ensure the desired high precision can be reached.

The authors performed a series of calculations and simulations to determine a viable experimental method for precision measurements, considering both the details of the apparatus and the low number of antiatoms available for the experiment.

Antihydrogen research has been underway for many years, but it is only recently that neutral antihydrogen has been able to be trapped for use in spectroscopy. One of the ultimate goals of this research is to make high precision tests of CPT invariance by comparing the energy level structure of antihydrogen with its matter counterpart – hydrogen.

This then becomes a strict test of our understanding of how the universe came to be in its current state, as well as of the fundamental rules governing nature. Current data for hydrogen reaches and accuracy of a few parts in 10⁻¹⁵, and future antihydrogen measurements aim to match this.

Dr Professor Madsen said: "These measurements ultimately aim to compare hydrogen and antihydrogen at the level of the spectacular detail to which hydrogen has been probed, to assist in answering why the Universe appears, unexpectedly, to be devoid of antimatter." [12]

New source of asymmetry between matter and antimatter

The LHCb experiment has found hints of what could be a new piece of the jigsaw puzzle of the missing antimatter in our universe. They have found tantalising evidence of a phenomenon dubbed charge-parity (CP) violation in particles known as baryons – a family of particles whose best-known members are the protons and neutrons that make up all the matter in the universe.

The idea that the baryons made of matter behave exactly like their antimatter counterparts is related to the idea of CP symmetry. Any violation of this symmetry would imply that the laws of physics are not the same for matter and antimatter particles.

This is important because a detailed understanding of how this symmetry is violated in nature can contribute to explaining the overwhelming excess of matter over antimatter observed in our universe, despite the fact that the Big Bang should have created equal amounts of matter and antimatter in the first place.

The Standard Model (SM) of particle physics predicts that a tiny amount of CP violation exists also in the baryon sector. Although CP-violating processes have been studied for over 50 years, no significant effects had been seen with baryonic particles. Moreover, CP violation as described in the SM is not large enough to account for the much larger matter-antimatter unbalance. Therefore, other CP violation sources must contribute, and one of the main goals of LHCb is precisely to search for new sources of CP violation.

The new LHCb result is based on an analysis of data collected during the first three years of the Large Hadron Collider (LHC) operations. Among all the possible short-living particles created as a result of a proton-proton collision, the collaboration compared the behavior of the Λ_b^0 baryon and its

antimatter counterpart, Λ_b^- , when they decay into a proton (or antiproton) and three charged particles called pions. This process is extremely rare and has never previously been observed. The high production rate of these baryons at the LHC and the specialised capabilities of the LHCb detector allowed the collaboration to collect a pure sample of around 6000 such decays.

The LHCb collaboration compared the distribution of the four decay products of the Λ_b^0 and Λ_b^- baryons and computed specific quantities that are sensitive to the CP symmetry. Any significant difference, or asymmetry, between such quantities for the matter and antimatter cases would be a manifestation of CP violation.

The LHCb data revealed a significant level of asymmetries in those CP-violation-sensitive quantities for the Λ_b^0 and Λ_b^- baryon decays, with differences in some cases as large as 20 percent.

Overall, the statistical significance – which is how physicists refer to the probability that this result hasn't occurred by chance – is at the level of 3.3 standard deviations, and a discovery is claimed when this value reaches five standard deviations. These results, published today in *Nature Physics*, will soon be updated with the larger data set collected so far during the second run of the LHC. If this earlier evidence for CP violation is seen again with greater significance in the larger sample, the result will be an important milestone in the study of CP violation. [11]

Protons and antiprotons appear to be true mirror images

The work, published in *Nature*, was carried out using CERN's Antiproton Decelerator, a device that provides low-energy antiprotons for antimatter studies.

CPT invariance—which the experiment was meant to test—means that a system remains unchanged if three fundamental properties are reversed—C (charge), which distinguishes matter from antimatter, P (parity), which implies a 180 degree flip in space, and T (time). It is a central tenet of the standard model, and implies that antimatter particles must be perfect mirror images of matter, with only their charges reversed.

"This is an important issue," says Stefan Ulmer, who led the research, "because it helps us to understand why we live in a universe that has practically no antimatter, despite the fact that the Big Bang must have led to the creation of both. If we had found violations of CPT, it would mean that matter and antimatter might have different properties—for example that antiprotons might decay faster than protons—but we have found within quite strict limits that the charge-to-mass ratios are the same."

To perform the research, the team used a scheme similar to that developed by the TRAP collaboration in the 1990s. They received antiprotons and negative hydrogen ions—as a proxy for protons—from the Antiproton Decelerator, and then trapped single antiproton-hydrogen ion pairs in a magnetic Penning trap, decelerating them to ultra-low energies. They then measured the cyclotron frequency of the pairs—a measurement that allows scientists to determine the charge-to-mass ratio—and compared them to find how similar they were. In total, they measured approximately 6,500 pairs over a 35-day period.

"What we found," says Ulmer, "is that the charge-to-mass ratio is identical to within just 69 parts per trillion." This measurement has four times higher energy resolution than previous measurements of

proton-antiproton pairs, and further constrains the possibility of violations of CPT invariance. "Ultimately," he says, "we plan to achieve measurements that are at least ten or a hundred times more precise than the current standard."

The work also has implications for what is known as the weak equivalence principle—the idea that all particles will be affected by gravity in the same way, regardless of their mass and charge. The team used their findings to calculate that within about one part per million, antimatter and matter behave in the same way with respect to gravity.

According to BASE member Christian Smorra, "There are many reasons to believe in physics beyond the standard model, including the mystery of dark matter and, of course, the imbalance between matter and antimatter. These high-precision measurements put important new constraints and will help us to determine the direction of future research." [10]

Scientists Mix Matter and Anti-Matter to Resolve Decade-Old Proton Puzzle

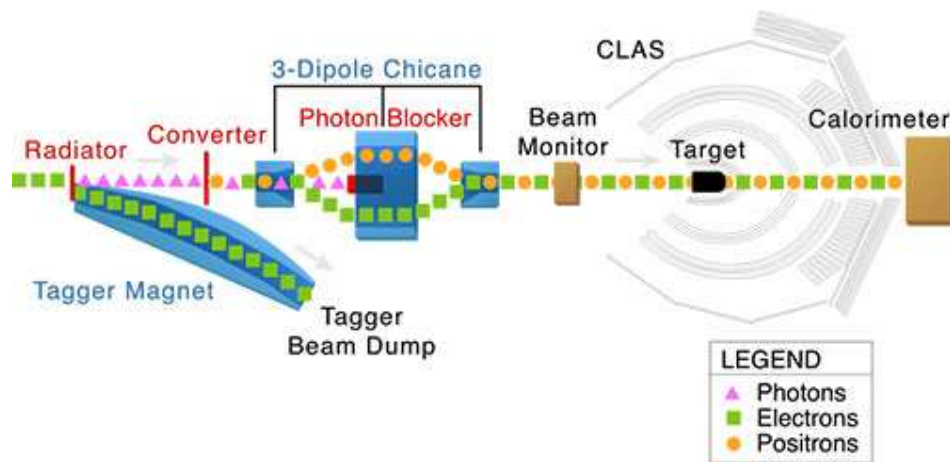


Nuclear physicists have used two different methods to measure the proton's electric form factor. But the deeper that they probe inside the proton, the more the results from these two different methods disagree. Eventually, the measurements provided by one method amount to about five times the quantity yielded by the other. This huge discrepancy is much larger than the experimental uncertainty in the measurements.

"The proposed solution for the discrepancy is that the analysis of one set of measurements was too simplistic," says Larry Weinstein, a professor of physics at Old Dominion University. "And that if we include something that is known as the two-photon effect, they both should agree."

The effect is a result of the manner in which nuclear scientists conduct their probes of the proton. The proton is probed by bombarding it with energetic electrons and observing how the two particles interact. Most of the time, this interaction consists of the electron exchanging a single virtual photon with the proton. A virtual photon is just a packet of energy that an electron gives up to the proton as it collides with the particle. But sometimes, the electron interacts with the proton differently; it may conjure up two virtual photons that it passes on to the proton.

“Normally, when an electron scatters off of a proton or off of a nucleus, it does it by exchanging a single virtual photon. Like two skaters passing by each other, and one throws a medicine ball to the other; it helps push them apart,” Weinstein explains. “Because the electromagnetic interaction is very weak, we expect that the second photon, second medicine ball, is only exchanged a few percent of the time. But that few percent effect could be big enough to explain this huge difference between the measurements of the proton’s electric form factor.”



This diagram shows the basic layout of the beam (electrons and positrons) and the magnets, target and detectors for Experiment E04-116 conducted using the CEBAF Large Acceptance Spectrometer in Experimental Hall B.

So, nuclear scientists needed a good measurement of how often an electron is likely to generate two photons via this two-photon effect. But there was a big problem: no one had ever measured this effect, and calculating it to any level of accuracy was too difficult due to the complexity of the proton.

To get that quantity, Weinstein and his colleagues turned to mixing matter with anti-matter.

It turns out that, while measuring the two-photon effect directly may be too difficult to do now, the scientists could instead measure a different quantity that relates to the effect. The two-photon effect can be measured indirectly by noting how often the electron interacts with the proton and comparing that to how often the electron’s anti-matter twin, the positron, interacts with the proton. The difference between electron and positron interactions calibrates the strength of the two photon effect and its effect on the form factor measurements.

Using the Continuous Electron Beam Accelerator Facility, or CEBAF, at Jefferson Lab, Weinstein and his colleagues set out to make the measurement in the winter of 2010. They started with a beam of

electrons, which they then passed through two gold foils and a few magnets to produce a beam composed of electrons and positrons. This beam was then directed onto the protons of a hydrogen target.

They then collected data on the electron-proton and positron-proton collisions with the CLAS spectrometer. Since an experiment like this had never been done before, it took them four years to analyze the data and extract precise results.

“There actually was a few percent difference. We got a few percent more positron-proton scattering events than electron-proton scattering events,” Weinstein says.

“So, our measurement agrees with the calculation, and the calculation accounts for most of the discrepancy between the two measurements of the proton’s electric form factor.”

According to the researchers, this means that the differences in the measurements of the proton’s electric form factor, which provides information on how quarks are distributed inside the proton, can be accounted for by the two-photon effect.

Two other research groups, the VEPP-3 collaboration at Novosibirsk and the OLYMPUS collaboration at DESY, have also been measuring this effect, although with single beams of electrons that they compare to single beams of positrons. VEPP-3 measured similar results and OLYMPUS collaborators are still analyzing their data. [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:

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

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

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

This gives us the idea of

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

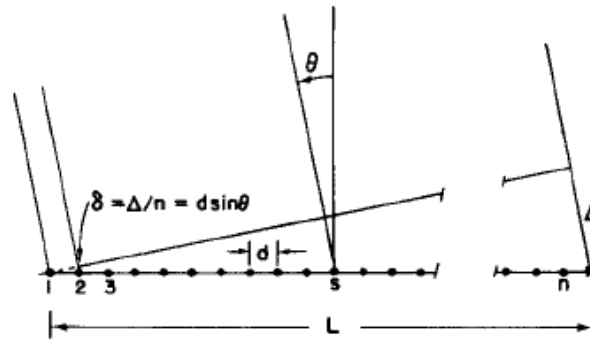


Fig. 30-3. A linear array of n equal oscillators, driven with phases $\alpha_s = s\alpha$.

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 $d_e < \lambda_e$ 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:

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

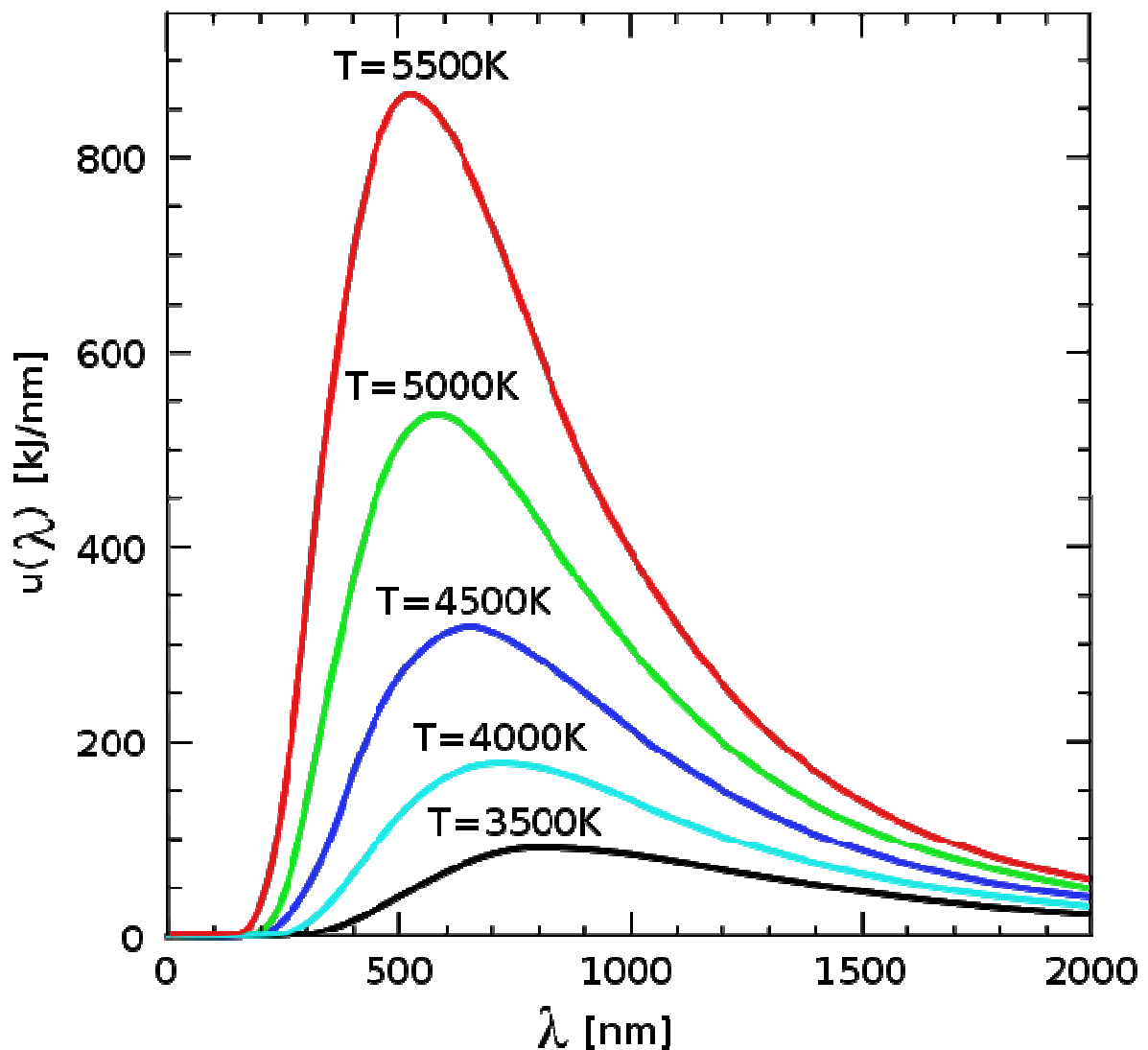


Figure 2. The distribution law for different T temperatures

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 $1/2$ 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

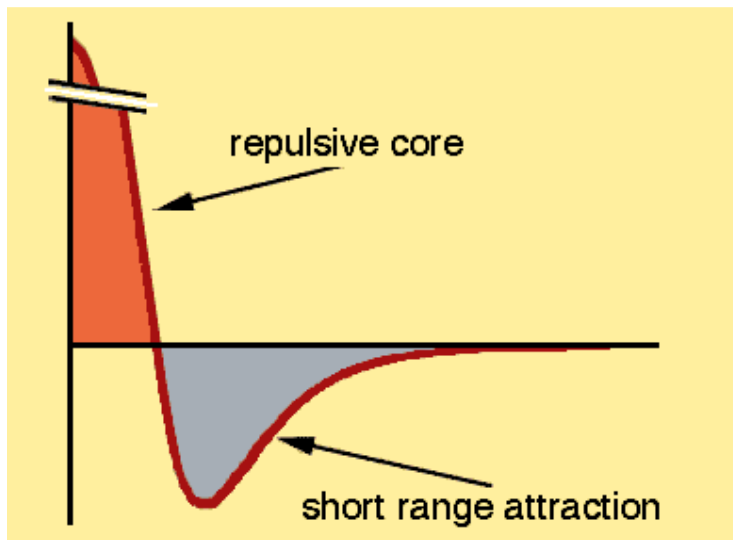
these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

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

According to BASE member Christian Smorra, "There are many reasons to believe in physics beyond the standard model, including the mystery of dark matter and, of course, the imbalance between matter and antimatter. These high-precision measurements put important new constraints and will help us to determine the direction of future research." [10]

Now that the proton-puzzle is apparently resolved, nuclear scientists will further explore the proton's electric form factor, revealing where quarks are in the proton, and the proton's magnetic form factor, revealing how quarks are moving inside the proton, to gain better insight into how quarks build protons. [9]

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]

References

[1] The Magnetic field of the Electric current and the Magnetic induction

http://academia.edu/3833335/The_Magnetic_field_of_the_Electric_current

[2] 3 Dimensional String Theory

http://academia.edu/3834454/3_Dimensional_String_Theory

[3] Color confinement - Wikipedia, the free encyclopedia

http://en.wikipedia.org/wiki/Color_confinement

[4] *INTRODUCTION TO LATTICE QCD*

<http://arxiv.org/abs/hep-lat/9807028>

[5] QCD http://en.wikipedia.org/wiki/Quantum_chromodynamics

[6] http://en.wikipedia.org/wiki/Lattice_QCD

[7]

<http://www.cartage.org.lb/en/themes/sciences/physics/NuclearPhysics/WhatIsNuclear/Forces/Forces.htm>

[8] Theory of Everything

http://www.academia.edu/4168202/Theory_of_Everything_-_4_Dimensional_String_Theory

[9] Scientists Mix Matter and Anti-Matter to Resolve Decade-Old Proton Puzzle

<https://www.jlab.org/news/stories/scientists-mix-matter-and-anti-matter-results-resolve-decade-old-proton-puzzle>

[10] Protons and antiprotons appear to be true mirror images

<http://phys.org/news/2015-08-protons-antiprotons-true-mirror-images.html>

[11] New source of asymmetry between matter and antimatter

<https://phys.org/news/2017-01-source-asymmetry-antimatter.html>

[12] Paper reveals the theory behind ALPHA antihydrogen breakthrough

<https://phys.org/news/2017-09-paper-reveals-theory-alpha-antihydrogen.html>