Neutrinos and Dark Matter

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Over the past few years, multiple neutrino experiments have detected hints for leptonic charge parity (CP) violation—a finding that could help explain why the universe is made of matter and not antimatter. So far, matter-antimatter asymmetry cannot be explained by any physics theory and is one of the biggest unsolved problems in cosmology. [8]

It could all have been so different. When matter first formed in the universe, our current theories suggest that it should have been accompanied by an equal amount of antimatter – a conclusion we know must be wrong, because we wouldn't be here if it were true. Now the latest results from a pair of experiments designed to study the behaviour of neutrinos – particles that barely interact with the rest of the universe – could mean we're starting to understand why. [7]

In 2012, a tiny flash of light was detected deep beneath the Antarctic ice. A burst of neutrinos was responsible, and the flash of light was their calling card. It might not sound momentous, but the flash could give us tantalising insights into one of the most energetic objects in the distant universe.

The light was triggered by the universe's most elusive particles when they made contact with a remarkable detector, appropriately called IceCube, which was built for the very purpose of capturing rare events such as this. [6]

Neutrinos and their weird subatomic ways could help us understand high-energy particles, exploding stars and the origins of matter itself. [5]

PHYSICS may be shifting to the right. Tantalizing signals at CERN's Large Hadron Collider near Geneva, Switzerland, hint at a new particle that could end 50 years of thinking that nature discriminates between left and right-handed particles. [4]

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.

The Neutrino Oscillation of the Weak Interaction shows that it is a General electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

Author: George Rajna

Elusive neutrinos and hypothetical 'dark sector' particles could hold answers to cosmic mysteries

All material things appear to be made of elementary particles that are held together by fundamental forces. But what are their exact properties? How do they affect how our universe looks and changes? And are there particles and forces that we don't know of yet?

Questions with cosmic implications like these drive many of the scientific efforts at the Department of Energy's SLAC National Accelerator Laboratory. Three distinguished particle physicists have joined the lab over the past months to pursue research on two particularly mysterious forms of matter: neutrinos and dark matter.

Neutrinos, which are abundantly produced in nuclear reactions, are among the most common types of particles in the universe. Although they were discovered 60 years ago, their basic properties puzzle scientists to this date.

Alexander Friedland, a senior staff scientist in SLAC's Elementary Particle Physics Theory Group, works on techniques that pave the way for future analyses of neutrino bursts from supernovae. Studying the details of these powerful star explosions helps scientists understand how dying stars spit out chemical elements into deep space.

Natalia Toro and Philip Schuster, associate professors of particle physics and astrophysics at SLAC, look for something even more enigmatic. They develop ideas for experiments that search for hidden particles and forces linked to dark matter, an invisible form of matter that is five times more prevalent than ordinary matter.

"Alex, Natalia and Philip are significant additions to the SLAC family, whose outstanding expertise tremendously strengthens our research in areas of national priority," says JoAnne Hewett, head of the lab's Elementary Particle Physics Division. Neutrino physics and dark matter research are among the five science drivers for U.S. particle physics identified in 2014 by the Particle Physics Project Prioritization Panel. Neutrino research also ranked high in the 2015 long-range plan for nuclear science issued by the Nuclear Science Advisory Committee.

Neutrinos from Across the Country and from Across the Galaxy

One of the major neutrino projects with SLAC involvement is the international Deep Underground Neutrino Experiment (DUNE) at the planned Long-Baseline Neutrino Facility (LBNF) – the world's flagship neutrino experiment for the coming decade and beyond. Researchers will send a neutrino beam produced at Fermi National Accelerator Laboratory in Illinois to the Sanford Underground Facility in South Dakota. After travelling 800 miles through the Earth, some of these neutrinos will be detected by the DUNE Far Detector, which will eventually consist of four 10,000-ton modules of liquid argon located 4,850 feet underground.

The ultrasensitive neutrino "eye" will measure how the three known types of neutrinos, called flavors, and their antiparticles morph from one into another during their underground journey. This study will provide crucial insights into the relative masses of neutrino flavors and the possibility that antineutrinos behave differently than neutrinos, which could potentially help explain why the universe is made of matter rather than antimatter. The experiment will also follow up on hints that there may be more than three neutrino flavors in nature.

"To help DUNE reach its full potential, my work addresses a number of fundamental questions," says Friedland, SLAC's first neutrino theorist, who joined the lab in the summer of 2015. "How can additional neutrinos be incorporated into our theories? Are there also additional forces? Is there a link between neutrinos and dark matter? How do neutrinos interact with atomic nuclei in the detector material?"

In addition to neutrinos from Fermilab, DUNE will also be able to detect very brief neutrino bursts from supernovae – powerful explosions of massive stars with cores that can no longer resist gravity and collapse to form dense neutron stars.

"Such a burst should be an exquisite probe of neutrino properties," Friedland says. "Our goal is to understand how to read the signal and optimize our detector for it."

Supernova explosions are important events in the universe. They inject chemical elements, synthesized inside stars over their lifetimes, into space, including crucial elements of life. Friedland hopes that DUNE's data will reveal never-before-seen details in the related neutrino bursts that could open a window into the processes inside dying stars.

"Our calculations show that those neutrino signals have a certain time structure that is linked to what's going on in the star," he says. "Measuring these minute details could help us understand the different stages of a supernova, from the collapse of the star's core to the outward propagation of powerful shock waves."

Such detailed analysis can only be done by looking at neutrinos. Unlike other particles, which frequently interact with their surroundings on their way out of the star and therefore carry the imprint of this complicated environment, neutrinos stream out nearly undisturbed and deliver direct information about the processes in which they were set free.

"Supernovae go off without warning, and detectable ones don't occur very often," says Friedland, who co-leads the DUNE supernova working group. "Although the next supernova neutrino burst may be a decade or more away, what will be seen then is affected by crucial decisions about the detector design made now. My job is to make sure that we'll be prepared."

SLAC provides a unique environment for the pursuit of this line of research, according to Friedland. "The lab is building a strong neutrino program, with experimentalists and theorists working closely together," he says. "It also unites a number of disciplines under one roof that stimulate and complement each other, from particle physics to astrophysics to computing."

Before coming to SLAC, Friedland was at Los Alamos National Laboratory, first as a Richard P. Feynman Fellow and then as a staff scientist. He received his doctorate in physics from the University of California, Berkeley in 2000 and pursued postdoctoral research at the Institute for Advanced Study in Princeton, New Jersey from 2000 to 2002. In addition to neutrinos, Friedland's studies look into unknown ultraweak forces in nature, extra dimensions beyond space and time and the effect of postulated particles on the evolution of stars.

Searching for 'Light Dark Matter'

Another burning question researchers around the world are yearning to answer is: What is dark matter? With 85 percent of all matter in the universe being dark, this invisible substance has tremendous influence on how the cosmos evolves. Although scientists know that dark matter exists because it gravitationally pulls on ordinary matter, they have yet to find out what it is made of.

At SLAC, Natalia Toro and Philip Schuster search for entire dark sectors of hypothetical particles and forces that could be linked to dark matter.

"We work on a number of small-scale experiments that have a real shot at discovering what dark matter is or what it isn't," Schuster says. "Unlike most dark matter searches, which focus on rather massive particles, we look for much lighter ones, in a mass range that is surprisingly unexplored."

The researchers participate in two experiments that hunt for light dark matter at the Thomas Jefferson National Accelerator Facility in Virginia: the Heavy Photon Search (HPS), for which the scientists developed the theoretical framework, and the A Prime Experiment (APEX), which they co-lead. Both experiments hope to catch a glimpse of dark photons – hypothetical carriers of a new force – that could potentially be produced when powerful electron beams slam into a target. Toro and Schuster are also members of a collaboration that proposed a third experiment at Jefferson Lab to search for dark matter, the Beam Dump Experiment (BDX).

Similar searches could also be done at SLAC once the upgrade to the lab's Linac Coherent Light Source (LCLS) X-ray laser, a DOE Office of Science User Facility, is complete. The future LCLS-II will produce X-rays from a rapid sequence of electron bunches – up to a million per second – that will fly through the facility's linear particle accelerator.

"We're developing ideas for an experiment that would use the dark current of LCLS-II's electron beam," Toro says. "This is a small number of unused electrons in between the main bunches that we could extract and shoot into targets for light dark matter searches."

A proposal based on this concept is the Light Dark Matter Experiment (LDMX), whose young collaboration is led by researchers from the University of California, Santa Barbara, the University of Minnesota and SLAC.

At the moment, the parasitic use of LCLS-II is only an idea, but Toro and Schuster have already teamed up with members of SLAC's Accelerator Directorate to think about how these experiments could be designed and, most importantly, operated without interfering with X-ray laser operations. Together they are exploring the possibility for a future facility for Dark Sector Experiments at LCLS-II (DASEL).

"The lab has a unique culture of vibrant collaborations," Toro says. "It creates an ideal environment to follow through with our projects from beginning to end. Here we can establish the theoretical foundation, work on the engineering aspects and turn them into successful experiments, all in one place."

The husband-and-wife team joined SLAC's faculty on Dec. 1, 2015. In addition to their work on dark sectors, the couple shares a variety of other research interests, such as searching for new physics in data from the Large Hadron Collider at CERN, the European particle physics laboratory, and making theories that aim at better understanding the spin of massless particles.

"It's great to share your passion for the most basic aspects of nature also outside work," Schuster says. "We amplify each other's excitement and hold each other to high standards. On top of that, it's also a lot of fun to go off on wild research adventures and explore new places together."

Prior to their appointments at SLAC, the particle physicists were junior faculty members at the Perimeter Institute for Theoretical Physics in Canada. After receiving their doctorates in physics from Harvard University in 2007, they spent three years in the San Francisco Bay Area, Toro as a postdoctoral scholar at Stanford University and Schuster as a research associate at SLAC. In 2015, both researchers received the New Horizons in Physics Prize. [10]

Evidence mounts that neutrinos are the key to the universe's existence

New experimental results show a difference in the way neutrinos and antineutrinos behave, which could explain why matter persists over antimatter.

The results, from the T2K experiment in Japan, show that the degree to which neutrinos change their type differs from their antineutrino counterparts. This is important because if all types of matter and antimatter behave the same way, they should have obliterated each other shortly after the Big Bang.

So far, when scientists have looked at matter-antimatter pairs of particles, no differences have been large enough to explain why the universe is made up of matter – and exists – rather than being annihilated by antimatter.

Neutrinos and antineutrinos are one of the last matter-antimatter pairs to be investigated since they are difficult to produce and measure, but their strange behaviour hints that they could be the key to the mystery.

Flavour change

Neutrinos (and antineutrinos) come in three 'flavours' of tau, muon and electron, each of which can spontaneously change into the other as the neutrinos travel over long distances.

The latest results, announced today by a team of researchers including physicists from Imperial College London, show more muon neutrinos changing into electron neutrinos than muon antineutrinos changing into electron antineutrinos.

This difference in muon-to-electron changing behaviour between neutrinos and antineutrinos means they would have different properties, which could have prevented them from destroying each other and allow the universe to exist.

To explore the (anti)neutrino flavour changes, known as osciallations, the T2K experiment fires a beam of (anti)neutrinos from the J-PARC laboratory at Tokai Village on the eastern coast of Japan.

It then detects them at the Super-Kamiokande detector, 295 km away in the mountains of the north-western part of the country. Here, the scientists look to see if the (anti)neutrinos at the end of the beam matched those emitted at the start.

Very intriguing

The latest results were concluded from relatively few data points, meaning there is still a one in 20 chance that the results are due to random chance, rather than a true difference in behaviour. However, the result is still exciting for the scientists involved.

Dr Morgan Wascko, international co-spokesperson for the T2K experiment from the Department of Physics at Imperial said: "This is an important first step towards potentially solving one of the biggest mysteries in science.

"T2K is the first experiment that is able to study neutrino and antineutrino oscillation under the same conditions, and the disparity we have observed is, while not yet statistically significant, very intriguing."

Dr Yoshi Uchida, also from the Department of Physics at Imperial and a principal investigator at T2K, added: "More data is needed to prove conclusively that neutrinos and antineutrinos behave differently, but this result is an indication that neutrinos will continue to provide breakthroughs in our understanding of the universe.

Upgrades to the equipment that produces (anti)neutrinos, as well as to the detector that measures them, are expected to add more data within the next decade, and determine whether the difference is in fact real. [9]

CP violation or new physics?

Over the past few years, multiple neutrino experiments have detected hints for leptonic charge parity (CP) violation—a finding that could help explain why the universe is made of matter and not antimatter. So far, matter-antimatter asymmetry cannot be explained by any physics theory and is one of the biggest unsolved problems in cosmology.

But now in a new study published in Physical Review Letters, physicists David V. Forero and Patrick Huber at Virginia Tech have proposed that the same hints could instead indicate CP-conserving "new physics," and current experiments would have no way to tell the difference.

Both possibilities—CP violation or new physics—would have a major impact on the scientific understanding of some of the biggest questions in cosmology.

Currently, one of the most pressing problems is the search for new physics, or physics beyond the Standard Model, which is a theory that scientists know is incomplete but aren't sure exactly how to improve. New physics could potentially explain several phenomena that the Standard Model cannot, including the matter-antimatter asymmetry problem, as well as dark matter, dark energy, and gravity.

As the scientists show in the new study, determining whether the recent hints indicate CP violation or new physics will be very challenging. The main goal of the study was to "quantify the level of confusion" between the two possibilities. The physicists' simulations and analysis revealed that both CP violation and new physics have distributions centered at the exact same value for what the neutrino experiments measure—something called the Dirac CP phase. This identical preference makes it impossible for current neutrino experiments to distinguish between the two cases.

"Our results show that establishing leptonic CP violation will need exceptional care, and that new physics can in many ways lead to non-trivial confusion," Huber told Phys.org.

The good news is that new and future experiments may be capable of resolving the issue. One possible way to test the two proposals is to compare the measurements of the Dirac CP phase made by two slightly different experiments: DUNE (the Deep Underground Neutrino Experiment) at Fermilab in Batavia, Illinois; and T2HK (the Tokai to Hyper-Kamiokande project) at J-PARC in Tokai, Japan.

"The trick is that the type of new physics we postulate in our paper manifests itself in the way in which neutrino oscillations are affected by the amount of earth matter through which the neutrino traverses," Huber said. "The more matter travelled through, the larger the effect of this type of new physics."

"Now, for DUNE, neutrinos would have to travel roughly 1300 km in the earth, whereas for T2HK they would travel only about 300 km. Thus one would find two different values for the Dirac CP phase in both cases, indicating a problem."

In order to be accurate, these experiments will require extremely high degrees of precision, which Huber emphasizes should not be overlooked.

"Of course, the same result could arise if for some reason either experiment was not properly calibrated and thus precisely calibrating these experiments will be extraordinarily important—a very difficult task, which I believe is not quite getting the attention it should." [8]

Neutrinos hint at why antimatter didn't blow up the universe

It could all have been so different. When matter first formed in the universe, our current theories suggest that it should have been accompanied by an equal amount of antimatter – a conclusion we know must be wrong, because we wouldn't be here if it were true. Now the latest results from a pair of experiments designed to study the behaviour of neutrinos – particles that barely interact with the rest of the universe – could mean we're starting to understand why.

Neutrinos and their antimatter counterparts, antineutrinos, each come in three types, or flavours: electron, muon and tau. Several experiments have found that neutrinos can spontaneously switch between these flavours, a phenomenon called oscillating.

The T2K experiment in Japan watches for these oscillations as neutrinos travel between the J-PARC accelerator in Tokai and the Super-Kamiokande neutrino detector in Kamioka, 295 kilometres away. It began operating in February 2010, but had to shut down for several years after Japan was rocked by a magnitude-9 earthquake in 2011.

Puff of radiation

In 2013, the team announced that 28 of the muon neutrinos that took off from J-PARC had become electron neutrinos by the time they reached Super-Kamiokande, the first true confirmation that the metamorphosis was happening.

They then ran the experiment with muon antineutrinos, to see if there was a difference between how the ordinary particles and their antimatter counterparts oscillate.

An idea called charge-parity (CP) symmetry holds that these rates should be the same.

CP symmetry is the notion that physics would remain basically unchanged if you replaced all particles with their respective antiparticles. It appears to hold true for nearly all particle interactions, and implies that the universe should have produced the same amount of matter and antimatter in the big bang.Matter and antimatter destroy one another, so if CP symmetry holds, both should have mostly vanished in a puff of radiation early on in the universe's history, well before matter was able to congeal into solid stuff. That's clearly not what happened, but we don't know why. Any deviation from CP symmetry we observe could help explain this discrepancy.

"We know in order to create more matter than antimatter in the universe, you need a process that violates CP symmetry," says Patricia Vahle, who works on NoVA, a similar experiment to T2K that sends neutrinos between Illinois and Minnesota. "So we're going out and looking for any process that can violate this CP symmetry."

Flavour changers

We already know of one: the interactions of different kinds of quarks, the constituents of protons and neutrons in atoms. But their difference is not great enough to explain why matter dominated so completely in the modern universe. Neutrino oscillations are another promising place to look for deviations.

This morning at the Neutrino conference in London, UK, we got our first signs of such deviations. Hirohisa Tanaka of the University of Toronto, Canada, reported the latest results from T2K. They have now seen 32 muon neutrinos morphing into the electron flavour, compared to just 4 muon antineutrinos becoming the anti-electron variety.

This is more matter and less antimatter than they expected to see, assuming CP symmetry holds. Although the number of detections in each experiment is small, the difference is enough to rule out CP symmetry holding at the 2 sigma level – in other words, there is only around a 5 per cent chance that T2K would see such differences if CP symmetry is preserved in this process.

Particle physicists normally wait until things reach the 3 sigma level before getting excited, and won't consider it a discovery until 5 sigma, so it's early days for neutrinos breaking CP symmetry. But at the same conference, Vahle presented the latest results from NoVA that revealed the two experiments were in broad agreement about the possibility.

The extent of CP violation rests on a key parameter called delta-CP, which ranges from 0 to 2π. Both teams found that their results were best explained by setting the value equal to 1.5π. "Their data really does prefer the same value that T2K does," says Asher Kaboth, who works on T2K. "All of the preferences for the delta-CP stuff are pointing in the same direction."

NoVA plans to run its own antineutrino experiments next year, which will help firm up the results, and both teams are continuing to gather more data. It's too soon to say definitively, but one of the mysteries of why we are here could be on the road to getting solved. [7]

What the universe's most elusive particles can tell us about the universe's most energetic objects

In 2012, a tiny flash of light was detected deep beneath the Antarctic ice. A burst of neutrinos was responsible, and the flash of light was their calling card.

It might not sound momentous, but the flash could give us tantalising insights into one of the most energetic objects in the distant universe.

The light was triggered by the universe's most elusive particles when they made contact with a remarkable detector, appropriately called IceCube, which was built for the very purpose of capturing rare events such as this.

The team of international researchers now suspects the event may have originated from a quasar, which is the active nucleus of a galaxy billions of light-years away.

The flash also potentially opens up a new era of neutrino astrophysics and may help unravel the mystery of neutrino production in the universe.

The antisocial particle that came in from the cold

Neutrinos are elementary particles and one of the smallest building blocks of the universe. Despite being one of the most abundant and energetic particles, neutrinos have a reputation of being notoriously hard to detect.

This is because they very rarely interact with normal matter. In fact, billions of them pass through your body every minute without even causing a tickle.

What the universe's most elusive particles can tell us about the universe's most energetic objects

There’s a lot more of the IceCube neutrino detector below the ice. Credit: Erik Beiser, IceCube/NSF

So how do you find such an antisocial particle?

It might not look it from the frosty surface of Antarctica, but Ice Cube is one of the world's largest telescopes, and the largest for detecting neutrinos.

IceCube occupies a cubic kilometre of clear ice, which provides the best medium for thousands of sensors to capture that elusive burst of light created when a high energy neutrino collides with an ice particle.

Although the probability of a collision is minuscule, there are so many neutrinos that pass through the detector that eventually some will interact with the ice.

The trick then is to determine where the neutrinos originated. Neutrinos are produced by the nuclear reactions going on at the centre of stars and in other highly energetic cosmic processes.

So when trying to find origin of the 2012 neutrino burst, Professor Sergei Gulyaev, the director of Auckland University of Technology's Institute for Radio Astronomy and Space Research told The Conversation that there was no shortage of candidates. The sky was literally the limit.

"Out of millions of astronomical objects, which one was responsible?"

Nucleus of a galaxy

A network of New Zealand, Australian and African radio telescopes searched the skies for what might have triggered the 2012 flash.

But one candidate stood out. Radio astronomers were able to create an image of a distant object that appeared to change dramatically after the neutrino burst was registered in South Pole.

What the universe's most elusive particles can tell us about the universe's most energetic objects

The IceCube detector contains 5,160 individual sensors that go down to a depth of nearly 2.5 kilometres beneath the ice. Credit: IceCube Collaboration

From this, they decided that the most likely source of the neutrinos was a quasar, called PKS 1424-418, located 9.1 billion light years away – nearly at the edge of the visible universe.

A quasar is the active nucleus of a primordial galaxy with a supermassive black hole at its core.

"We knew before that huge fluxes of very energetic particles came from space. We call them 'cosmic rays'. Neutrinos are part of them. But we had no idea which astronomical objects are responsible for this."

Gulyaev emphasised that they had to be cautious before drawing any conclusions about the source of the neutrinos.

"We were very careful, but combining radio astronomical and gamma-ray observations made by NASA's Fermi gamma-ray space telescope, we now know where or what it is. Given the huge increase in energy, shape change and activity, we are 95% sure that a quasar was responsible for the event registered by IceCube."

Gulyaev added that this particular quasar was active while the universe was very young.

"Quasars are like dinosaurs. They became extinct a long time ago," said Gulyaev. "But because astronomy is like a time machine, we were able to study this quasar."

The study may also open a new window into the distant universe. Whereas most astronomy is conducted by studying electromagnetic radiation, such as light or radio waves, these can be obscured or distorted as they travel through space.

But because neutrinos pass through most matter, and aren't influenced by magnetic fields, they can pass through vast stretches of the cosmos uninterrupted. If we can detect them reliably, we might be able to observe things we can't normally see.

An exciting problem

Professor Ron Ekers, an astrophysicist from CSIRO, said the study presents tantalising possibilities of an extragalatic origin of the high energy neutrino burst.

However, the true test of time will be if the model can eventually predict future detections alongside more precise measurements of neutrino positions that would be possible in the future.

Ekers said that although the model presents a possible origin, a crucial step would be to increase the level of accuracy in neutrino detection instruments to more precisely pinpoint and narrow down possible sources.

"Current position errors for these neutrinos are quite large and there are many possible objects which could be the source."

Ekers added that both IceCube and the Mediterranean Neutrino Array (KM3NeT) have future plans to greatly improve positional accuracy to fulfil that need.

"Finding out where the high energy neutrinos come from is one of the most exciting problems in astrophysics today. Now we have a possible identification we desperately need to improve the directional accuracy of the neutrino detections. " [6]

Neutrinos: Ghosts of the Universe

Why, after millions of years of steadily lighting the cold darkness, does a supergiant star suddenly explode in a blinding blaze of glory brighter than 100 billion stars?
What exotic objects in deep space are firing out particles at by far the highest energies in the universe? And perhaps most mind-bending, why does the universe contain any matter at all? These mysteries have vexed astrophysicists and particle physicists for decades. The key to solving all three deep conundrums is itself one of the greatest enigmas of physics: the neutrino.

The universe is awash in these peculiar, nearly massless, subatomic particles. Created in tremendous numbers right after the Big Bang, and constantly churned out in stars and other places by radioactive decay and other reactions, trillions of these ghostly particles sail right through stars and planets, including our own.

Carrying no electrical charge, neutrinos are attracted neither to protons nor electrons, so they don’t interact with electromagnetic fields. They also don’t feel a powerful force that operates on tiny scales, known simply as the strong force, which binds protons and neutrons together in an atom’s nucleus.

Neutrinos are more aloof than supermodels, rarely interacting meaningfully with one another or with anything else in the universe. Paradoxically, it is their disengaged quality that earns them a crucial role both in the workings of the universe and in revealing some of its greatest secrets.

Neutrino physics is entering a golden age. As part of one experiment, neutrinos have recently opened a new window on high-energy sources in deep space, such as black holes spewing out particles in beams trillions of miles long.

Another astronomy experiment deep underground in a Japanese mine will use neutrinos to learn the average temperature and energy of ancient supernovae to better understand their typical behavior. And physicists are using computer modeling to close in on the neutrino’s critical role in triggering the kind of supernovae that distribute essential elements like oxygen and nitrogen.

Beyond expanding the role of neutrinos in astronomy and uncovering their role in astrophysics, physicists are still trying to discover some of the neutrino's basic properties. Some researchers, for instance, are trying to pin down the particle's possible masses. That fundamental information would influence theories that explain the masses of other particles.

By determining yet another elusive fundamental property of neutrinos, researchers also hope to answer one of theoretical physics's great riddles: why all the matter and antimatter created by the Big Bang didn't cancel each other out and leave nothing but energy. At the dawn of the universe, for every particle of matter, such as an electron, there was an anti-electron; for every quark (a fundamental constituent of matter), there was an antiquark, explains physicist Chang Kee Jung of Stony Brook University. When these opposites meet, they should annihilate each other, creating pure energy.

So why is any matter left? The most plausible solution, leading physicists like Jung say, hinges on the theory that today's neutrinos, which have barely any mass, once had superheavy partners. These neutrino cousins, 100 trillion times more massive than a proton, formed in the tremendous heat that existed right after the Big Bang. They had the special androgynous ability to decay into either matter or antimatter counterparts. One such overweight particle might have decayed into a neutrino plus some other particle — like an electron, for instance — while another superheavy neutrino might have decayed into an antineutrino and another particle.

For this theory to explain why matter exists, those early superheavy neutrinos would have had to decay more frequently into particles than antiparticles. Physicists at neutrino detectors such as NOvA in Minnesota, in addition to trying to determine the masses of the neutrino, are studying whether today's lighter neutrinos switch from one type (or "flavor") to another at a different rate than antineutrinos. The same theory that could explain this behavior in today's light neutrinos could also explain the inclinations of superheavy neutrinos at the dawn of time. If the superheavy neutrino theory is correct, then these primordial particles are the "supreme ancestor" from which every particle in the cosmos descended.

Neutrino-related discoveries have already earned three Nobel prizes, and the path-breaking experiments underway could well earn more tickets to Stockholm. The seemingly superfluous neutrino couldn't be more essential to our understanding of the cosmos, or less concerned with its profound importance.

The Ice Telescope Cometh

Computers at the IceCube Laboratory at the Amundsen-Scott South Pole Station collect raw data and analyze results from the underground neutrino detector.

Scientists who want to detect neutrinos must build their detectors deep underground or underwater to filter out the cosmic rays that constantly bombard Earth.
(Neutrinos travel through matter, regardless of how dense.) Francis Halzen, a physicist at the University of Wisconsin-Madison, realized decades ago that Antarctica was an ideal spot because the ice was thick enough to bury thousands of light sensors more than a mile deep.

When a neutrino chances to slam into an atomic nucleus in the ice, an electron or muon (a heavier cousin of the electron) is created, releasing a trace of light. That trace of light can be picked up by IceCube, an underground telescope and particle detector at the South Pole. Halzen is one of nearly 250 people involved with the project.

In May 2012, IceCube physicists discovered the light footprints of two neutrinos with an incredible 1,000 times more energy than any neutrino ever detected before on Earth. Christened Bert and Ernie after the Sesame Street characters, they spurred IceCube scientists to re-examine the data at that energy level. Sure enough, they found 26 more high-energy neutrinos. When the scientists looked at more recent data through May 2013, they found nine more high-energy neutrinos, one of which had the energy of Bert and Ernie combined. “It’s named Big Bird, of course,” says Halzen.

Some neutrinos almost certainly hail from beyond our galaxy, and they could help solve a century-old mystery on the source of incredibly high-energy cosmic rays.
That source also is thought to produce high-energy neutrinos. Some possible scenarios: incredibly massive black holes erupting in jets of matter, galaxies colliding or star-producing factories known as starburst galaxies.

“IceCube is finally opening a new window on the universe,” says physicist John Beacom of Ohio State University. “All these years we have been doing astronomy with light (not just visible light), we have been missing a big part of the action.”

Neutrino Mysteries

Shape-Shifting

Neutrinos are notorious shape-shifters. Each one is born as one of three types, or flavors — electron, muon and tau — but they can change flavor in a few thousandths of a second as they travel, as if they can’t make up their mind what to be. Neutrinos, like other subatomic particles, sometimes behave like waves. But as the neutrino travels, the flavor waves combine in different ways. Sometimes the combination forms what is mostly an electron neutrino and sometimes mostly a muon neutrino.

Because neutrinos are quantum particles, and by definition weird, they are not one single flavor at a time, but rather always a mixture of flavors. On the very, very rare occasion that a neutrino interacts with another particle, if the reaction appears to produce an electron, then the neutrino was an electron flavor in its final moments; if it produces a muon, the neutrino was muon-flavored. It’s as if the shy neutrino’s identity crisis can only be resolved when it finally interacts with another particle.

Heavyweight Competition

Physicists hope to use neutrinos' strange shape-shifting behavior to unlock several mysteries. Scientists know the mass of every other fundamental particle, such as the electron, but the neutrino — at least a million times as light as the electron — is far more elusive because of its transformative ways.

The discovery of neutrino masses would influence the fundamental theory of how particles and forces interact, the so-called standard model of particle physics.
Physicists already know the theory is incomplete because it incorrectly predicts neutrinos have no mass. "It may help us to better understand the reasons behind the masses of all particles," says William Louis of Los Alamos National Laboratory. "A jigsaw puzzle is much easier to put together once all of the pieces are available."

The difficulty in pinning down neutrino masses lies in the Heisenberg uncertainty principle, a cornerstone of quantum physics. It states that certain properties of subatomic particles are linked such that the more precisely you know one, the less precisely you can know the other. For instance, if you know exactly where a particle is, then you can't know its momentum. And once you've pinned down the particle's momentum, you can't absolutely know its location. A neutrino's flavor and mass are linked in a similar way, says Indiana University physicist Mark Messier. You can't know both at the same time. For that reason, he says, "We always measure some combination of masses. … It does not even make sense to ask what the mass is for a single flavor of neutrino."

As far as scientists can tell, each neutrino is a combination of three masses, but they can't learn that combination without taking a measurement. Two of those masses are likely to identify as electron neutrinos a significant portion of the time, and one mass only infrequently comes up as electron neutrino, says Messier. Physicists are not sure if the greatest, or heaviest, of the three masses is most likely to be an electron neutrino or least likely to be an electron neutrino.

When Lefties Turn Right

All matter has a mirror image, called antimatter. For an electron, which has a negative charge, the antimatter twin — the positron — is identical except that it has a positive charge. If matter meets antimatter, they destroy each other in a burst of energy.

For each of the three flavors of neutrino, there is also a corresponding antineutrino called, sensibly enough, electron antineutrino, muon antineutrino and tau antineutrino.

Because neutrinos are neutral, their antiparticles cannot have opposite charges. Instead, their "spin" is reversed. (Neutrinos are too small to really spin like a planet; the term spin refers to a property that is in some ways equivalent to spin.) Neutrinos are "left-handed" — they always spin to the left, relative to their direction of motion. Antineutrinos are "right-handed." The eccentric Sicilian theorist Ettore Marjorana suggested that since neutrinos are neutral, they may be their own antiparticle — meaning that under certain circumstances, a neutrino could act like an antineutrino. If that were true, it would satisfy one necessary condition for the supreme ancestor neutrino theory that explains why we and all matter in the universe exist.

Cracked Mirror?

If you apply the laws of physics to antimatter, everything works out the same, just reversed. A magnetic field would push on an electron and a positron with exactly the same force: For example, if the electron were pushed right, the positron would be pushed left. Physicists hope that neutrinos don't necessarily follow this mirror effect, and that they may once again be the oddballs that lead to a new understanding of nature.

In experiments in the U.S. and Japan, researchers are trying to determine if the metamorphosis of neutrinos into different flavors happens at a different rate than the antineutrino transformations. So rather than, say, a 10 percent chance of an electron neutrino turning into a muon neutrino, for example, physicists wonder if the odds are lower that an electron antineutrino turns into a muon antineutrino. They've seen precedents for such "asymmetrical" behavior in a few other particles, and certain theories predict that behavior in neutrinos.

If neutrinos do indeed transform into other flavors at a different rate from antineutrinos, it's likely that this matter/antimatter difference in neutrinos was present in their superheavy ancestors at the dawn of time, too.

Seeing Stars

Astrophysicist Hans-Thomas Janka and his team use a bank of supercomputers to create 3-D models of the heat that builds in a neutrino-driven explosion of a star.

Leonhard Scheck and H.-Thomas Janka (Max Planck Institute for Astrophysics)

Somewhere in the universe, at least once a second, a massive star goes supernova, blowing to smithereens with the intensity of an entire galaxy's worth of shining stars. After 50 years of investigation, no one knows exactly why supernovae occur. But to astrophysicist Hans-Thomas Janka, it's clear the neutrino is a major culprit in this mystery.

Working from the Max Planck Institute for Astrophysics in Munich, Janka has enlisted dozens of the world's most powerful computers on a decades-long quest to understand the incredibly complex mechanism of a supernova. Advances in computing power and physics have helped him build sophisticated models, spun from hundreds of thousands of lines of computer code, that capture the nuances of the stars' shape while taking into account everything from stars' rotation and nuclear reactions to Einstein's theory of gravity. Now, for the first time, Janka's latest models fully describe the behavior of neutrinos under the hellish conditions of a star's demise.

In 1982, James Wilson of Lawrence Livermore National Laboratory first showed how neutrinos might trigger the explosion. Wilson knew that when a massive star burns up the last of its fuel after some

10 million years, its core rapidly implodes, pulling all of the star's matter inward. The implosion begins to turn into an explosion, and a shock wave forms. But within a few thousandths of a second, it stops cold. Then something causes the shock wave to "revive" and trigger the explosion, leaving behind a dense neutron star.

Through rudimentary computer modeling, Wilson discovered that that something was neutrinos, generated in copious amounts — on the order of 1 followed by 58 zeroes — when the electrons and protons in the core turn into neutrons. Because those neutrons are packed so tightly — a teaspoon would weigh 100 million tons — the neutrinos would get trapped there, bouncing off and interacting with the other particles (mostly neutrons, but some protons and electrons) trillions of times.

The neutrinos would be delayed in the core only for a second, but Wilson suspected that enough heat would be generated to trigger the supernova explosion.

Limited by the era's computers and understanding of physics, Wilson's model relied on simplifications — such as the star being a perfect sphere — and incorrect assumptions about the behavior of very dense matter and how neutrinos move from the core's interior to the crucial outer parts where the heating of the shock wave occurs. The model did not work. Janka learned about Wilson's model four years later, as a graduate student at Technical University Munich. He thought the theory sounded plausible and developed a new way to describe neutrino physics in supernovae, working on newly available $25 million supercomputers at the Max Planck Institute, one of the few places in Europe where the computers were available for unclassified research. Janka seemed to work nonstop, his ferocious drive coexisting with a persistent fear: Because he was one of only a handful working in what was then a limited field of study, Janka worried that by the time he completed his doctorate, he'd be a 30-something with few job prospects.

But the heavens intervened. In 1987, the first supernova visible to the naked eye since 1604 appeared in the Large Magellanic Cloud, our closest neighboring galaxy. Of the trillions of neutrinos the blast emitted, detectors on Earth captured 24, suddenly inaugurating a new field of particle astrophysics. "It was an initial boost that affected all my career," says Janka. "That was the reason that a big neutrino astrophysics research program was started in Munich and that I got a permanent job there in 1995."

That 1987 supernova confirmed the basic picture of a collapsed core of a massive star spewing an enormous blast of neutrinos. Janka eagerly started building computer models, but like Wilson, he had to assume the star was spherical, an oversimplification dictated by the high costs of computing power. When Janka ran the models, the star did not explode. Over the next decade, he collaborated with Ewald Mueller of the Max Planck Institute for Astrophysics to create more complex models. They fleshed out how neutrinos interact and how they leak out of the core of a collapsed star. "He built up his expertise very systematically as he attacked different pieces of the puzzle," says physicist Thomas Baumgarte of Bowdoin College, who has known Janka for about 20 years.

By 2005, Janka had developed more sophisticated code for a model that more accurately represented the shape of the star, though it was still an approximation. In this model, called a two-dimensional type, Janka refined the physics of how neutrinos moved in connection with the flow of the other matter in the star. But he lacked computer power to test the model.

Then in 2006, fortune struck again. The managing director of the Max Planck Institute asked Janka if he could do anything with 700,000 euros, at the time equal to $875,000. Janka bought 96 1.282-gigahertz processors, the fastest available. “The computers worked on the problem continuously for the next three years to get one second of evolution — from supernova core collapse to 750 milliseconds after the neutron star at the center begins to form,” Janka says. This work led to the first sophisticated 2-D model of a giant star in extremis — and this time, the model star exploded.

Janka’s group had worked out highly complex physical equations to describe neutrino interactions and how the gas of the star flows and bubbles, turning Wilson’s theoretical vision into a far more detailed and sophisticated simulation.

Since Janka simplified the star’s shape, his model didn’t completely solve the mystery. His group is now incorporating what’s been learned about neutrino interactions into new, state-of-the-art models that don’t idealize a star’s shape. At Janka’s disposal is a fair share of the processors of two huge supercomputers, one in Paris and one in Munich, with the power of 32,000 workstations: Together, they can calculate more than 100 trillion operations per second. But Janka finds himself once again at the outer limit of computing power. These 3-D models, he says, are in their infancy and don’t yet explode. Janka’s group recently won a five-year, $4 million grant to give the 3-D model higher resolution and to push the simulation “backward in time, and also forward, linking the model to observed supernova remnants,” he says.

Janka “is doing the leading work” in this highly competitive field, says supernova pioneer Stanford Woosley of the University of California, Santa Cruz. Groups at Princeton University and Oak Ridge National Laboratory, he says, are also within reach. “Victory will go to the one who gets the 3-D model of a 15-solar-mass star [the size of 15 suns] to explode with the right energy,” says Woosley, since that’s the size of star that can synthesize elements important for life.

That’s ultimately the allure of these fiery enigmas. “The oxygen we breathe, the iron in our blood, the carbon in plants, the silicon in the sand — all the matter that makes up you and the Earth is made and distributed by supernovae,” Janka says. We are all star descendants, forged from matter created hundreds to thousands of light-years away in a titanic explosion where a reticent ghost particle finally, violently, made its presence felt.

Double Trouble

Several major experiments around the world are designed to catch the elusive neutrino in the act of not showing up. In a radioactive metamorphosis called single beta decay, a neutron (a neutral particle) in the nucleus of an unstable atom spontaneously turns into a proton (a positive particle) and emits an electron and an antineutrino — the antimatter twin of a neutrino.

In double beta decay, the interaction is doubled: Two neutrons simultaneously decay into two protons. However, instead of producing two electrons and two antineutrinos, as one might expect, physicists such as Giorgio Gratta of Stanford University suspect that in some instances, no antineutrinos are emitted. That can happen only if neutrinos are their own antiparticle, in which case an antineutrino would be emitted by a neutron and then — presto! — absorbed as a neutrino by a neutron.

The discovery of the neutrino's double anti-identity, although expected by many physicists, would contradict the standard model of particle physics, the current mainstream understanding of the way particles and fundamental forces behave, necessitating a paradigm-shifting extension. If the decay of an unstable atom produces two electrons but no antineutrinos, physicists will have found decisive evidence for this elusive, eccentric behavior.

Experiments in the United States, such as the Enriched Xenon Observatory 200 (EXO-200) in New Mexico, as well as ones in Japan and Europe, are trying to catch a glimpse of this fantastically rare interaction.

"People have been trying to find this critical decay for a long time," says Gratta, the lead scientist at EXO.

The Super-K's detector houses 13,000 photomultipliers that help detect the smallest trace of light from neutrino interactions.

Built in a zinc mine near Hida, Japan, the Super-Kamiokande (Super-K) experiment has been searching for telltale flashes of light in a 50,000-ton tank of the purest water on Earth since 1996.

When a low-energy neutrino or antineutrino from a supernova collides with a water molecule in the tank, the resulting light signal is recorded by about 100 of 13,000 photomultipliers, ultrasensitive light-detecting devices that turn a tiny flash of light into a larger recordable burst of electricity. But sometimes, false positives occur: Radioactive decays in the detector also create light, as do neutrinos produced in the atmosphere when they collide with the water.

Now, Super-K scientists plan to silence the false positives using a method suggested by physicists John Beacom and Mark Vagins that focuses on the antineutrinos that supernovae produce. They'll add 50 tons of the rare earth metal gadolinium to the water in Super-K, allowing them to tell the difference between encounters with antineutrinos and other light-emitting pretenders.

When an antineutrino knocks into a proton in the Super-K water, that proton turns into a neutron and instantly emits a positively charged particle that gives off blue light as it rapidly moves through the water. The gadolinium would capture the neutron about 20 microseconds after it's created, taking it into its own nucleus and leading to the immediate burst of gamma rays. The photomultipliers capture the whole sequence. No other particle interaction would lead to that one-two "heartbeat." The light in each beat reveals two things: The first flash indicates the energy of the antineutrino; the second confirms that the particle was an antineutrino.

"Currently, Super-Kamiokande can detect neutrinos from supernova explosions anywhere in our own Milky Way galaxy," says Vagins, of the Kavli Institute for the Physics and Mathematics of the Universe. "Adding gadolinium will make the detector vastly more sensitive, which will enable Super-K to begin collecting antineutrinos from supernova explosions anywhere within half the known universe." That would include lower-energy, harder-to-detect antineutrinos created by massive stars that exploded billions of years ago. Adding gadolinium would "allow us to determine the total energy and temperature of an average supernova, two key inputs in all kinds of cosmological and stellar evolution models," says Vagins.

Called GADZOOKS! — for Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super! — the enriched detector, expected to go online in 2017, will also have a better chance of catching the birth of a black hole in the remnants of an exploding star. Neutrinos can't escape from black holes, and the supersensitive Super-K will be able to detect a telltale stream of neutrinos that suddenly shuts down. "Super-K would be able to see a black hole form minutes or even hours after the initial core collapse. … Without gadolinium, it will be limited to 10 seconds or so," says Vagins.

Flying High

The balloon-borne experiment ANITA (Antarctic Impulsive Transient Antenna) heads to the heavens at the end of this year. It will try to detect the sources of the highest-energy neutrinos in the universe. These neutrinos are thought to result from ultrahigh-energy cosmic rays crashing into the low-energy invisible photons left over from the Big Bang that still suffuse all of space.

What sort of phenomenon creates and launches the cosmic ray sources of these neutrinos? Perhaps a hypernova — a "supernova on steroids" — or a rapidly spinning black hole or, more likely yet, a supermassive black hole, says physicist Peter Gorham of the University of Hawaii, the project's lead investigator.

The NASA-funded balloon will be 35,000 meters over the Antarctic ice cap. Circling the South Pole, ANITA's antennas will scan a million cubic kilometers of ice at a time, looking for the telltale radio waves emitted when an ultrahigh-energy neutrino hits a nucleus in ice. It will be ANITA's third voyage.

Last year, physicists began shooting 150 trillion neutrinos per second from the Fermi National Accelerator Laboratory, west of Chicago, to a detector in Minnesota — a 503-mile underground trip that will take them just 2.7 milliseconds.

Called the NuMI Off-axis Electron Neutrino Appearance experiment, or NOvA, the project relies on a 15,400-ton detector containing 3 million gallons of a liquid solution with a material known as a scintillator. Scintillators absorb the energy of incoming particles and emit that energy in the form of light. Of the torrent of particles Fermilab sends, only about 10 neutrinos interact with the scintillator each week. But the result will be a light signature that reveals the neutrino's flavor and energy.

More than 200 scientists, engineers and technicians helped design and build Fermilab's flagship experiment over the past 12 years. Physicist Mark Messier of Indiana University, one of the experiment's co-leads, says NOvA "has the best shot at taking the next big step in uncovering new properties of neutrinos."

One of NOvA's goals, Messier says, is to help figure out which of the three mixes of neutrino flavors is heaviest and which is lightest — their so-called mass ordering. Mass is a fundamental but mysterious property of neutrinos that affects many physics theories because the origin of neutrino masses is still unknown.

The NOvA neutrinos will start off as muon flavor, but then do their typical transforming act into electron neutrinos. Electron-flavor neutrinos are special because they can interact with the Earth: They alone can meaningfully interact with electrons in atoms. The key for NOvA is that the greater the mass of the electron neutrino flavor, the more likely the beam of neutrinos will interact with the hundreds of miles of matter they cross on the way to the detector. “Because the electrons in the Earth ‘drag’ on the electron neutrinos, that effectively gives the electron neutrinos some additional mass,” says Messier.

That effect determines the neutrino’s transformation rate. If electron neutrinos tend to have the lightest mix of masses, the added heaviness from its earthly interactions would make it change to muon neutrinos at a higher rate because it would “mix” or “overlap more” with the muon masses, as Messier puts it, referring to the wavelike behavior of these particles. On the other hand, if the electron neutrinos contain the heaviest masses, then the additional Earth-induced mass would make them mix less with those of the other two neutrino flavors.

NOvA is also doing the experiment with antineutrinos, which offer a valuable comparison, Messier says. And it might give a hint of whether neutrinos and antineutrinos morph at different rates, yet another unusual neutrino property that would not be totally unexpected.

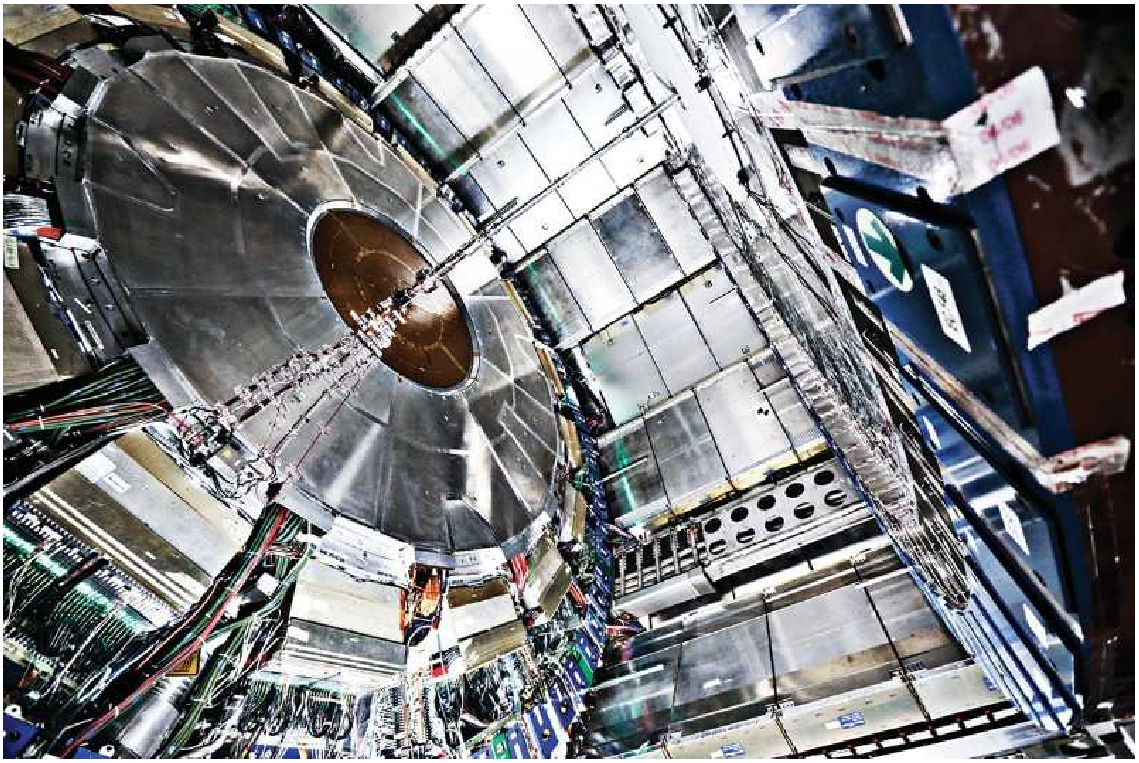
Neutrino Gold

1988: Leon Lederman, Melvin Schwartz and Jack Steinberger win the Nobel Prize in Physics for developing a way to generate beams of neutrinos in a particle collider and for discovering the muon neutrino.

1995: Frederick Reines wins a Nobel for detecting neutrinos for the first time in a 1953 experiment dubbed Project Poltergeist. Clyde Cowan, his collaborator, had died 21 years earlier.

2002: Ray Davis earns the prize for detecting neutrinos from the sun using 600 tons of dry-cleaning fluid in a giant underground tank in South Dakota. Davis shared the Nobel with Masatoshi Koshiba, who used the gigantic Kamiokande detector in Japan to confirm Davis’ results and to capture neutrinos from a supernova that exploded in a neighboring galaxy. [5]

Possible new particle hints that universe may not be left-handed



Mirroring the universe (Image: Claudia Marcelloni/CERN)

Like your hands, some fundamental particles are different from their mirror images, and so have an intrinsic handedness or “chirality”. But some particles only seem to come in one of the two handedness options, leading to what’s called “left-right symmetry breaking”.

In particular, W bosons, which carry the weak nuclear force, are supposed to come only in left-handed varieties. The debris from smashing protons at the LHC has revealed evidence of unexpected right-handed bosons.

After finding the Higgs boson in 2012, the collider shut down for upgrades, allowing collisions to resume at higher energies earlier this year. At two of the LHC’s experiments, the latest results appear to contain four novel signals. Together, they could hint at a W-boson-like particle, the W’, with a mass of about 2 teraelectronvolts. If confirmed, it would be the first boson discovered since the Higgs.

The find could reveal how to extend the successful but frustratingly incomplete standard model of particle physics, in ways that could explain the nature of dark matter and why there is so little antimatter in the universe.

The strongest signal is an excess of particles seen by the ATLAS experiment (arxiv.org/abs/1506.00962), at a statistical significance of 3.4 sigma. This falls short of the 5 sigma regarded as proof of existence (see “Particle-spotting at the LHC“), but physicists are intrigued because three other unexpected signals at the independent CMS experiment could point to the same thing.

"The big question is whether there might be some connection between these," says Bogdan Dobrescu at Fermilab in Chicago. In a paper posted online last month, Dobrescu and Zhen Liu, also at Fermilab, showed how the signals could fit naturally into modified versions of left-right symmetric models (arxiv.org/abs/1507.01923). They restore left-right symmetry by introducing a suite of exotic particles, of which this possible W' particle is one.

Another way to fit the right-handed W' into a bigger theory was proposed last week by Bhupal Dev at the University of Manchester, UK, and Rabindra Mohapatra at the University of Maryland. They invoke just a few novel particles, then restore left-right symmetry by giving just one of them special properties (arxiv.org/abs/1508.02277).

Some theorists have proposed that these exotic particles instead hint that the Higgs boson is not fundamental particle. Instead, it could be a composite, and some of its constituents would account for the observed signals.

"In my opinion, the most plausible explanation is in the context of composite Higgs models," says Adam Falkowski at CERN. "If this scenario is true, that would mean there are new symmetries and new forces just around the corner."

"If the Higgs is really a composite particle, that would mean new forces just around the corner"

The next step is for the existence of the right-handed W' boson to be confirmed or ruled out. Dobrescu says that should be possible by October this year. But testing the broader theories could take a couple of years.

Other LHC anomalies have disappeared once more data became available. That could happen again, but Raymond Volkas at the University of Melbourne, Australia, says this one is more interesting.

"The fact that the data hint at a very sensible and well-motivated standard model extension that has been studied for decades perhaps is reason to take this one a bit more seriously," he says. [4]

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) $M_p = n^2 M_e$

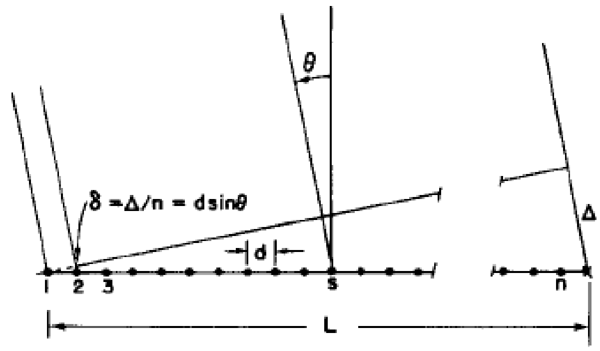


Fig. 30–3. A linear array of *n* equal oscillators, driven with phases $\alpha_s = s\alpha$.

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) $d \sin\theta = m\lambda$

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) $2(m+1) = n$

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:

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

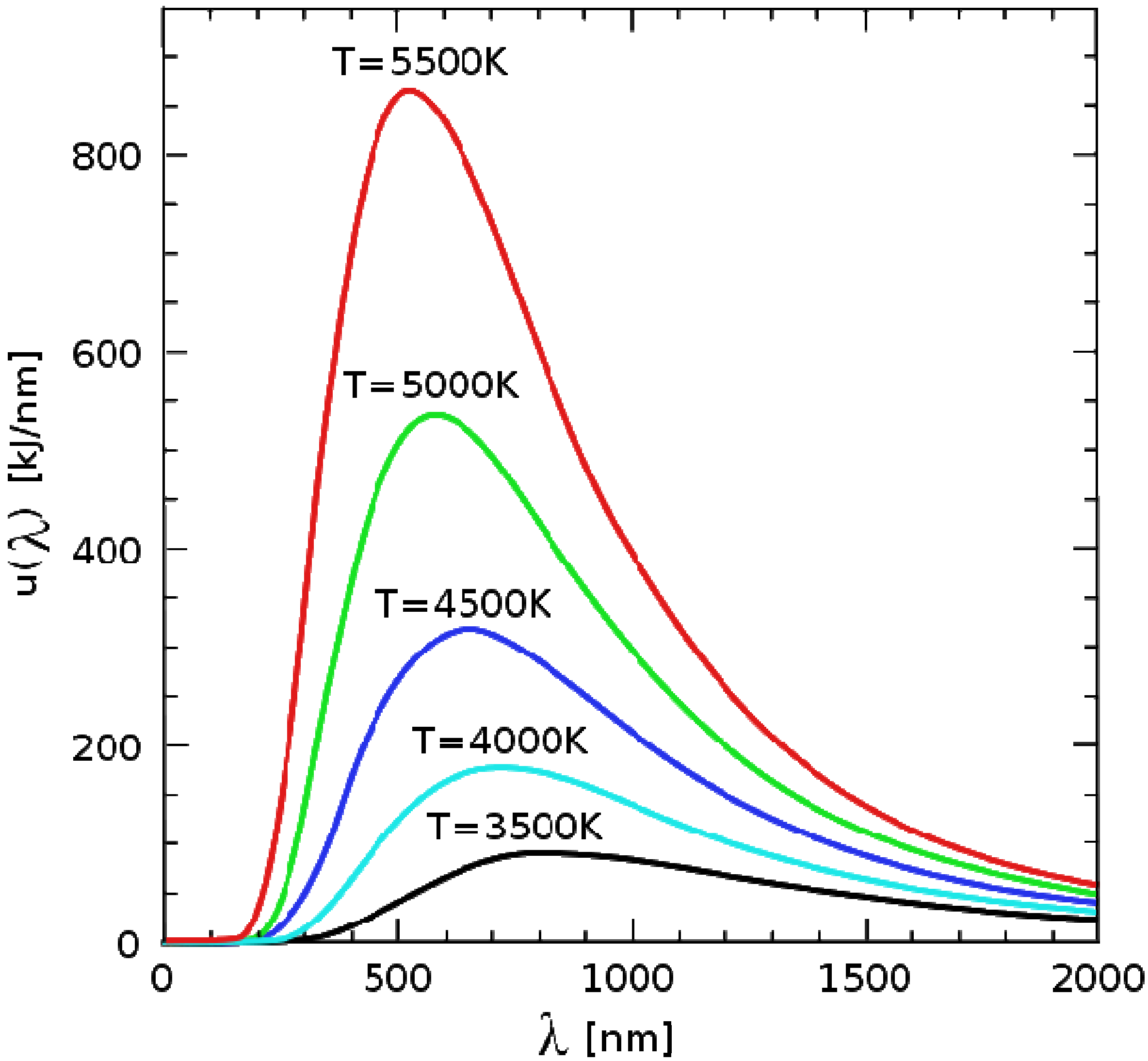


Figure 2. The distribution law for different T temperatures

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) $$\lambda_{\max} = \frac{b}{T}$$

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 $2.8977685(51)\times10^{-3}$ m·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 $d<10^{-13}$ cm. 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 an asymptotic freedom while their energy are increasing to turn them to the orthogonally. 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 Pauli Exclusion Principle says that the diffraction points are exclusive!

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 order, 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 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ 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 ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

The Weak Interactions 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 for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.

The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change. There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

Fermions and Bosons

The fermions are the diffraction patterns of the bosons such a way that they are both sides of the same thing.

The Higgs boson or Higgs particle is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson's existence would have profound importance in particle physics because it would prove the existence of the hypothetical Higgs field - the simplest of several proposed explanations for the origin of the symmetry-breaking mechanism by which elementary particles gain mass. [3]

The fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.

The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = d x d p or 1/2 h = d t d E, that is the value of the basic energy status.

What are the consequences of this in the weak interaction and how possible that the neutrinos' velocity greater than the speed of light?

The neutrino is the one and only particle doesn't participate in the electromagnetic interactions so we cannot expect that the velocity of the electromagnetic wave will give it any kind of limit.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ 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 source of the Maxwell equations

The electrons are accelerating also in a static electric current because of the electric force, caused by the potential difference. The magnetic field is the result of this acceleration, as you can see in [2].

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

Also an interesting question, how the changing magnetic field creates a negative electric field?
The answer also the accelerating electrons will give. When the magnetic field is increasing in time by increasing the electric current, then the acceleration of the electrons will increase, decreasing the charge density and creating a negative electric force. Decreasing the magnetic field by decreasing the electric current will decrease the acceleration of the electrons in the electric current and increases the charge density, creating an electric force also working against the change.
In this way we have explanation to all interactions between the electric and magnetic forces described in the Maxwell equations.
The second mystery of the matter is the mass. We have seen that the acceleration change of the electrons in the flowing current causing a negative electrostatic force. This is the cause of the relativistic effect - built-in in the Maxwell equations - that is the mass of the electron growing with its acceleration and its velocity never can reach the velocity of light, because of this growing negative electrostatic force. The velocity of light is depending only on 2 parameters: the magnetic permeability and the electric permittivity.
There is a possibility of the polarization effect created by electromagnetic forces creates the negative and positive charges. In case of equal mass as in the electron-positron pair it is simply, but on higher energies can be asymmetric as the electron-proton pair of neutron decay by week interaction and can be understood by the Feynman graphs.
Anyway the mass can be electromagnetic energy exceptionally and since the inertial and gravitational mass are equals, the gravitational force is electromagnetic force and since only the magnetic force is attractive between the same charges, is very important for understanding the gravitational force.

The Uncertainty Relations of Heisenberg gives the answer, since only this way can be sure that the particles are oscillating in some way by the electromagnetic field with constant energies in the atom indefinitely. Also not by chance that the uncertainty measure is equal to the fermions spin, which is one of the most important feature of the particles. There are no singularities, because the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greatest proton mass.

The Special Relativity

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

The Heisenberg Uncertainty Principle

Moving faster needs stronger acceleration reducing the dx and raising the dp. It means also mass increasing since the negative effect of the magnetic induction, also a relativistic effect!

The Uncertainty Principle also explains the proton – electron mass rate since the dx is much less requiring bigger dp in the case of the proton, which is partly the result of a bigger mass m_p because of the higher electromagnetic induction of the bigger frequency (impulse).

The Gravitational force

The changing magnetic field of the changing current causes electromagnetic mass change by the negative electric field caused by the changing acceleration of the electric charge.

The gravitational attractive force is basically a magnetic force.

The same electric charges can attract one another by the magnetic force if they are moving parallel in the same direction. Since the electrically neutral matter is composed of negative and positive charges they need 2 photons to mediate this attractive force, one per charges. The Bing Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

Since graviton is a tensor field, it has spin = 2, could be 2 photons with spin = 1 together.

You can think about photons as virtual electron – positron pairs, obtaining the necessary virtual mass for gravity.

The mass as seen before a result of the diffraction, for example the proton – electron mass rate M_p = 1840 M_e. In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass. [1]

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.
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 Graviton

In physics, the graviton is a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory. If it exists, the graviton is expected to be massless (because the gravitational force appears to have unlimited range) and must be a spin-2 boson. The spin follows from the fact that the source of gravitation is the stress-energy tensor, a second-rank tensor (compared to electromagnetism's spin-1 photon, the source of which is the four-current, a first-rank tensor). Additionally, it can be shown that any massless spin-2 field would give rise to a force indistinguishable from gravitation, because a massless spin-2 field must couple to (interact with) the stress-energy tensor in the same way that the gravitational field does. This result suggests that, if a massless spin-2 particle is discovered, it must be the graviton, so that the only experimental verification needed for the graviton may simply be the discovery of a massless spin-2 particle. [3]

What is the Spin?

So we know already that the new particle has spin zero or spin two and we could tell which one if we could detect the polarizations of the photons produced. Unfortunately this is difficult and neither ATLAS nor CMS are able to measure polarizations. The only direct and sure way to confirm that the particle is indeed a scalar is to plot the angular distribution of the photons in the rest frame of the centre of mass. A spin zero particles like the Higgs carries no directional information away from the original collision so the distribution will be even in all directions. This test will be possible when a much larger number of events have been observed. In the mean time we can settle for less certain indirect indicators.

The Casimir effect

The Casimir effect is related to the Zero-point energy, which is fundamentally related to the Heisenberg uncertainty relation. The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = dx dp or 1/2 h = dt dE, that is the value of the basic energy status.
The moving charges are accelerating, since only this way can self maintain the electric field causing

their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light. In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass. This means that the electron is not a point like particle, but has a real charge distribution.
Electric charge and electromagnetic waves are two sides of the same thing; the electric charge is the diffraction center of the electromagnetic waves, quantified by the Planck constant h.

The Fine structure constant

The Planck constant was first described as the proportionality constant between the energy (*E*) of a photon and the frequency (*ν*) of its associated electromagnetic wave. This relation between the energy and frequency is called the **Planck relation** or the **Planck–Einstein equation**:

$$E = h\nu \,.$$

Since the frequency ν, wavelength *λ*, and speed of light *c* are related by *λν* = *c*, the Planck relation can also be expressed as

$$E = \frac{hc}{\lambda}.$$

Since this is the source of Planck constant, the e electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths.

The expression of the fine-structure constant becomes the abbreviated

$$\alpha = \frac{e^2}{\hbar c}$$

This is a dimensionless constant expression, 1/137 commonly appearing in physics literature.

This means that the electric charge is a result of the electromagnetic waves diffractions, consequently the proton – electron mass rate is the result of the equal intensity of the corresponding electromagnetic frequencies in the Planck distribution law, described in my diffraction theory.

Conclusions

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. We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

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