Light-Warping Hyperbolic Metamaterials

Manipulating light in a variety of ways—shrinking its wavelength and allowing it to travel freely in one direction while stopping it cold in another—hyperbolic metamaterials have wide application in optical communications and as nanoparticle sensors. [18]

A new way of enhancing the interactions between light and matter, developed by researchers at MIT and Israel's Technion, could someday lead to more efficient solar cells that collect a wider range of light wavelengths, and new kinds of lasers and light-emitting diodes (LEDs) that could have fully tunable color emissions. [17]

A team of researchers at the Center for Relativistic Laser Science, within the Institute for Basic Science (IBS) have developed a method to measure the shape of laser pulses in ambient air. [16]

Studying the fleeting actions of electrons in organic materials will now be much easier, thanks to a new method for generating fast X-rays. [15]

In a laboratory at the University of Rochester, researchers are using lasers to change the surface of metals in incredible ways, such as making them super water-repellent without the use of special coatings, paints, or solvents. [14]

The interaction of high-power laser light sources with matter has given rise to numerous applications including; fast ion acceleration; intense X-ray, gamma-ray, positron and neutron generation; and fast-ignition-based laser fusion. [13]

Conventional electron accelerators have become an indispensable tool in modern research. [12]

An outstanding conundrum on what happens to the laser energy after beams are fired into plasma has been solved in newly-published research at the University of Strathclyde. [11]

Researchers at Lund University and Louisiana State University have developed a tool that makes it possible to control extreme UV light - light with much shorter wavelengths than visible light. [10]

Tiny micro- and nanoscale structures within a material's surface are invisible to the naked eye, but play a big role in determining a material's physical, chemical, and biomedical properties. [9]

A team of researchers led by Leo Kouwenhoven at TU Delft has demonstrated an on-chip microwave laser based on a fundamental property of superconductivity, the ac Josephson effect. They embedded a small section of an interrupted superconductor, a Josephson junction, in a carefully engineered on-chip cavity. Such a device opens the door to many applications in which microwave radiation with minimal dissipation is key, for example in controlling qubits in a scalable quantum computer. [8]

Optical scientists from the Warsaw Laser Centre of the Institute of Physical Chemistry of the Polish Academy of Sciences and the Faculty of Physics of the University of Warsaw have generated ultrashort laser pulses in an optical fiber with a method previously considered to be physically impossible. [7]

Researchers at the Max Planck Institute for the Science of Light in Erlangen have discovered a new mechanism for guiding light in photonic crystal fiber (PCF). [6]

Scientists behind a theory that the speed of light is variable - and not constant as Einstein suggested - have made a prediction that could be tested. [5]

Physicists' greatest hope for 2015, then, is that one of these experiments will show where Einstein got off track, so someone else can jump in and get closer to his long-sought "theory of everything."

This article is part of our annual "Year In Ideas" package, which looks forward to the most important science stories we can expect in the coming year. It was originally published in the January 2015 issue of Popular Science. [4]

The self maintained electric potential of the accelerating charges equivalent with the General Relativity space-time curvature, and since it is true on the quantum level also, gives the base of the Quantum Gravity.

The magnetic induction creates a negative electric field, causing an electromagnetic inertia responsible for the relativistic mass change; it is the mysterious Higgs Field giving mass to the particles.

The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate by the diffraction patterns. The accelerating charges explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Relativistic Quantum Theories.

Contents

Author: George Rajna

Preface

Popular questions about the Higgs Field and General Relativity:

1.) If the Higgs field is responsible for imbuing particles with mass, and mass is responsible for gravity, is it possible that the Higgs field will provide the missing link between general relativity and quantum mechanics i.e. could the Higgs field be the basis of a quantum theory of gravity?

2.) Can the theoretical Higgs Field be used as the “cause” of relativistic momentum or relativistic kinetic energy of a moving body?

3.) Does Einstein's General Relativity need to be adjusted for the Higgs field?

4.) Since the Higgs field gives most particles mass, and permeates all space, then GR needs the Higgs field to be a theory of space?

5.) So where GR is highly curved, the Higgs field is also curved? And does a highly curved Higgs field affect the way particles acquire mass? For that matter, a curved space-time would also curve electromagnetic field?

How can we answer these questions?

Discovering the magnetic effect of the electric current from the observed effects of the accelerating electrons - causing naturally the experienced changes of the electric field potential along the electric wire - the accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron’s spin also, building the bridge between the Classical and Quantum Theories. [1]

Another bridge between the classical and quantum mechanics in the realm of relativity is that the charge distribution is lowering in the reference frame of the accelerating charges linearly: ds/dt =

at (time coordinate), but in the reference frame of the current it is parabolic: $s = a/2\ t^2$ (geometric coordinate).

One origin of the Quantum Physics is the Planck Distribution Law of the electromagnetic oscillators, giving equal intensity for 2 different wavelengths on any temperature. Any of these two wavelengths will give equal intensity diffraction patterns, building different asymmetric constructions, for example proton - electron structures (atoms), molecules, etc. Since the particles are centers of diffraction patterns they also have particle – wave duality as the electromagnetic waves have. [2]

The Electroweak Interaction shows that the Weak Interaction is basically electromagnetic in nature. The arrow of time shows the entropy grows by changing the temperature dependent diffraction patterns of the electromagnetic oscillators.

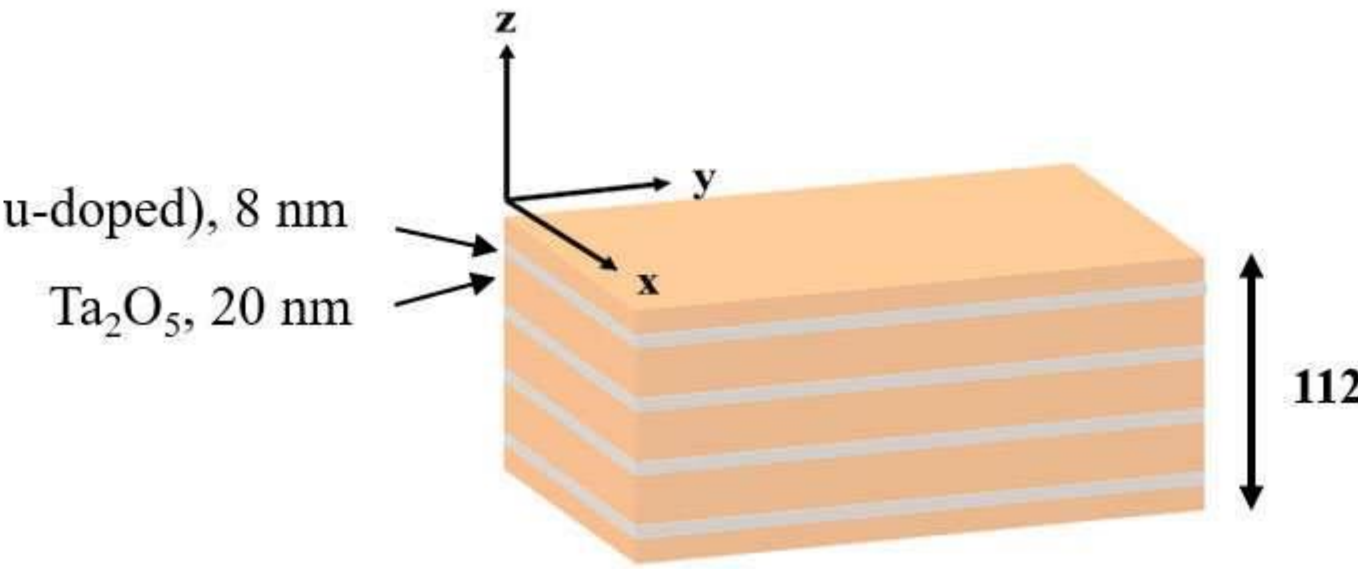
A new way to measure the light-warping properties of hyperbolic metamaterials

Manipulating light in a variety of ways—shrinking its wavelength and allowing it to travel freely in one direction while stopping it cold in another—hyperbolic metamaterials have wide application in optical communications and as nanoparticle sensors. But some of the same optical properties that make these metamaterials so appealing make them frustratingly difficult to evaluate.

For example, the mismatch between the wavelength of incident light, traveling through air, and the much shorter wavelength inside these metamaterials typically prevents the incident light from penetrating very far. That property can be used to create a nanoparticle sensor but poses a problem for measuring just how well a hyperbolic metamaterial performs its light-warping feats, characterized by an electrical property known as permittivity. If light can't probe deeply into a hyperbolic metamaterial, it can't accurately assess the permittivity.

CNST researchers have now developed a new measurement method that circumvents this difficulty. Using an off-the-shelf glass prism to enhance the interaction of incident light with hyperbolic metamaterials, a team led by Cheng Zhang of the CNST and the University of Maryland's NanoCenter and Henri Lezec of NIST has devised a simple and much more accurate way to determine the permittivity.

Zhang, Lezec and their colleagues, which include researchers from the J.A. Woollam Co. in Lincoln, Nebraska, and the University of Michigan in Ann Arbor, described their findings in a recent issue of *ACS Photonics*.



Cross-sectional view of the hyperbolic metamaterial examined in the new study shows layers of copper-doped silver and tantalum pentoxide. Credit: NIST

The glass prism serves two functions. Light traveling through glass has a wavelength intermediate in size between that of the incident light and the light inside a hyperbolic metamaterial. By sending light into the glass prism before it enters the hyperbolic metamaterial, the researchers minimize the mismatch in wavelength, enabling the light to penetrate farther into the material. In addition, the shape of the prism directs the light to strike the hyperbolic metamaterial at the optimum angle to probe the material

Because the technique uses an off-the-shelf prism and does not require any modification of the hyperbolic metamaterial, it promises to serve as a reliable and easy to adopt method to characterize a broad class of highly anisotropic materials—structures whose optical properties depend on the angle at which light strikes the surface. And as Zhang and his colleagues fabricate more complex versions of such materials, using nanoengineered layers of different compounds, such measurements will take on added importance. [18]

Researchers devise new way to make light interact with matter

A new way of enhancing the interactions between light and matter, developed by researchers at MIT and Israel's Technion, could someday lead to more efficient solar cells that collect a wider range of light wavelengths, and new kinds of lasers and light-emitting diodes (LEDs) that could have fully tunable color emissions.

The fundamental principle behind the new approach is a way to get the momentum of light particles, called photons, to more closely match that of electrons, which is normally many orders of magnitude greater. Because of the huge disparity in momentum, these particles usually interact very weakly; bringing their momenta closer together enables much greater control over their interactions, which could enable new kinds of basic research on these processes as well as a host of new applications, the researchers say.

The new findings, based on a theoretical study, are being published today in the journal *Nature Photonics* in a paper by Yaniv Kurman of Technion (the Israel Institute of Technology, in Haifa); MIT graduate student Nicholas Rivera; MIT postdoc Thomas Christensen; John Joannopoulos, the Francis Wright Davis Professor of Physics at MIT; Marin Soljacic, professor of physics at MIT; Ido Kaminer, a professor of physics at Technion and former MIT postdoc; and Shai Tsesses and Meir Orenstein at Technion.

While silicon is a hugely important substance as the basis for most present-day electronics, it is not well-suited for applications that involve light, such as LEDs and solar cells—even though it is currently the principal material used for solar cells despite its low efficiency, Kaminer says. Improving the interactions of light with an important electronics material such as silicon could be an important milestone toward integrating photonics—devices based on manipulation of light waves—with electronic semiconductor chips.

Most people looking into this problem have focused on the silicon itself, Kaminer says, but "this approach is very different—we're trying to change the light instead of changing the silicon." Kurman adds that "people design the matter in light-matter interactions, but they don't think about designing the light side."

One way to do that is by slowing down, or shrinking, the light enough to drastically lower the momentum of its individual photons, to get them closer to that of the electrons. In their theoretical study, the researchers showed that light could be slowed by a factor of a thousand by passing it through a kind of multilayered thin-film material overlaid with a layer of graphene. The layered material, made of gallium arsenide and indium gallium arsenide layers, alters the behavior of photons passing through it in a highly controllable way. This enables the researchers to control the frequency of emissions from the material by as much as 20 to 30 percent, says Kurman, who is the paper's lead author.

The interaction of a photon with a pair of oppositely charged particles—such as an electron and its corresponding "hole"—produces a quasiparticle called a plasmon, or a plasmon-polariton, which is a kind of oscillation that takes place in an exotic material such as the two-dimensional layered devices used in this research. Such materials "support elastic oscillations on its surface, really tightly confined" within the material, Rivera says. This process effectively shrinks the wavelengths of light by orders of magnitude, he says, bringing it down "almost to the atomic scale."

Because of that shrinkage, the light can then be absorbed by the semiconductor, or emitted by it, he says. In the graphene-based material, these properties can actually be controlled directly by simply varying a voltage applied to the graphene layer. In that way, "we can totally control the properties of the light, not just measure it," Kurman says.

Although the work is still at an early and theoretical stage, the researchers say that in principle this approach could lead to new kinds of solar cells capable of absorbing a wider range of light wavelengths, which would make the devices more efficient at converting sunlight to electricity. It could also lead to light-producing devices, such as lasers and LEDs, that could be tuned electronically to produce a wide range of colors. "This has a measure of tunability that's beyond what is currently available," Kaminer says.

"The work is very general," Kurman says, so the results should apply to many more cases than the specific ones used in this study. "We could use several other semiconductor materials, and some other light-matter polaritons." While this work was not done with silicon, it should be possible to apply the same principles to silicon-based devices, the team says. "By closing the momentum gap, we could introduce silicon into this world" of plasmon-based devices, Kurman says.

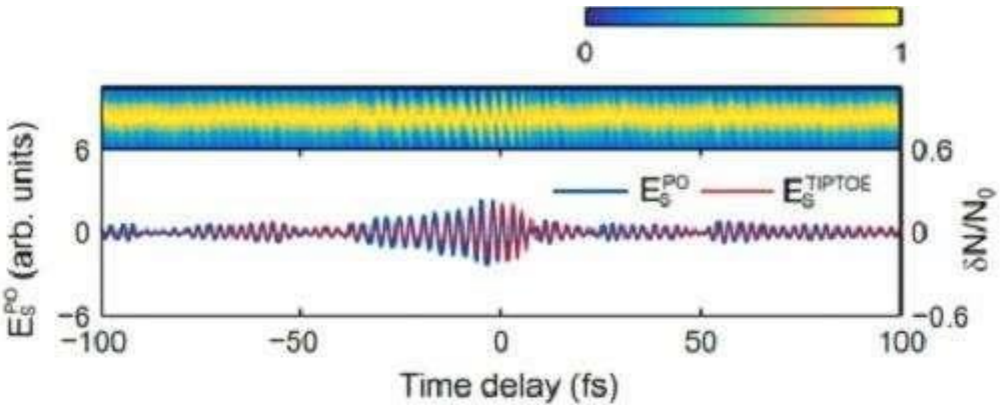
Because the findings are so new, Rivera says, it "should enable a lot of functionality we don't even know about yet." [17]

Detecting the shape of laser pulses

A team of researchers at the Center for Relativistic Laser Science, within the Institute for Basic Science (IBS) have developed a method to measure the shape of laser pulses in ambient air. Unlike conventional strategies, it is does not require a vacuum environment and can be applied to laser beams of different wavelengths (UV, visible or longer). This patented technique, currently available for technology transfer and commercialization, has now been published in *Optica*, and it is expected to accelerate studies on light-matter interaction.

Experts aim to employ laser light to control the behavior of the electrons, and potentially to manipulate electric currents. However, in order to reach these goals, it is essential to know the waveform of a laser pulse. As molecular events occur in just attoseconds (1 as = 10-18 seconds), the existing method to study them relies on the generation of attosecond X-ray pulses which requires detection equipment in vacuum chambers. IBS researchers devised an alternative approach called TIPTOE (tunneling ionization with a perturbation for the time-domain observation of an electric field) which needs neither X-rays pulses nor vacuum conditions.

TIPTOE is based on two superimposed laser pulses: a strong one and a weak one. Atoms or molecules exposed to intensive electric fields, like the ones created by strong laser pulses, can lose some of their electrons in a phenomenon called tunnel ionization. The TIPTOE method depends on the intensity of the electric field and the tunnel ionization of the electrons of the atoms in the air. Time differences between the strong and the weak superimposed laser pulses cause the electric field intensity to vary. As a higher electric field intensity corresponds to higher ionization, changes in the electric field are directly reflected on the tunnel ionization. And in turn, these changes in tunnel ionization are used to measure the shape of the laser pulse. Since tunneling ionization lasts only 200 attoseconds, the TIPTOE method can provide enough temporal resolution to measure UV, visible, and longer wavelength pules.



Comparison between attosecond X-ray pulse method X-ray (blue) and TIPTOE (red) to validate the new technique developed by IBS scientists. The waveforms measured with TIPTOE match the ones obtained with the conventional method. Credit: Institute for Basic Science

IBS scientists validated TIPTOE by comparing it with the conventional X-ray pulse generation technique, and the results were the same.

"TIPTOE's biggest advantage is the universality of this technique at different wavelengths," explains Kyung Taec Kim, the leading author of this study. [16]

X-rays from tabletop lasers allows scientists to peer through the 'water window'

Studying the fleeting actions of electrons in organic materials will now be much easier, thanks to a new method for generating fast X-rays.

The technique means advanced measurements of fast reactions will now be possible in physics labs around the world, without having to wait to use expensive and scarce equipment. It could be used, for example, to study and improve light-harvesting technologies like solar panels and water splitters.

When 'soft' X-rays, beyond the range of ultraviolet light, strike an object, they are strongly absorbed by some kinds of atoms and not others. In particular, water is transparent to these X-rays, but carbon absorbs them, making them useful for imaging organic and biological materials.

However, a challenge has been to generate very fast soft X-rays. Creating pulses of X-rays that only last one thousandth of a millionth of a millionth of a second would allow researchers to image the extremely quick motions of electrons, crucial for determining how charge travels and reactions occur.

Fast soft X-rays have been created with large facilities, such as multi-billion dollar costing free-electron lasers, but now a research team from Imperial College London have generated fast and powerful fast soft X-ray pulses using standard laboratory lasers. The method, which can produce bright soft X-ray pulses that last hundreds of attoseconds (quintillionths of a second), is published today in *Science Advances*.

With the new technique, researchers will be able to watch the movement of electrons on their natural timescale, giving them a dynamic picture of the smallest and fastest reaction steps.

Senior author Professor Jon Marangos, from the Department of Physics at Imperial, said: "The strength of this technique is that it can be used by many physics labs around the world with lasers they already have installed.

"This discovery will allow us to make measurements at extreme timescales for the first time. We are at the frontiers of what we can measure, seeing faster-than-ever processes important for science and technology."

Generating X-rays in a lab requires exciting atoms until they release photons—particles of light. Normally, atoms in a long, dispersed cloud are excited in sequence so that they emit photons in 'phase', meaning they add up and create a stronger X-ray pulse. This is known as phase matching.

But when trying to generate soft X-rays this way, effects in the cloud of atoms strongly defocus the laser, disrupting phase matching.

Instead, the team discovered that they needed a thin, dense cloud of atoms and short laser pulses. With this setup, while the photons could not stay in phase over a long distance, they were still in phase over a shorter distance and for a short time. This led to unexpectedly efficient production of the short soft X-ray pulses.

The team further measured and simulated the exact effects that cause high harmonic generation in this situation, and from this were able to predict the optimum laser conditions for creating a range of X-rays.

Lead researcher Allan Johnson, from the Department of Physics at Imperial, said: "We've managed to look inside what was before the relatively black-box of soft X-ray generation, and use that information to build an X-ray laser on a table that can compete with football-field spanning facilities. Knowledge is quite literally power in this game."

The team at Imperial plan to use the technique to study organic polymer materials, in particular those that harvest the Sun's rays to produce energy or to split water. These materials are under intense study as they can provide cheaper renewable energy.

However, many currently used materials are unstable or inefficient, due to the action of electrons that are excited by light. Closer study of the fast interactions of these electrons could provide valuable insights into methods for improving solar cells and catalysts. [15]

A laser focus on super water-repellent metals

In a laboratory at the University of Rochester, researchers are using lasers to change the surface of metals in incredible ways, such as making them super water-repellent without the use of special coatings, paints, or solvents.

The commercial applications of the technology range from de-icing of commercial airplanes and large trucks, to rust and corrosion prevention of exposed metal surfaces, to cleaner, anti-microbial surfaces for surgical and medical facilities.

But to make the technology commercially viable, the lasers must become much more powerful.

A venture capital-backed technology company, FemtoRoc Corp., is undertaking a joint research project with John Marciante, an associate professor of optics, and the University's Institute of Optics to develop those more powerful lasers. The project, expected to take six years, has a research budget estimated at $10 million.

"What they [FemtoRoc] need is a high-powered, ultra-fast, femtosecond-class laser system with average power measured in kilowatts, rather than the 10's of watts now commercially available," says Marciante. "So, we need to scale up by over a factor of 10."

"It's a very ambitious undertaking."

The proprietary, super-hydrophobic technology uses lasers to create an intricate pattern of micro and nanoscale structures, giving the treated metal surfaces a new set of physical properties.

In 2015, Chunlei Guo, a professor of optics, and Anatoliy Vorobyev, a senior scientist at the Institute of Optics, described the extremely powerful, but ultra-short laser pulses they used to permanently change the surface of metals.

Guo and Vorobyev have successfully used this technique to create not only metal surfaces that are extremely water repellent, but ones that attract water as well. Guo's laboratory has also created a process to treat metal surfaces to absorb virtually all wavelengths of ambient light and which has a wide array of commercial applications, including thin, ultra-efficient solar cells.

However, it takes about an hour for Guo's laboratory to pattern a 1-inch-by-1-inch metal sample using commercially available, low-powered lasers. More powerful, ultra-fast femtosecond laser pulses are needed to speed up the process to make the technology commercially viable.

To develop the lasers, Marciante's laboratory, which specializes in developing advanced, high-power, fiber lasers, will need to address two main challenges.

One is that laser beams are usually confined in conventionally designed optical fibers, which tend to be very small in core diameter. In scaling up the laser power, too much light becomes concentrated in the fiber's core, and nonlinear properties proliferate, causing the laser beam to broaden or become modulated.

"When you try to compress the beam to a short pulse, there's a lot of energy that doesn't fit in that pulse," Marciante explains. "The usable power spreads out, or does not focus where you want it to."

The second challenge is overheating. "You're pumping the laser beam at one energy level, at one end, and then extracting it at a lower energy level, at the other end, and no process is 100 percent thermally efficient. So that extra energy ends up in the fiber. The fiber can get very hot, even to the point of melting," Marciante says.

In addition to the research done by his own team, Marciante will leverage a network of veteran researchers in the United States and abroad and bring in third party vendors with proven fiber design and manufacturing capabilities.

Marciante's research has already yielded the following results:

a proprietary larger core optical fiber with superior laser beam qualities that is compatible with high power ultra-fast femtosecond fiber lasers

a way to greatly reduce the effects of nonlinearities in the core of the proprietary fiber. "In principal, if you cut fiber length in half, you can go to twice as much energy," Marciante says. "The tradeoff is, you're also dumping the heat into half as much space."

"It's a very exciting challenge," Marciante says.

"No one in the world has been able to do this specific kind of femtosecond laser treatment of metal surfaces," he adds. "To launch commercial products using this technology will be a real game changer. This is a once-in-a-lifetime opportunity to create new science." [14]

Shedding high-power laser light on the plasma density limit

The interaction of high-power laser light sources with matter has given rise to numerous applications including; fast ion acceleration; intense X-ray, gamma-ray, positron and neutron generation; and fast-ignition-based laser fusion. These applications require an understanding of energy absorption and momentum transfer from the high-intensity lasers to plasma particles.

A group of Japanese researchers led by Osaka University has proposed that substances heated with high-power lasers produce an ultrahigh pressure plasma state, comparable with those found at the centers of stars, and that the surface tension of the plasma can push back light. Since lasers with energies capable of heating material sufficiently to create this pressure had not been available to date, the process had not been considered. Their work published in *Nature Communications*describes their theory and supporting simulations.

"Understanding extreme high pressure states created by laser light interacting with materials is crucial for laser-based applications," co-author Yasuhiko Sentoku says. "Our theory proposes that steepening of surface plasma by intense laser, i.e., hole boring, is stopped eventually by ultrahigh plasma pressure, and a new stage of plasma heating appears."

They derived the limit density for laser hole boring, which corresponds to the maximum plasma density laser light can reach. They found that after reaching the density limit, the surface plasma starts to blowout towards the laser, even if the laser irradiates the plasma continuously.

The researchers' theory explains the transition to blowout in terms of a balance relationship between the pressure of the laser light and that of the surface plasma. The theory provides a guideline in controlling electron energy which is important for applications such as ion acceleration and pair plasma creation.

"We also derived the time scale for the transition from hole boring to blowout, showing that our findings will be applicable for multi-picosecond laser experiments," lead author Natsumi Iwata says. "We hope our work will provide a grounding for application focused research, for example laser initiated nuclear fusion." [13]

When electrons ride a wave

Conventional electron accelerators have become an indispensable tool in modern research. The extremely bright radiation generated by synchrotrons, or free electron lasers, provides unique insights into matter at the atomic level. But even the smallest versions of these super-microscopes are the size of a soccer field. Laser plasma acceleration could offer an alternative. With a much smaller footprint and much higher peak currents, it could be the basis for the next generation of compact light sources. So far, the challenge with laser accelerators has been to create a reliable and stable electron beam, which is the prerequisite for possible applications. Physicists at the HelmholtzZentrum Dresden-Rossendorf (HZDR) have now developed a method to increase both beam stability and quality.

The basic principle of laser acceleration seems quite simple: A bundled, ultra-strong laser beam hits a trace of gas, which instantly creates plasma—an ionized state of matter best described as a whirling mix of charged particles. The power of the light pulse pushes electrons away from their parent ions, creating a sort of bubble-like structure with a strong electric field in the plasma. This field, which the laser pulse drags behind itself like a stern wave, traps the electrons, accelerating them to nearly the speed of light. "These speedy particles allow us to generate x-rays," says Dr. Arie Irman from the HZDR Institute of Radiation Physics. "For instance, when we make these electron bundles collide with another laser beam, the impact generates bright, ultra-short X-ray flashes—an immensely valuable research tool for examining extreme states of matter."

Right Time + Right Place = Perfect Acceleration

The strength of the secondary radiation greatly depends on the particles' electrical current. The current, in turn, is mostly determined by the number of electrons fed into the process. Laserpowered acceleration therefore holds great potential, because it reaches significantly higher peak currents in comparison with the conventional method. However, as physicist Jurjen Pieter

Couperus points out, the so-called beam loading effect kicks in: "These higher currents create an electric selffield strong enough to superimpose and disturb the laser-driven wave, distorting thereby the beam. The bundle is stretched out and not accelerated properly. The electrons therefore have different energies and quality levels." But in order to use them as a tool for other experiments, each beam must have the same parameters. "The electrons have to be in the right place at the right time," says Couperus.

Together with other colleagues at the HZDR, the two researchers were the first to demonstrate how the beam loading effect can be exploited for improved beam quality. They add a bit of nitrogen to the helium at which the laser beam is usually directed. "We can control the number of electrons we feed into the process by changing the concentration of the nitrogen," Irman explains. "In our experiments, we found out that conditions are ideal at a charge of about 300 picocoulomb. Any deviation from it—if we add more or fewer electrons to the wave—results in a broader spread of energy, which impairs beam quality."

As the physicists' calculations have shown, experiments under ideal conditions yield peak currents of about 50 kiloamperes. "To put this in context, only about 0.6 kiloamperes flow through the standard overhead line for a German high-speed train," Jurjen Pieter Couperus says. He is confident that they can beat their own record: "Using our findings and a laser pulse in the petawatt range, which our high-intensity laser DRACO can achieve, we should be able to generate a high-quality electron beam with peak currents of 150 kiloamperes. That would exceed modern large-scale research accelerators by about two orders of magnitude." The researchers believe this achievement would pave the way for the next generation of compact radiation sources. [12]

Where does laser energy go after being fired into plasma?

An outstanding conundrum on what happens to the laser energy after beams are fired into plasma has been solved in newly-published research at the University of Strathclyde.

The study discovered that the same forces that produce a bubble in plasma in the laser-plasma wakefield accelerator produce two additional low-energy but high-charge electron beams simultaneously with a low charge high energy beam. These high charge beams can have a thousand times more charge than the high energy beam.

Plasma, the state in which nearly all of the universe exists, can support electric fields that are 1,000 to 10,000 times higher than in conventional accelerators, simply by separating the positive and negative charged particles that makes up the plasma medium, which is quasi-neutral.

This can easily be achieved using an intense laser pulse, the light pressure of which pushes electrons out of its way, leaving behind the much heavier ions which remain in place and exert an attractive force on the displaced electrons. The displaced electrons then oscillate around the stationary ions resulting in a wake behind the laser pulse, in a similar manner to the wake behind a boat.

Because the laser pulse travels at a velocity close to that of light in vacuum, the wake can track and accelerate charged particles rapidly to very high energies, over extremely short lengths.

The research paper, entitled Three electron beams from a laser-plasma wake?eld accelerator and the energy apportioning question, has been published in Scientific Reports.

Professor Dino Jaroszynski, of Strathclyde's Department of Physics, led the study. He said: "The intense laser pulse we used, and the acceleration of the wake it creates, lead to a very compact laser wakefield accelerator, which is millimetres long, rather than tens of metres long, for an equivalent conventional accelerator. The plasma wake forms into something like a bubble-shaped, laserpowered miniature Van de Graaf accelerator, which travels at close to the speed of light.

"Some of the laser energy is converted to electrostatic energy of the plasma bubble, which has a diameter of several microns. Conventional accelerators store their microwave energy in copper or superconducting cavities, which have limited power-carrying capability.

"An interesting conundrum that has not been considered before is the question of where laser energy goes after being deposited in plasma. We know where some of this energy goes because of the presence of high-energy electrons emitted in a narrow, forward directed beam.

"One of these beams is emitted by a sling-shot action into a broad forward-directed cone, with several MeV (mega electron volt) energies and nanocoulomb-level charge. Paradoxically, another beam is emitted in the backward direction, which has similar charge but an energy of around 200 keV (kilo electron volt). These beams carry off a significant amount of energy from the plasma bubble.

"It is interesting to observe that answering a very basic question - where does the laser energy go? - yields surprising and paradoxical answers. Introducing a new technology, such as the laser-wakefield accelerator, can change the way we think about accelerators. The result is a very novel source of several charge particle beams emitted simultaneously.

"My research group has shown that the wakefield accelerator produces three beams, two of which are low energy and high charge, and the third, high energy and low charge."

Dr Enrico Brunetti, a Research Fellow in Strathclyde's Department of Physics and a member of the research group, said: "These beams can provide a useful high flux of electrons or bremsstrahlung photons over a large area, which can be used for imaging applications, or for investigating radiation damage in materials. If not properly dumped, they can, however, have undesirable side-effects, such as causing damage to equipment placed close to the accelerator.

"This is a particular concern for longer accelerators, which often use plasma wave guides based on capillaries to guide the laser beam over long distances. These low energy, high charge beams also carry a large amount of energy away from the plasma, setting a limit to the efficiency of laserwakefield accelerators.

"This is an issue which needs to be taken into account in the future design and construction of laserwakefield accelerators." [11]

Electrons used to control ultrashort laser pulses

We may soon get better insight into the microcosm and the world of electrons. Researchers at Lund University and Louisiana State University have developed a tool that makes it possible to control extreme UV light - light with much shorter wavelengths than visible light. The new method uses strong laser pulses to direct the short bursts of light.

Something very exciting happens when light hits electrons: they start to move, and when they do that they reemit the light again. The electron, which is very small, can easily follow the fast light oscillations. However, reemitting the light takes some time, and during that time the electrons can be controlled so that they emit the light in a different direction.

"This means we can control the properties of the light, for instance change the direction, change the pulse duration, split the light or focus it, " says Johan Mauritsson.

Since he and his colleagues control the electrons with another laser pulse, is it possible to precisely control the timing between the two pulses - and set it to exactly what they want it to be.

"What makes this field of research so interesting is that we still do not know exactly what happens when light hits a material. What is, for example, the first thing that happens when sunlight hits a flower? We do not know all the details", says Johan Mauritsson, researcher in the field of attosecond science at Lund University in Sweden.

Yet it isn't that strange that many details are still unknown. You cannot probe shorter time intervals than the time it takes for the light to make one oscillation. This makes it impossible to use visible light to follow electron dynamics, since one oscillation takes about 2 femtoseconds, or 10-15 seconds. During that time, the electron circles the nuclei more than 13 times. We therefore need light that oscillates much faster, i.e. with shorter wavelengths.

This technique to control the light is new and there is still a lot to improve.

"Right now we are working on improving the time resolution with various experiments with XUV light, for instance for free electron lasers. However, our main focus is developing the technique so we can learn more about the light/electron interaction. But who knows, in 50 years we may all be using ultrafast optics in our everyday lives", concludes Samuel Bengtsson, PhD student in atomic physics. [10]

Imaging at the speed of light

Tiny micro- and nanoscale structures within a material's surface are invisible to the naked eye, but play a big role in determining a material's physical, chemical, and biomedical properties.

Over the past few years, Chunlei Guo and his research team at the University of Rochester have found ways to manipulate those structures by irradiating laser pulses to a material's surface. They've altered materials to make them repel water, attract water, and absorb great amounts of light—all without any type of coating.

Now, Guo, Anatoliy Vorobyev, and Ranran Fang, researchers at the University's Institute of Optics, have advanced the research another step forward. They've developed a technique to visualize, for the first time, the complete evolution of micro- and nanoscale structural formation on a material's surface, both during and after the application of a laser pulse.

"After we determined that we could drastically alter the property of a material through creating tiny structures in its surface, the next natural step was to understand how these tiny structures were formed," Guo says. "This is very important because after you understand how they're formed you can better control them."

Having that control will open the way for improvements in all kinds of technologies, including anticorrosive building materials, energy absorbers, fuel cells, space telescopes, airplane de-icing, medical instrumentation, and sanitation in third world countries.

Over the past few years, Chunlei Guo and his research team at the University of Rochester have used lasers to manipulate the properties of target materials and make them, for instance, superhydrophilic or superhydrophobic. Now the team has developed …more

In a paper published in the Nature journal Light: Science & Applications, the group introduced a scattered-light imaging technique that allows them to record an ultrafast movie of the ways in which laser radiation alters a material's surface. The technique opens a window on the entire process, from the moment a laser hits the material to melting, transient surface fluctuations, and resolidification resulting in permanent micro- and nanostructures.

It currently takes about an hour to pattern a one-inch by one-inch metal sample. Identifying how micro- and nanostructures form has the potential to allow scientists to streamline the creation of these structures—including increasing the speed and efficiency of patterning surfaces.

Creating and altering these small structures makes properties intrinsically part of the material and reduces the need for temporary chemical coatings.

To produce these effects, researchers use a femtosecond laser. This laser produces an ultra-fast pulse with a duration of tens of femtoseconds. (A femtosecond is equal to one quadrillionth of a second.)

Changing the laser's conditions causes changes in the morphological features of the surface structures— such as their geometry, size, and density—leading the material to exhibit various specific physical properties.

It is difficult to obtain detailed images and movies of events in micro- and nanoscales because they occur during a matter of femtoseconds, picoseconds (one trillionth of a second), and nanoseconds (one billionth of a second).

To put this into perspective: Vorobyev explains that it takes about one second for light to travel from
Earth to the moon. However, light travels only about one foot in a nanosecond and approximately 0.3 micrometers in a femtosecond, which is a distance comparable to the diameter of a virus or bacteria.

A typical video camera records a series of images at a rate of five to 30 frames per second. When playing the series of images in real time, human eyes perceive continuous motion rather than a series of separate frames.

So how was Guo's team able to record frames at an interval of femtoseconds, picoseconds, and nanoseconds? They used a technique involving scattered light. During a femtosecond laser pulse, the beam is split in two: one pump beam is aimed at the material target in order to cause micro- and nanostructural change, and the second probe beam acts as a flashbulb to illuminate the process and record it into a CCD camera—a highly-sensitive imaging device with high-resolution capabilities.

"We worked very hard to develop this new technique," Guo says. "With the scattered light pulsing at femtosecond time intervals, we can capture the very small changes at an extremely fast speed. From these images we can clearly see how the structures start to form."

Guo explains that this scattered light visualization technique has applications for capturing any process that takes place on a minute scale. "The technique we developed is not necessarily limited to just studying the surface effects produced in my lab. The foundation we laid in this work is very important for studying ultrafast and tiny changes on a material surface." This includes studying melting, crystallography, fluid dynamics, and even cell activities. [7]

Researchers demonstrate new type of laser

Lasers are everywhere nowadays: Doctors use them to correct eyesight, cashiers to scan your groceries, and quantum scientist to control qubits in the future quantum computer. For most applications, the current bulky, energy-inefficient lasers are fine, but quantum scientist work at extremely low temperatures and on very small scales. For over 40 years, they have been searching for efficient and precise microwave lasers that will not disturb the very cold environment in which quantum technology works.

A team of researchers led by Leo Kouwenhoven at TU Delft has demonstrated an on-chip microwave laser based on a fundamental property of superconductivity, the ac Josephson effect. They embedded a small section of an interrupted superconductor, a Josephson junction, in a carefully engineered on-chip cavity. Such a device opens the door to many applications in which microwave radiation with minimal dissipation is key, for example in controlling qubits in a scalable quantum computer.

The scientists have published their work in Science on the 3rd of March.

Lasers have the unique ability to emit perfectly synchronized, coherent light. This means that the linewidth (corresponding to the color) is very narrow. Typically lasers are made from a large number of emitters (atoms, molecules, or semiconducting carriers) inside a cavity. These conventional lasers are often inefficient, and dissipate a lot of heat while lasing. This makes them difficult to operate in cryogenic environments, such as what is required for operating a quantum computer.

Superconducting Josephson junction

In 1911, the Dutch physicist Heike Kamerlingh Onnes discovered that some materials transition to a superconducting state at very low temperatures, allowing electrical current to flow without any loss of energy. One of the most important applications of superconductivity is the Josephson effect: if a very short barrier interrupts a piece of superconductor, the electrical carriers tunnel through this non-superconducting material by the laws of quantum mechanics. Moreover, they do so at a very characteristic frequency, which can be varied by an externally applied DC voltage. The Josephson junction is therefore a perfect voltage to light (frequency) converter.

Josephson junction laser

The scientists at QuTech coupled such a single Josephson junction to a high-quality factor superconducting micro-cavity, no bigger than an ant. The Josephson junction acts like a single atom, while the cavity can be seen as two mirrors for microwave light. When a small DC voltage is applied to this Josephson junction, it emits microwave photons that are on resonance with the cavity frequency. The photons bounce back and forth between two superconducting mirrors, and force the Josephson junction to emit more photons synchronized with the photons in the cavity. By cooling the device down to ultra-low temperatures (< 1 Kelvin) and applying a small DC voltage to the Josephson junction, the researchers observe a coherent beam of microwave photons emitted at the output of the cavity. Because the on-chip laser is made entirely from superconductors, it is very energy efficient and more stable than previously demonstrated semiconductor-based lasers. It uses less than a picoWatt of power to run, more than 100 billion times less than a light globe.

Low-loss quantum control

Efficient sources of high quality coherent microwave light are essential in all current designs of the future quantum computer. Microwave bursts are used to read out and transfer information, correct errors and access and control the individual quantum components. While current microwave sources are expensive and inefficient, the Josephson junction laser created at QuTech is energy efficient and offers an on-chip solution that is easy to control and modify. The group is extending their design to use tunable Josephson junctions made from nanowires to allow for microwave burst for fast control of multiple quantum components. In the future, such a device may be able to generate so-called "amplitude-squeezed" light with has smaller intensity fluctuations compared to conventional lasers, this is essential in most quantum communication protocols. This work marks an important step towards the control of large quantum systems for quantum computing. [8]

Researchers develop surprising technique for ultrashort laser pulses

Pulse lasers built entirely on optical fibers are increasingly used by industry. Optical scientists from the Warsaw Laser Centre of the Institute of Physical Chemistry of the Polish Academy of Sciences and the Faculty of Physics of the University of Warsaw have generated ultrashort laser pulses in an optical fiber with a method previously considered to be physically impossible. Their solution is not only useful, but also surprisingly simple.

An innovative fiber laser has been developed at the Laser Centre of the Institute of Physical Chemistry of the Polish Academy of Sciences (IPC PAS) and the Faculty of Physics of the University of Warsaw. Using a simple solution, the Warsaw optical scientists have "forced" one of the types of optical fiber lasers to generate ultrashort, high-energy pulses. The new laser is devoid of any mechanically sensitive external parts, which seems to be especially interesting for future applications. The invention greatly expedites the processing of materials in industrial laser machines.

"Fiber lasers can be built so that all the processes important for the generation and shaping of the ultrashort pulses takes place in the fiber itself. Such devices, without any external mechanically sensitive components, operate in a very stable manner, and are ideal for working in difficult conditions," says Dr. Yuriy Stepanenko (IPC PAS).

Laser action in the fiber leads to the generation of a continuous light beam. The release of energy in the shortest possible pulses is, however, much more favourable, since it signifies a great increase of power. Pulses are generated in fiber lasers via a saturable absorber system. When the light intensity is low, the absorber blocks light; when it is high, the absorber lets it through. Since femtosecond pulses have greater intensity than a continuous beam, the parameters of the absorber can be adjusted so that it only admits pulses.

"Up to now, graphene sheets, among others, have been used as the saturable absorbers, in a form of a thin layer deposited on the tip of the fiber. But the diameters of optical fibers are in the order of single microns. Even a little energy cramped in such a small cross-section has a significant density per unit area, affecting the lifetime of the materials. Therefore, if an attempt was made to increase the power of the femtosecond pulses, the graphene on the tip of the connector was destroyed. Other absorbers, such as carbon nanotubes, may also undergo degradation," explains Jan Szczepanek, a PhD student from the Faculty of Physics of the University of Warsaw.

In order to generate higher energy femtosecond pulses in the optical fiber, the Warsaw physicists decided to improve saturable absorbers of a different type, via the clever use of optical phenomena such as nonlinear effects that cause a change in the refractive index of glass.

Impossible (but working!) recipe for ultrashort laser pulses

A nonlinear artificial saturable absorber works as follows. The plane of polarization of low intensity light beam does not change in the absorber and the output polarizer blocks the light (images at the bottom). At a high enough intensity, …more

Electric and magnetic fields of light usually oscillate in random, mutually perpendicular directions. When the fields oscillate all the time in the same plane, the wave is called linearly polarized. In classical optics, it is assumed that when such a wave passes through a medium, it experiences a constant refractive index, regardless of the light intensity. In nonlinear optics this is different: At a sufficiently high light intensity, the refractive index begins to increase slightly.

A nonlinear artificial saturable absorber works as follows. At the input, the linearly polarized light is divided into a beam with a low intensity and a beam with a high intensity. The medium of the absorber can be chosen for both light beams to experience a slightly different refractive index in order for them to travel at slightly different (phase) velocities. As a result of the velocity difference, the plane of polarization starts to rotate. At the output of the absorber, there is a polarization filter that only lets through waves oscillating perpendicularly to the plane of polarization of the incoming light. When the laser is operating in continuous mode, the light in the beam is of a relatively low intensity, an optical path difference does not occur, the polarization does not change, and the output filter blocks the light. At a high enough intensity, typical for femtosecond pulses, the rotation of polarization causes the pulse to pass through the polarizer.

For the saturable absorber with polarization rotation to work, the fibre must have different refractive indices in different directions (thus it has to be birefringent), and both indices should also be stable. The problem is that in ordinary optical fibers, birefringence occurs accidentally, e.g. due to stress caused by the touch of a finger. Lasers built in this manner are extremely sensitive to external factors. In turn, birefringence of the polarization preserving fibers is so large that the light propagates in only one direction, and the construction of artificial saturable absorbers becomes physically impossible.

"Birefringent optical fibers retaining the polarization state of the entering light are already in production. We are the first to demonstrate how they can be used to construct a saturable absorber: We cut the optical fiber into segments of an appropriate length and then reconnect them, rotating each successive segment 90 degrees in relation to its predecessor," says Ph.D. student Szczepanek.

"Rotation means that if in one segment a pulse with, shall we say, vertical polarization travels slowly, in the next, it will run faster and catch up with the second pulse, polarized perpendicularly. A simple procedure has therefore allowed us to eliminate the main obstacle to increasing the energy, that is, the great difference in velocities between pulses of different polarities, typical for all polarization preserving fibres," explains Dr. Stepanenko.

The more rotated segments there are, the better the quality of the pulses generated in the fiber. In the laser built in the Warsaw laboratory, the saturable absorber consisted of a fiber with a length of approximately 3 m, divided into three segments, and a filtering polarizer. The potential number of rotated segments can be increased up to even a dozen or so.

The new laser produces high-quality femtosecond pulses, and their energy can be up to 1000 times larger than typical for lasers with material absorbers. In comparison to the devices with artificial absorbers, the laser made by Warsaw scientists has a much simpler construction and therefore its reliability is significantly greater. [7]

Optical fibre with Einstein effect

Researchers at the Max Planck Institute for the Science of Light in Erlangen have discovered a new mechanism for guiding light in photonic crystal fibre (PCF). PCF is a hair-thin glass fibre with a regular array of hollow channels running along its length. When helically twisted, this spiralling array of hollow channels acts on light rays in an analogous manner to the bending of light rays when they travel through the gravitationally curved space around a star, as described by the general theory of relativity.

Optical fibres act as pipes for light. And just as the inside of a pipe is enclosed by a wall, optical fibres normally have a light-guiding core, whose glass has a higher refractive index than the glass of the enclosing outer cladding. The difference in the refractive index causes the light to be reflected at the cladding interface and trapped in the core like water in a pipe. A team headed by Philip Russell, Director at the Max Planck Institute for the Science of Light, is the first to succeed in guiding light in a PCF with no core.

Photonic crystals give butterflies their colour and can also guide light

A typical photonic crystal consists of a piece of glass with holes arranged in regular periodic pattern throughout its volume. Since glass and the air have different refractive indices, the refractive index has a periodic structure. This is the reason these materials are called crystals—their atoms form an ordered, three-dimensional lattice as found in crystalline salt or silicon, for example. In a conventional crystal, the precise design of the 3-D structure determines the behaviour of electrons, resulting for example in electrical insulators, conductors and semiconductors.

In a similar manner, the optical properties of a photonic crystal depend on the periodic 3-D microstructure, which is responsible for the shimmering colours of some butterfly wings, for example. Being able to control the optical properties of materials is useful in a wide variety of applications. The photonic crystal fibres developed by Philip Russell and his team at the Erlangenbased Max Planck Institute can be used to filter specific wavelengths out of the visible spectrum or to produce very white light, for example.

As is the case with all optical fibres used in telecommunications, all conventional photonic crystal fibres have a core and cladding each with different refractive indices or optical properties. In PCF, the air-filled channels already give the glass a refractive index different from the one it would have if completely solid.

The holes define the space in a photonic crystal fibre

"We are the first to succeed in guiding light through a coreless fibre," says Gordon Wong from the Max Planck Institute for the Science of Light in Erlangen. The researchers working in Philip Russell's team have fabricated a photonic crystal fibre whose complete cross-section is closely packed with a large number of air-filled channels, each around one thousandth of a millimetre in diameter, which extend along its whole length.

While the core of a conventional PCF is solid glass, the cross-sectional view of the new optical fibre resembles a sieve. The holes have regular separations and are arranged so that every hole is surrounded by a regular hexagon of neighbouring holes. "This structure defines the space in the fibre," explains Ramin Beravat, lead author of the publication. The holes can be thought of as distance markers. The interior of the fibre then has a kind of artificial spatial structure which is formed by the regular lattice of holes.

"We have now fabricated the fibre in a twisted form," continues Beravat. The twisting causes the hollow channels to wind around the length of the fibre in helical lines. The researchers then transmitted laser light through the fibre. In the case of the regular, coreless cross-section, one would actually expect the light to distribute itself between the holes of the sieve as evenly as their pattern determines, i.e. at the edge just as much as in the centre. Instead, the physicists discovered something surprising: the light was concentrated in the central region, where the core of a conventional optical fibre is located.

In a twisted PCF, the light follows the shortest path in the interior of the fibre

"The effect is analogous to the curvature of space in Einstein's general theory of relativity," explains Wong. This predicts that a heavy mass such as the Sun will distort the space surrounding it – or more precisely, distort spacetime, i.e. the combination of the three spatial dimensions with the fourth dimension, time – like a sheet of rubber into which a lead sphere is placed. Light follows this curvature. The shortest path between two points is then no longer a straight line, but a curve. During a solar eclipse, stars which should really be hidden behind the Sun thus become visible. Physicists call these shortest connecting paths "geodesics".

"By twisting the fibre, the 'space' in our photonic crystal fibre becomes twisted as well," says Wong. This leads to helical geodesic lines along which light travels. This can be intuitively understood by taking into account the fact that light always takes the shortest route through a medium. The glass strands between the air-filled channels describe spirals, which define possible paths for the light rays. The path through the wide spirals at the edge of the fibre is longer than that through the more closely wound spirals in its centre, however, resulting in curved ray paths that at a certain radius are reflected by a photonic crystal effect back towards the fibre axis.

A twisted PCF as a large-scale environmental sensor

The more the fibre is twisted, the narrower is the space within which the light concentrated. In analogy to Einstein's theory, this corresponds to a stronger gravitational force and thus a greater deflection of the light. The Erlangen-based researchers write that they have created a "topological channel" for the light (topology is concerned with the properties of space which are conserved under continuous distortion).

The researchers emphasize that their work is basic research. They are one of the very few research groups working in this field anywhere in the world. Nevertheless, they can think of several applications for their discovery. A twisted fibre which is less twisted at certain intervals, for example, will allow a portion of the light to escape to the outside. Light could then interact with the environment at these defined locations. "This could be used for sensors which measure the absorption of a medium, for instance." A network of these fibres could collect data over large areas as an environmental sensor. [6]

Theory that challenges Einstein's physics could soon be put to the test

Scientists behind a theory that the speed of light is variable - and not constant as Einstein suggested - have made a prediction that could be tested.

Einstein observed that the speed of light remains the same in any situation, and this meant that space and time could be different in different situations.

The assumption that the speed of light is constant, and always has been, underpins many theories in physics, such as Einstein's theory of general relativity. In particular, it plays a role in models of what happened in the very early universe, seconds after the Big Bang.

But some researchers have suggested that the speed of light could have been much higher in this early universe. Now, one of this theory's originators, Professor João Magueijo from Imperial College London, working with Dr Niayesh Afshordi at the Perimeter Institute in Canada, has made a prediction that could be used to test the theory's validity.

Structures in the universe, for example galaxies, all formed from fluctuations in the early universe – tiny differences in density from one region to another. A record of these early fluctuations is imprinted on the cosmic microwave background – a map of the oldest light in the universe – in the form of a 'spectral index'.

Working with their theory that the fluctuations were influenced by a varying speed of light in the early universe, Professor Magueijo and Dr Afshordi have now used a model to put an exact figure on the spectral index. The predicted figure and the model it is based on are published in the journal Physical Review D.

Cosmologists are currently getting ever more precise readings of this figure, so that prediction could soon be tested – either confirming or ruling out the team's model of the early universe. Their figure is a very precise 0.96478. This is close to the current estimate of readings of the cosmic microwave background, which puts it around 0.968, with some margin of error.

RADICAL IDEA

Professor Magueijo said: "The theory, which we first proposed in the late-1990s, has now reached a maturity point – it has produced a testable prediction. If observations in the near future do find this number to be accurate, it could lead to a modification of Einstein's theory of gravity.

"The idea that the speed of light could be variable was radical when first proposed, but with a numerical prediction, it becomes something physicists can actually test. If true, it would mean that the laws of nature were not always the same as they are today."

The testability of the varying speed of light theory sets it apart from the more mainstream rival theory: inflation. Inflation says that the early universe went through an extremely rapid expansion phase, much faster than the current rate of expansion of the universe.

THE HORIZON PROBLEM

These theories are necessary to overcome what physicists call the 'horizon problem'. The universe as we see it today appears to be everywhere broadly the same, for example it has a relatively homogenous density.

This could only be true if all regions of the universe were able to influence each other. However, if the speed of light has always been the same, then not enough time has passed for light to have travelled to the edge of the universe, and 'even out' the energy.

As an analogy, to heat up a room evenly, the warm air from radiators at either end has to travel across the room and mix fully. The problem for the universe is that the 'room' – the observed size of the universe – appears to be too large for this to have happened in the time since it was formed.

The varying speed of light theory suggests that the speed of light was much higher in the early universe, allowing the distant edges to be connected as the universe expanded. The speed of light would have then dropped in a predictable way as the density of the universe changed. This variability led the team to the prediction published today.

The alternative theory is inflation, which attempts to solve this problem by saying that the very early universe evened out while incredibly small, and then suddenly expanded, with the uniformity already imprinted on it. While this means the speed of light and the other laws of physics as we know them are preserved, it requires the invention of an 'inflation field' – a set of conditions that only existed at the time.

'Critical geometry of a thermal big bang' by Niayesh Afshordi and João Magueijo is published in Physical Review D. [4]

The Test in 2015

Over the course of four Thursdays in November 1915, Albert Einstein stood before the Prussian Academy in Berlin and unveiled a set of equations that upended our ideas about space and time. A century later, his grand project remains frustratingly incomplete. Sure, the general theory of relativity has become the foundation of our modern understanding of the big bang, black holes, and gravity itself—but crucial parts of it remain unverified.

One unproved prediction is that an accelerating mass should create gravitational waves, like the ripples from a boat sailing across the surface of a lake. In July, the hunt for those waves will heat up with the launch of a detector called Lisa Pathfinder, which will test technology for a new gravitational wave observatory in space. Starting in 2015, two earthbound experiments, Advanced Ligo and Advanced Virgo, will be brought online. They should be able to pick up gravitational disturbances from exploding stars. Another test will examine the motions of a triple-star system called PSR J0337+1715 to check if gravity behaves the same toward all kinds of matter, as Einstein believed.

Some scientists suspect other aspects of relativity are just flat-out wrong. For years, cosmologists have observed dramatic, unexplained movements of galaxies. Those motions are normally attributed to hypothetical dark matter and dark energy, but at a series of conferences this year, physicists will explore the possibility that gravity simply doesn’t work the way Einstein thought.
And then there’s the elephant in the lab: General relativity clashes with quantum mechanics. Attempts to reconcile them have so far yielded nothing but endless, inconclusive papers about string theory. [4]

The Classical Relativistic effect

The moving charges are self maintain the electromagnetic field locally, causing their movement and this is the result of their acceleration under the force of this field.
In the classical physics the charges will distributed along the electric current so that the electric potential lowering along the current, by linearly increasing the way they take every next time period because this accelerated motion.

The Relativistic Quantum Mechanics

The same thing happens on the atomic scale giving a dp impulse difference and a dx way difference between the different part of the not point like particles.

Commonly accepted idea that the relativistic effect on the particle physics it is the fermions' spin - another unresolved problem in the classical concepts. If the electric charges can move only with accelerated motions in the self maintaining electromagnetic field, once upon a time they would reach the velocity of the electromagnetic field. The resolution of this problem is the spinning particle, constantly accelerating and not reaching the velocity of light because the acceleration is radial.

The Heisenberg Uncertainty Relation

I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

The General Relativity - 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]

Relativistic change of mass

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

The frequency dependence of mass

Since $E = hv$ and $E = mc^2$, $m = hv / c^2$ that is the m depends only on the v 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_o 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 – can be seen as a gravitational force. [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 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. The Electroweak Interaction shows that the Weak Interaction is basically electromagnetic in nature. The arrow of time shows the entropy grows by changing the temperature dependent diffraction patterns of the electromagnetic oscillators.

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 1/2spin 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.

The Higgs boson

By March 2013, the particle had been proven to behave, interact and decay in many of the expected ways predicted by the Standard Model, and was also tentatively confirmed to have + parity and zero spin, two fundamental criteria of a Higgs boson, making it also the first known scalar particle to be discovered in nature, although a number of other properties were not fully proven and some partial results do not yet precisely match those expected; in some cases data is also still awaited or being analyzed.

In my opinion, the best explanation of the Higgs mechanism for a lay audience is the one invented by David Miller. You can find it here: http://www.strings.ph.qmul.ac.uk/~jmc/epp/higgs3.html . The field must come first. The boson is an excitation of the field. So no field, no excitation. On the other hand in quantum field theory it is difficult to separate the field and the excitations. The Higgs field is what gives particles their mass.

There is a video that gives an idea as to the Higgs field and the boson. It is here: http://www.youtube.com/watch?v=RIg1Vh7uPyw . Note that this analogy isn't as good as the Miller one, but as is usually the case, if you look at all the analogies you'll get the best understanding of the situation.

Since the Higgs boson is necessary to the W and Z bosons, the dipole change of the Weak interaction and the change in the magnetic effect caused gravitation must be conducted. The Wien law is also important to explain the Weak interaction, since it describes the T_{max} change and the diffraction patterns change. [2]

Higgs mechanism

The magnetic induction creates a negative electric field, causing an electromagnetic inertia. Probably it is the mysterious Higgs field giving mass to the charged particles? We can think about the photon as an electron-positron pair, they have mass. The neutral particles are built from negative and positive charges, for example the neutron, decaying to proton and electron. The wave – particle duality makes sure that the particles are oscillating and creating magnetic induction as an inertial mass, explaining also the relativistic mass change. Higher frequency creates stronger magnetic induction, smaller frequency results lesser magnetic induction. It seems to me that the magnetic induction is the secret of the Higgs field.

In particle physics, the Higgs mechanism is a kind of mass generation mechanism, a process that gives mass to elementary particles. According to this theory, particles gain mass by interacting with the Higgs field that permeates all space. More precisely, the Higgs mechanism endows gauge bosons in a gauge theory with mass through absorption of Nambu–Goldstone bosons arising in spontaneous symmetry breaking.

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. This mechanism may also leave behind elementary scalar (spin-0) particles, known as Higgs bosons.

In the Standard Model, the phrase "Higgs mechanism" refers specifically to the generation of masses for the $W^{\pm}$, and Z weak gauge bosons through electroweak symmetry breaking. The Large Hadron Collider at CERN announced results consistent with the Higgs particle on July 4, 2012 but stressed that further testing is needed to confirm the Standard Model.

Gravity from the point of view of quantum physics

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 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]

Conclusions

Physicists’ greatest hope for 2015, then, is that one of these experiments will show where Einstein got off track, so someone else can jump in and get closer to his long-sought “theory of everything.” [4]

The electric currents causing self maintaining electric potential is the source of the special and general relativistic effects. The self maintained electric potential of the accelerating charges equivalent with the General Relativity space-time curvature, and since it is true on the quantum level also, gives the base of the Quantum Gravity. Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions.

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

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] Graviton Production By Two Photon and Electron-Photon Processes In Kaluza-Klein Theories

With Large Extra Dimensions http://arxiv.org/abs/hep-ph/9909392

[4] WHAT TO EXPECT IN 2015: GENERAL RELATIVITY GETS PUT TO THE TEST

http://www.popsci.com/general-relativity-gets-put-test

[5] Theory that challenges Einstein's physics could soon be put to the test

http://phys.org/news/2016-11-theory-einstein-physics.html

[6] Optical fibre with Einstein effect https://phys.org/news/2017-02-optical-fibre-einstein-effect.html [7] Researchers develop surprising technique for ultrashort laser pulses https://phys.org/news/2017-02-technique-ultrashort-laser-pulses.html [8] Researchers demonstrate new type of laser https://phys.org/news/2017-03-laser.html [9] Imaging at the speed of light https://phys.org/news/2017-03-imaging.html [10] Electrons used to control ultrashort laser pulses https://phys.org/news/2017-03-electrons-ultrashort-laser-pulses.html

[11] Where does laser energy go after being fired into plasma?

https://phys.org/news/2017-03-laser-energy-plasma.html

[12] When electrons ride a wave https://phys.org/news/2017-09-electrons.html

[13] Shedding high-power laser light on the plasma density limit

https://phys.org/news/2018-02-high-power-laser-plasma-density-limit.html

[14] A laser focus on super water-repellent metals

https://phys.org/news/2018-02-laser-focus-super-water-repellent-metals.html

[15] X-rays from tabletop lasers allows scientists to peer through the 'water window'

https://phys.org/news/2018-05-x-rays-tabletop-lasers-scientists-peer.html

[16] Detecting the shape of laser pulses

https://phys.org/news/2018-05-laser-pulses.html

[17] Researchers devise new way to make light interact with matter

https://phys.org/news/2018-06-interact.html

[18] A new way to measure the light-warping properties of hyperbolic metamaterials

https://phys.org/news/2018-06-light-warping-properties-hyperbolic-metamaterials.html