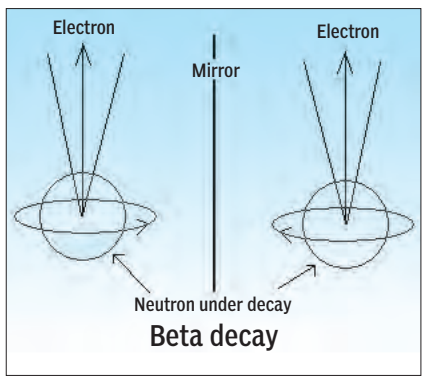
Testing the anti-world

THE QUEST FOR ANOMALY IN FUNDAMENTAL PHYSICS HAS DRAWN ANOTHER BLANK, SAYS **S ANANTHANARAYANAN**

Like any theory, the imposing edifice of physics stands on assumptions, however evident. And then, physics has run into an impasse and is waiting for a way forward. Trials to test whether the basic symmetries that physics assumes to exist are true are then doubly important, both to validate all that is going on and also to show us if a new path needs to be taken.

We are aware that there are two kinds of charge — positive and negative. Atoms have the positive charge on the nucleus and the negative charge evenly distributed outside, around the nucleus, so that the two kinds exactly cancel out. And based on this model all of physics and the technological marvels of our times have been constructed. But underlying the model is the assumption that the units that make up the positive and negative charge, the charge on the electrons, the tiny particles at the exterior of atoms, and the charge on the protons, the more massive particles that lie at the centre, are equal, although opposite. A team working at Cern in Geneva has reported in the journal *Nature Communications* that the most accurate verification, to date, of this assumption has proved that it is still valid.

This assumption itself corresponds to basic symmetries that are assumed in all physical laws — that the laws should be the same wherever and however events are viewed. There are three such basic symmetries – one, that physics should work the same way even if the charges of the components of an experiment are interchanged; second, if the experiment were viewed through a mirror, which is to say that left were changed to right; and, third, if the experiment were viewed backwards in time, which is to say that an apple bounding off the ground should rise just till the height of the branch and attach itself to the stalk from which it fell!



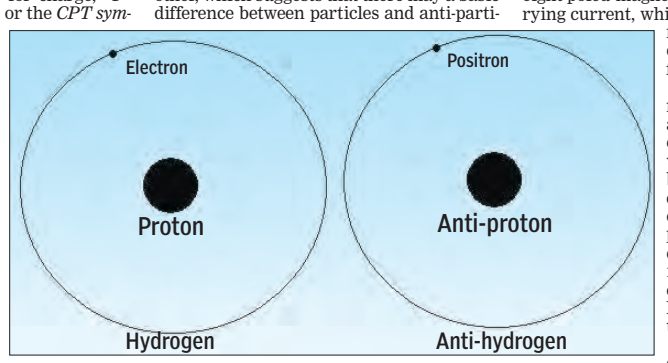
These assumptions do seem to be wholly reasonable and generally valid. The three symmetries are called "C" for charge, "P" for parity and "T" for time, or the *CPT symmetry*.

But nature contains some instances where the symmetries are not conserved. In the case of *beta decay*, a neutron (a neutral particle in the nucleus) decays into a proton and an electron (to conserve charge). It is seen, however, that the direction of emission of the electron is related to the sense of spin of the neutron that is undergoing decay. Now if this event were viewed as a reflection in a mirror, the sense of spin of the neutron would be reversed, but the direction of emission of the electron would stay the same. This would be a case of behaviour changing on reflection and a violation of "P".

But this violation gets resolved if we change the nature of the particles, along with reflection. In the subatomic world, particles also have "antiparticles", which are the same as the particles except for charge and some internal parameters. Thus, for electrons and protons, there are the positrons and antiprotons and there can be anti-atoms and an anti-universe. Particles and anti-particles can arise spontaneously from a photon that has sufficient energy and if a pair of anti-particles should meet, they annihilate, emitting photons. If beta decay, on reflection, were viewed in terms of anti-particles as "positron decay", where the positively charged anti-particle of the electron was emitted, then the fact that the direction is unchanged with the reversal of the sense of spin is no longer a problem, as charge has also changed. The combined symmetry of charge and parity, or CP, is then said to be conserved, although "P" alone is not, in this kind of interaction.

It was also seen that a neutral particle called the neutrino, which is always emitted in beta decay, had a given sense of "spin". The neutrino was then assigned an "intrinsic parity", and when the "anti-neutrino" was considered, there was a case of "C" violation, but again with CP invariance.

This state of CP invariance also did not last long, as a case of *kaon decay* was discovered, where even CP was violated. It was found that there were two forms of kaon decay, with emission of neutrinos and anti-neutrinos, and these were equivalent to each other under the "CP" reversal. This should suggest that both forms be equally likely. But an experiment showed that one form of decay was slightly more frequent than the other, which suggests that there may a basic difference between particles and anti-particles. It also suggests why the real universe is made of particles.



But the one bastion that has not been breached is *CPT invariance*. This symmetry also lies at the base of the equality of opposite charges and the observation that atoms, which are built of positive and negative charges, are truly neutral. That atoms, which are available in plenty, are neutral has been verified to a very great degree, but the real test would be if atoms made of anti-particles were also isolated and shown to be neutral.

Anti-hydrogen

The hydrogen atom, which is one proton and one electron, is the simplest and the best understood atom. In principle, the forces between an anti-proton and a positron should be the same and they should also form an atom, which should have the same energy levels and should, hence, emit the same spectral lines as normal hydrogen. Such anti-hydrogen atoms have, in fact, been created in the lab, but the problem is to get a good enough number of them for long enough.

Anti-hydrogen is created by bringing together equal numbers of anti-protons, created in a particle accelerator and then slowed down, and positrons, from a radioactive source. The constituent particles are guided to the place of merger with carefully designed electric and magnetic fields and good numbers of anti-hydrogen atoms do get produced. But the problem is that once the atoms form, they become neutral and do not respond to the confining electric and magnetic fields. The newborn atoms just spread out and annihilate as soon as they contact the container walls and that is the end of their short existence!

The Geneva team used the equipment of the *Anti-hydrogen Laser Physics Apparatus* international collaboration based at Cern. The arrangement consists of an octuple, or eight-poled magnet and a pair of coils carrying current, which create a pocket of low magnetic field, where the charged particles meet to form anti-hydrogen.

Depending on the movement energy of the anti-atoms, their production can be confined to a small volume for a short while, by magnetic fields, as even electrically neutral atoms still have magnetic properties. After the short confinement and switching off the fields, the atoms rush out to annihilate against the walls of the container.

Annihilation creates radiation, which is detected by silicon-based imaging equipment, resulting in data of each anti-atom annihilation event.

As the equipment was first designed to create numbers of anti-atoms, it is provided with a pair of opposite electric fields, which would sweep away any leftover anti-protons, while leaving the anti-atoms undisturbed. As the present experiment was to test the charge neutrality of the anti-atoms, this pair of electric fields became a useful means to test the linearity of the anti-atom paths. Out of some 1,300 events considered, 386 were proved anti-hydrogen annihilation events and their position was distributed — 241 on one side and 145 on the other. Any charge on the anti-atoms would result in a level of deviation. After providing the necessary allowances for statistical errors, the distribution was found to be closely centred and the extent of deviation allowed calculation of how much the charge on the anti-atom could have been.

The result was that the charge, if there were any, was less than a hundred-millionth of the charge on the electron. As the anti-hydrogen atom consists of an anti-proton and a positron, this means the charge of the two particles does not differ by a fraction more than one in 100 million. This is the best assessment made so far in respect of the rare and short-lived anti-hydrogen atom.

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A QUESTION OF FUNCTION

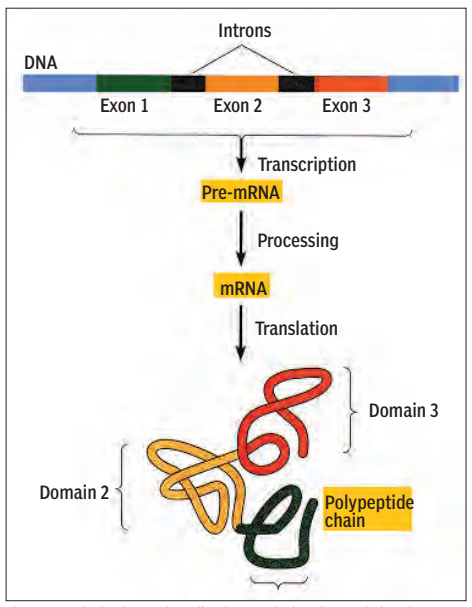
WHY DO EUKARYOTIC GENES HAVE INTRONS? **TAPAN KUMAR MAITRA** EXPLAINS

The burning question about introns is *why* nearly all genes in multicellular eukaryotes have them. Why do cells have so much DNA that seems to serve no coding function? Why, in generation after generation of cells, is so much energy invested in synthesising segments of DNA — and of RNA transcripts — that appear to serve no useful function and are destined only for the splicing scrap heap?

In fact, it is not true that introns never perform any functions of their own. In a few cases, intron RNAs are processed to yield functional products rather than being degraded. For example, some types of snoRNA — whose role in guiding pre-rRNA methylation and cleavage are derived from introns that are first removed from pre-mRNA and then processed to form snoRNA. And in a few cases, introns are even translated into proteins.

But in spite of these exceptions, most introns are destroyed without serving any obvious function.

One possible reason for such an apparently wasteful arrangement is that the presence of introns allows individual pre-mRNAs to be spliced in different ways, thereby generating several different mRNAs and, hence, polypeptides from the same gene. This phenomenon, called alternative RNA splicing, is made possible by the fact that individual splice sites can be either activated or skipped.



The proposed role of exons in coding for protein domains. Each domain represents a separate region of a polypeptide chain that is capable of independently folding into a functional unit.

As a result, a pre-mRNA molecule containing multiple introns may be spliced dozens or even hundreds of different ways. The ability to produce multiple mRNAs from a single gene may help to explain how the biological complexity of vertebrates is achieved without a major increase in the number of genes compared to simpler organisms. (Humans have only about twice the number of genes as worms or flies.) More than half of all human genes give rise to pre-mRNAs that are spliced in more than one way, allowing the roughly 30,000 human genes to produce mRNA coding for more than 100,000 polypeptides.

Another interesting role proposed for introns is an *evolutionary* one. It is possible that introns hasten the evolution of new and potentially useful proteins. This potential role is based on the discovery that exons often code for different functional regions of polypeptide chains, each of which can independently fold into a separate *domain*. For example, the three exons of the b-globin gene correspond to different structural and functional regions of the polypeptide. This kind of arrangement suggests that protein-coding genes with multiple exons may have been assembled during evolution from what were originally separate entities. Introns could be involved in two ways, both of which depend on the fact that they provide long stretches of DNA where "incorrect" genetic recombination can take place without harming coding sequences.

First, crossing over within introns of different genes could lead to the creation of genes containing new combinations of exons — *exon shuffling*. Second, recombination within other combinations of introns could easily produce duplicates of particular exons within a single gene. These exons might continue as exact duplicates, or one might mutate to a sequence that produces a new activity in the polypeptide.

Many biologists believe that introns are actually relics of ancient unicellular organisms that were the ancestors of all of today's organisms, both prokaryotes and eukaryotes. Some support for this idea has come from the discovery that introns are present in a few of the genes of archaea and bacteria. However, over billions of years, evolutionary pressure for a streamlined genome in such unicellular organisms may have led to the loss of most of the introns that were originally present.

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The battered look

STEVE CONNOR REPORTS ON A NEW STUDY THAT SUGGESTS FACIAL FEATURES EVOLVED TO PROTECT OUR ANCESTORS FROM INJURY

Bare-knuckle fighting helped to shape the human face which evolution has designed to minimise the damage inflicted by a fast-moving fist, according to a radical new theory about how violence changed the way we looked compared to our ape-like ancestors. The transition in facial structure from apes to early hominins had previously been explained largely by the need to chew on nuts and other hard foods that needed crushing, which led to a robust jaw, large molar teeth, a prominent brow and strong cheek muscles.

However, scientists have devised another plausible explanation based on the need for the face to be buttressed against the impact of flying fists which had become a principal weapon in unarmed combat between competing males.

"We suggest that many of the facial features that characterise early hominins evolved to protect the face from injury during fighting with fists," said David Carrier and Michael Morgan in a study published in the journal *Biological Reviews*.

The researchers analysed the facial bone structures of a number of hominins, such as an early human ancestor known as *Australopithecus*, and compared them to apes and modern man. They found that the parts of the face that changed most were the ones most likely to be damaged in a fist fight. They also found that these changes in facial anatomy closely coincided with the ability of the early hominins to clench their fists and use them as swinging clubs in a fight — a key tactical change from the biting and scratching preferred by fighting apes.

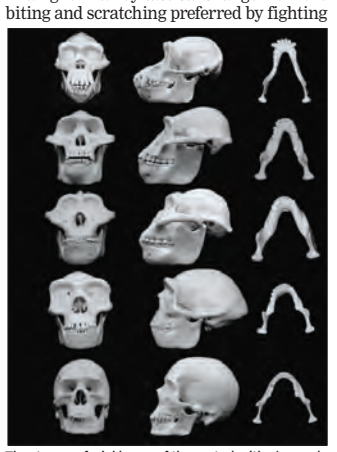
"Compared to apes like chimps and gorillas, early hominins had very robust jaws, with large molar teeth and strong jaw muscles. They also had very stout cheek bones and brow ridges," said David Carrier of the University of Utah in Salt Lake City. "The Australopiths were characterised by a suite of traits that may have improved fighting ability, including hand proportions that allow formation of a fist, effectively turning the delicate musculoskeletal system of the hand into a club for striking.

"If, indeed, the evolution of our hand proportions were associated with selection for fighting behaviour, you might expect the primary target, the face, to have undergone evolution to better protect it from injury when punched," he said.

With his colleague Mike Morgan, a medical doctor at Utah University, Carrier analysed the facial bones that were most likely to be fractured in fights between modern humans and found that these were the same bones that were most likely to have been changed during human evolution. "When modern humans fight, the face is the primary target. The bones of the face that suffer the highest rates of fracture from fights are the bones that show the greatest increase in robusticity during the evolution of early bipedal apes, the australopiths," he said. "These are also the bones that show the greatest difference between women and men in both Australopiths and modern humans."

The gender differences in facial bones supports the view that they evolved to buttress the face against flying fists, given that fights between males are more common than those between females. "In other words, male and female faces are different because the parts of the skull that break in fights are bigger in males," Carrier said. "In both apes and humans, males are much more violent than females and most male violence is directed at other males. Because males are the primary target of violence, one would expect more protective buttressing in males and that is what we find."

The large, thickly enamelled molar teeth of Australopiths may have allowed the energy of an upward blow to the jaw, for instance, to be transferred from the lower jaw to the skull, allowing the energy to be absorbed with the help of jaw muscles, the scientists suggested. "What our research has been showing is that many of the anatomical characters of great apes and our ancestors, the early hominins — such as bipedal posture, the proportions of our hands and the shape of our faces — do in fact improve fighting performance," Carrier said.



The stronger facial bones of the australopiths (second and third rows) appeared at the same time that our ancestors learned to clench their fists, before declining along with upper body strength.

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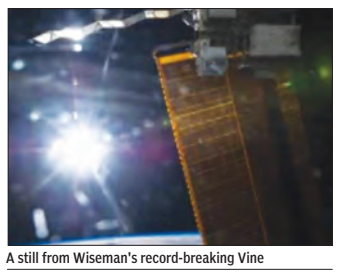
PLUS POINTS



A still from Wiseman's record-breaking Vine

A constant sun

National Aeronautics and Space Administration astronaut Reid Wiseman has posted a Vine from space giving a six-second snapshot of life aboard the International Space Station. The vast majority of Vines might focus on sleepy dogs, backflips and outlandish dance moves, but this one condenses the ISS's 92-minute lap around the earth, showing how, for astronauts aboard it, the sun never sets.

When the space station aligns with the point at which night and day meet on earth in the weeks either side of the summer solstice, it never passes the dark side of the earth, essentially meaning it never experiences a sunset. The Vine demonstrates this in quite breathtaking fashion, showing how strange, beautiful and yet disorientating life on the ISS must be.

"1st Vine from space! Single Earth orbit. Sun never sets flying parallel w/terminator line #ISS #Exp40," Wiseman wrote alongside the video. In other Internet-based space news, it was found last month that the moon now has faster broadbans speeds that some parts of the UK.

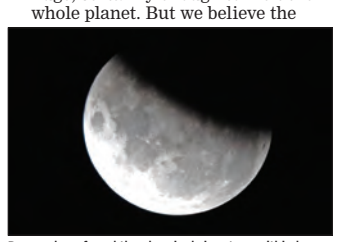
CHRISTOPHER HOOTON/THE INDEPENDENT

Ancient echoes

The idea that the moon was created after a massive cosmic collision between a Mars-sized object and a primordial earth some 4.5 billion years ago has received its second boost in less than a week. Scientists have detected the chemical signature of the ancient earth, as it was before the collision took place, in material found deep within the planet's mantle, which separates earth's molten iron core from the surface crust.

Last week, a separate team of researchers found the chemical signature of the ancient object itself, known as Theia, within lunar rock samples brought back to earth by the *Apollo* missions 40 years ago. The second piece of evidence comes from a study of unexplained ratios of chemical isotopes in deep mantle rock that scientists believe are the signature of the primordial earth before it was hit by Theia.

The collision would have generated enough energy to melt the entire planet but the researchers believe that although material would have vaporised on the side of impact, some of the planet remained solid and intact on the opposite hemisphere. "The energy released by the impact between earth and Theia would have been huge, certainly enough to melt the whole planet. But we believe the



Researchers found the chemical signature within lunar rock samples brought back to earth by the *Apollo* missions

impact energy was not evenly distributed throughout the ancient earth," said Professor Sujoy Mukhopadhyay of Harvard University.

"This means a major part of the impacted hemisphere would probably have been completely vaporised, but the opposite hemisphere would have been partly shielded and would not have undergone complete melting." Another piece of evidence comes from the analysis of xenon gas isotopes, which result from the slow radioactive decay of iodine gas. This suggests that the formation of the more ancient part of the mantle came within the first 100 million years of earth's origins — thereby putting a possible date on the impact with Theia.

Professor Richard Carlson of the Carnegie Institute in Washington and past president of the Geochemical Society, said, "This exciting result is adding to the observational evidence that important aspects of earth's composition were established during the violent birth of the planet and is providing a new look at the physical processes by which this can occur."

The research was presented to the Goldschmidt conference in Sacramento, California.

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