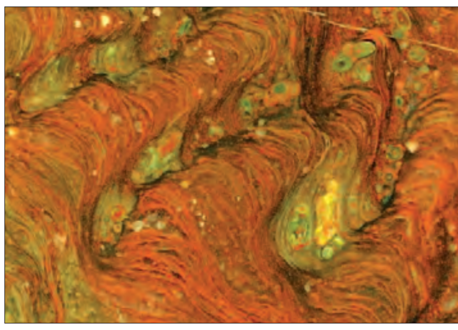
People power to save biodiversity

A LEADING MARINE BIOLOGIST AND MUSEOLOGIST CANVASSES FOR GETTING COMMONERS INVOLVED, WRITES **S ANANTHANARAYANAN**

Professor Gilles Boeuf, president of the National Museum of Natural History in Paris since 2009 and professor at the Pierre and Marie Curie University and the Collège de France, in a presentation at the Alliance Française auditorium in Bengaluru pressed passionately for the public to become aware of the interconnectedness of living things and their environment as the only way to check relentless exploitation of the natural world. In the course of an outline of the evolution of biodiversity, Professor Beouf said, "Science cannot be the property of scientists, it belongs to all people and they must participate."

From the early chemistry nurtured in the geological variety of the planet came the first scraps of replicating genetic code and the first living things. The oldest sedimentary rocks that contain carbon from biological origin are dated at 3,850 million years ago. Fossil remains dated at 3,500 million years ago have show evidence of *cyanobacteria*, also known as blue-green algae, an organism that gets its energy through photosynthesis, or using sunlight to form organic molecules from water, as a source of negative ions to split carbon dioxide, releasing oxygen.

Till cyanobacteria appeared, life processes were based on the reactions of hydrogen sulphide gas rather than water, and there was no atmospheric oxygen. The entry of cyanobacteria tapped the resource of the oceans and they multiplied and thrived. But the great change was that now oxygen was generated.



Fossilised colonies of filamentary cyanobacteria (blue-green algae) and other microbes.

The Grand Gallery of Evolution at the National Museum of Natural History in Paris.

During the first millennia, the oxygen rel eased by photosynthesis was consumed in oxidising dissolved iron. But when all free iron was used up, oxygen started building up in the atmosphere. As the existing life forms were also oxygen intolerant, the oxygen build-up set off one of the greatest *extinction events* in earth's history. And at the same time, rising levels of oxygen cleared the atmosphere of methane, a greenhouse gas, and earth cooled to create the *great glaciation* event of 2,400 million years ago.

Professor Gilles Boeuf in Bengaluru.

But with rising oxygen levels, *aerobic*, or *oxygen using* organisms evolved and multiplied apace and these began using up oxygen till there was a balance of the production and consumption, with a steady 21 per cent oxygen content in the atmosphere. This condition was reached about 100 million years ago, after a very long time for aerobic life forms to evolve and there grew a vast multitude of species, plant and animal, land-based as well as aquatic. This may hence be considered the first instance of a global web of interconnected bio-systems assuring an aspect of stability of the environment.

Professor Boeuf explained that evolution took four crucial steps for the emergence of biodiversity before life moved out of the oceans. The first of these was the development of the nucleus of the cell, by the growth of a membrane, to enclose the nucleus within the cell. The second was the capture of cyanobacteria by cells, which became components of the cell, like little cells with their own DNA, within the cells. And the third was the emergence of multi-cellular organisms that happened by about 2,100 million years ago. And then came the greatest step — sexual reproduction, where there is a division and recombination of genes, or *genetic mixing*, rather than just replication.

"All individuals are different. A population equipped with sexuality evolves much faster and encourages an 'arms race' (of changes and responses) among parasites and their hosts," he said. Sexuality thus paved the way for new traits to arise and flourish separately, to create new species and vastly more nodes in the matrix of connections and alternate connections of inter-dependence to make for a biosphere of unprecedented robustness and resilience.

Between the land and the sea, it is the sea that is more uniform by far. The open sea has shown an extraordinary stability for the last 100 million years at least. "pH", which is the level of acidity, osmotic pressure and salinity, temperature, hydrostatic pressures of the depths and dissolved gas content remain constant over thousands of kilometres. This uniformity, which is maintained by biodiversity, in fact is not favourable to growth of new species. In contrast, conditions on the land are fragmented and have led to a greater variety of species. The sea is known to have only some 13 per cent of the known species. This may be an underestimate, as there is still much to be discovered about the sea. But there are still over 250,000 known species in the sea and the important thing is that their mass is huge.

Drifting weeds called *phytoplankton*, for instance, account for 50 per cent of the productivity of the planet. The biodiversity of the sea, although less than that of the land, has a great bearing on making sure that conditions on earth remain suitable for life, as we know it, to continue.

Human populations have been exploiting the riches of the sea for thousands of years. Although the resource is mostly renewable, the present levels are so high that questions of sustainability have been raised. The Food and Agriculture Organisation estimate is that 176 million tones of aquatic produce are harvested every year and large numbers of species are reported rapidly going extinct. Apart from living species, the sea is also a source of chemical molecules of pharmaceutical and industrial value. This apart, the mechanisms in the sea provide us with templates for research or new *bio-inspired* industrial processes.

The current levels of exploitation and pollution of nature are seen as rapidly dismantling this framework, assembled over millions of years. The destruction of the Great Library of Alexandria may be dwarfed by the loss of information developed over thousands of years, which is being lost every day due to destruction of species. The greatest absorber of CO_2 emissions, from all sources living and non-living, is again the sea. But the rising levels of CO_2, caused by human activity, would lead to acidification of seawater and elimination of great numbers of species that have adapted to rock steady pH levels for centuries.

Professor Boeuf gave a number of examples of noted species of plants, insects and animals, of scientific, medical or industrial value, that had gone extinct or were on the point of doing so. His mission, he said, was to tour the world making presentations so that people became aware of what their lifestyle was doing and the value of what was being destroyed. The drive to make living sustainable was not likely to succeed through government action or business initiatives, he said.

Professor Boeuf is on several international committees, of the UN and otherwise, and is adviser to the government of France for the forthcoming world conference on climate change. But he sees little may come from the talks, which, he says, may be a repeat of earlier climate change conferences.

The real initiator of change, a "leap over boundaries" or *sursaut*, as he put it, would have to be civil society, the common people. And scientists need to empower the common people by making science accessible to them. The National Museum of Natural History in Paris has a great engagement with the public it serves. The museum has a collection of 70 million species, with a herbarium that houses eight million varieties of plants. Every day, there are as many as 30,000 communications, by telephone or by email, that are received from all kinds of people to provide new information that enriches the museum. "If we have 10,000 people who watch butterflies or birds, this translates into one and a half million hours of watching on behalf of the museum," says Professor Boeuf, explaining what it means to get the public to participate in science activity.

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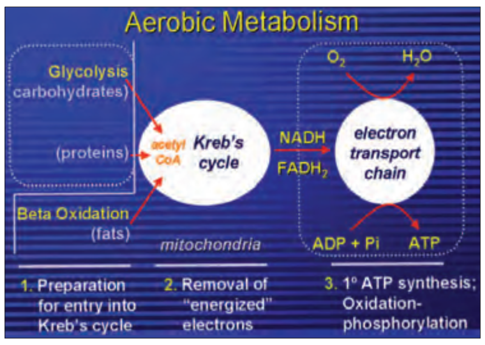
AEROBIC RESPIRATION

ENERGY METABOLISM IS ACHIEVED WITH NO TRANSISTORS, NO MECHANICAL PARTS, NO NOISE, NO POLLUTION ~ IT'S ALL DONE IN UNITS OF ORGANISATION THAT REQUIRE AN ELECTRON MICROSCOPE TO VISUALISE, SAYS **TAPAN KUMAR MAITRA**

Compared with fermentation, aerobic respiration gives access to much more of the free energy that is available from organic substrates such as sugars, fats and proteins. The complete catabolism of carbohydrates begins with the glycolytic pathway, but the pyruvate that is formed is then passed into the mitochondrion, where it is oxidatively decarboxylated to acetyl CoA. This, in turn, is then oxidised fully to CO_2 by enzymes of the TCA cycle.

Fatty acids are alternative substrates for energy metabolism in many cells. Their catabolism occurs in the mitochondrial matrix and begins with *ft* oxidation to acetyl CoA, which then enters the TCA cycle. Proteins can also be used as energy sources, particularly under conditions of fasting or starvation. In such cases, proteins are degraded to amino acids, each of which is then catabolised to one or more end products that enter either the glycolytic pathway or the TCA cycle.



Most of the energy yield from the aerobic catabolism of glucose is obtained as the reduced coenzymes (NADH and $FADH_2$) are reoxidised by an electron transport system. This system consists of respiratory complexes that are large multi-protein assemblies embedded in the inner mitochondrial membrane (or, in the case of prokaryotes, in the plasma membrane). The respiratory complexes are free to move laterally within the membrane. Key intermediates in the electron transport system are coenzyme Q and cytochrome *c*, which transfer electrons between the complexes. In aerobic organisms, oxygen is the ultimate electron acceptor and water is the final product.

Of the four main respiratory complexes, three (I, III, and IV) couple the transfer of electrons to the outward pumping of protons. This establishes an electrochemical proton gradient that is the driving force for ATP generation. The ATP-synthesising system consists of a proton translocator, F_0, embedded in the membrane, and an ATP synthase, F_1, a knoblike structure that projects from the inner membrane on the matrix side (or on the cytoplasmic side of the plasma membrane in prokaryotic cells). ATP is synthesised by F_1, as the proton gradient powers the movement of protons through F_0. Thus, the electrochemical proton gradient and ATP are, in effect, interconvertible forms of stored energy.

Mitochondria are the site of respiratory metabolism in eukaryotic cells and are prominent organelles in both size and numbers. Mitochondria may form large, interconnected networks in some cell types but are regarded here as discrete organelles. They are usually several micrometres long and range in abundance from one or a few up to hundreds or even a few thousand per cell. A mitochondrion is surrounded by two membranes, the inner one having many infoldings, called cristae, that greatly increase the surface area of the membrane and hence its ability to accommodate the numerous respiratory complexes, F_0F_1, and transport proteins needed for respiratory function.

The outer membrane of the mitochondrion is freely permeable to ions and small molecules due to the presence of porins. However, specific carriers are required for the inward transport of pyruvate, fatty acids and other organic molecules across the inner membrane of the organelle. ATP transport outward is coupled to the inward movement of ADP, and the concurrent inward movement of phosphate ions is coupled to the outward movement of hydroxyl ions, driven by the proton gradient. The electrons of coenzyme molecules that undergo reduction in the cytosol must be passed inward to the electron transport system by specific electron shuttle mechanisms because the inner membrane is not permeable to the coenzymes themselves.

This, then, is aerobic energy metabolism. No transistors, no mechanical parts, no noise, no pollution — and all done in units of organisation that require an electron microscope to visualise. Yet the process goes on continuously in living cells with a degree of integration, efficiency, fidelity and control that we can scarcely understand well enough to appreciate fully, let alone aspire to reproduce in our test tubes.

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Big Bang deflated?

THE UNIVERSE MAY HAVE HAD NO BEGINNING, WRITES **TIA GHOSE**

In the new formulation, the universe was never a singularity or an infinitely small and infinitely dense point of matter. In fact, the universe may have no beginning at all. "Our theory suggests that the age of the universe could be infinite," said study co-author Saurya Das, a theoretical physicist at the University of Lethbridge in Alberta, Canada. The new concept could also explain what dark matter — the mysterious, invisible substance that makes up most of the matter in the universe — is actually made of, Das added.

According to the Big Bang theory, the universe was born about 13.8 billion years ago. All the matter that exists today was once squished into an infinitely dense, infinitely tiny, ultra-hot point called a singularity. This tiny fireball then exploded and gave rise to the early universe.

The singularity comes out of the math of Isaac Einstein's theory of general relativity, which describes how mass warps space-time, and another equation (called Raychaudhuri's equation) that predicts whether the trajectory of something will converge or diverge over time. Going backward in time, according to these equations, all matter in the universe was once in a single point — the Big Bang singularity.

But that's not quite true. In Einstein's formulation, the laws of physics actually break before the singularity is reached. But scientists extrapolate backward as if the physics equations still hold, said Robert Brandenberger, a theoretical cosmologist at McGill University in Montreal, who was not involved in the study. "So when we say that the universe begins with a big bang, we really have no right to say that," he said.

There are other problems brewing in physics — namely, that the two most dominant theories, quantum mechanics and general relativity, can't be reconciled. Quantum mechanics says that the behaviour of tiny subatomic particles is fundamentally uncertain. This is at odds with Einstein's general relativity, which is deterministic, meaning that once all the natural laws are known, the future is completely predetermined by the past, Das said.

And neither theory explains what dark matter, an invisible form of matter that exerts a gravitational pull on ordinary matter but cannot be detected by most telescopes, is made of. Das and his colleagues wanted a way to resolve at least some of these problems. To do so, they looked at an older way of visualising quantum mechanics, called Bohmian mechanics. In it, a hidden variable governs the bizarre behaviour of subatomic particles. Unlike other formulations of quantum mechanics, it provides a way to calculate the trajectory of a particle.

Using this old-fashioned form of quantum theory, the researchers calculated a small correction term that could be included in Einstein's theory of general relativity. Then, they figured out what would happen in deep time.

The upshot? In the new formulation, there is no singularity, and the universe is infinitely old.

One way of interpreting the quantum correction term in their equation was that it was related to the density of dark matter, Das said. If so, the universe could be filled with a superfluid made up of hypothetical particles, such as the gravity-carrying particles known as gravitons, or ultra-cold, ghostlike particles known as axions, he said.

One way to test the theory was to look at how dark matter was distributed in the universe and see if it matched the properties of the proposed superfluid, Das said. "If our results match with those, even approximately, that's great."

However, the new equations are just one way to reconcile quantum mechanics and general relativity. For instance, a part of string theory known as string gas cosmology predicts that the universe once had a long-lasting static phase, while other theories predict there was once a cosmic "bounce", where the universe first contracted until it reached a very small size, then began expanding, Brandenberg said. Either way, the universe was once very, very small and hot.

Saurya Das

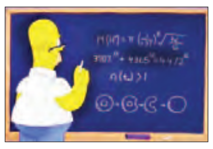
"The fact that there's a hot fireball at very early times: that is confirmed. When you try to go back all the way to the singularity, that's when the problems arise," he said.

The new theory was explained in a paper published on 4 February in the journal *Physical Letters B*, and another paper that is currently under peer review, which was published in the preprint journal *arXiv*.

PLUS POINTS

Homer & Higgs boson

Homer Simpson almost predicted the mass of the elementary particle, the Higgs boson, more than a decade before it was discovered, according to a new book on maths in *The Simpsons*. In the episode, *The Wizard of Evergreen Terrace*, aired in 1998, Homer becomes an inventor and is shown in front of a blackboard with a complicated equation.



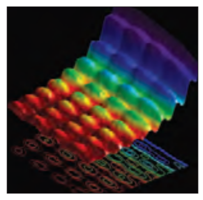
"That equation predicts the mass of the Higgs boson," said Simon Singh. "If you work it out, you get the mass of a Higgs boson that's only a bit larger than the nano-mass of a Higgs boson actually is. It's kind of amazing as Homer makes this prediction 14 years before it was discovered."

Singh, author of *The Simpsons and their Mathematical Secrets*, said, "*The Simpsons* is the most mathematical TV show on prime-time television in history. A lot of the writers on *The Simpsons* are mathematicians." He said the first full episode of *The Simpsons* had a joke about calculus, adding there was a "tonne of maths" in the show that references concepts including Fermat's last theorem, perfect numbers, mersenne primes and narcissistic numbers.
The Simpsons may "encourage and nourish" those who are into maths, Singh said, and hoped teenagers who loved maths would feel inspired by the fact that the show's creators shared their interests.

NICK CLARK/THE INDEPENDENT

Particle & wave

Since the days of Einstein, scientists have been trying to directly observe how light can be both a particle and a wave at the same time. Never before has an experiment able to capture both natures of light at the same time — the closest we have come is seeing either wave or particle, but always at different times — but taking a radically different experimental approach, scientists at the École Polytechnique Fédérale de Lausanne have now been able to take the first ever snapshot of light behaving both as a wave and as a particle. The breakthrough work is published in *Nature Communications*. The team team led by Fabrizio Carbone carried out an experiment with a clever twist: using electrons to image light. They captured, for the first time ever, a single snapshot of light behaving simultaneously as both a wave and a stream of particles. They fired a pulse of laser light at a tiny metallic nanowire. The laser added energy to the charged particles in the nanowire, causing them to vibrate. Light traveled along this tiny wire in two possible directions, like cars on a highway. When waves travelling in opposite directions met each other they formed a new wave that looked like it was standing in place. Here, this standing wave became the source of light for the experiment, radiating around the nanowire.

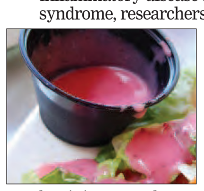


Energy-space photography of light confined on a nanowire, simultaneously shows both spatial interference and energy quantisation.

"This experiment demonstrates that, for the first time ever, we can film quantum mechanics — and its paradoxical nature — directly," said Carbone. In addition, the importance of this pioneering work can extend beyond fundamental science and to future technologies. As Carbone explained, "Being able to image and control quantum phenomena at the nanometre scale like this opens up a new route towards quantum computing."

Food additives

Two of the 15 most common emulsifiers — carboxymethylcellulose and polysorbate 80 — that bind the oily and watery components of processed foods can alter the gut microbiome and reduce the barrier layer of mucus between immune cells and bacteria, according to a mouse study published on 25 February in *Nature*. As a result, mice that consumed the emulsifiers were more prone to a range of symptoms that are hallmarks of inflammatory disease and metabolic syndrome, researchers at Georgia State University and Cornell reported. Emulsifiers are common in ice-cream, salad dressing and many other packaged foods, but it is not yet known how they may affect the human gut.



"When it comes to people making their own decisions, between our studies and others out there, it's better to eat less processed food," said study co-author Andrew Gewirtz of Georgia State.

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