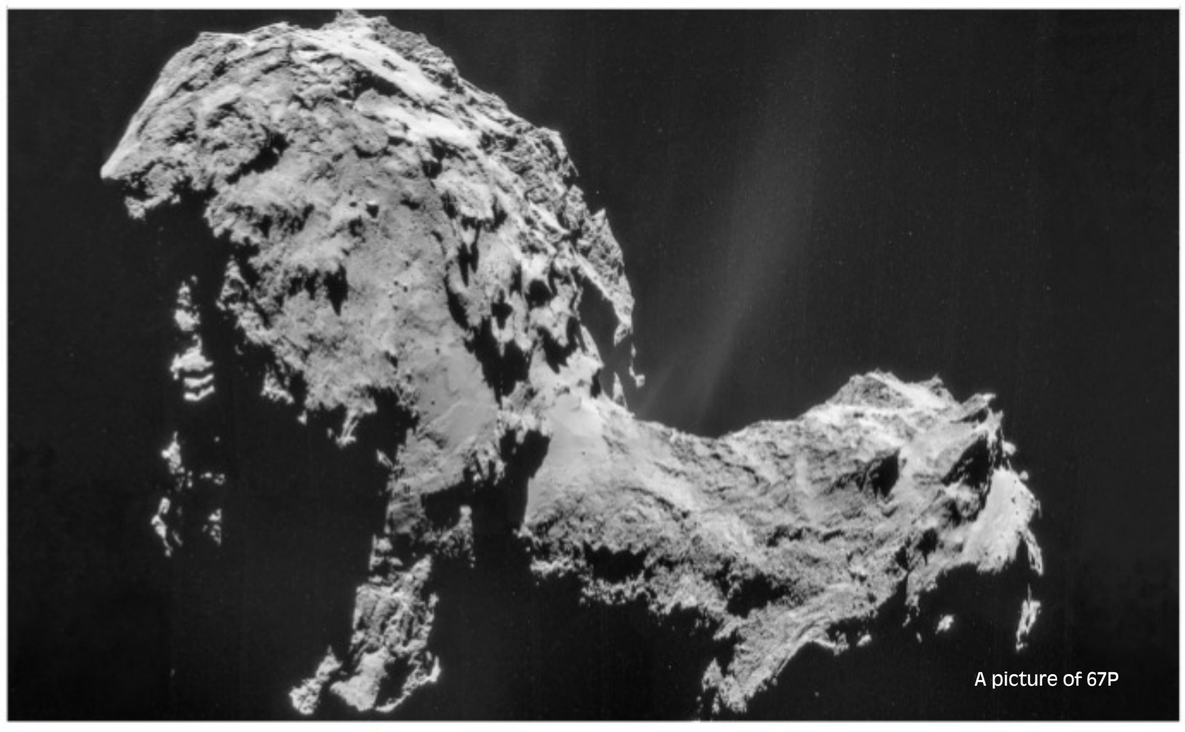
Unusual sources of oxygen

Space and materials scientists are working together to refine a point in the quest for extra-terrestrial life


A picture of 67P

S ANANTHANARAYANAN

Ordinary oxygen, as free oxygen molecules, is abundant on Earth but is rare in other parts of the universe. This is because free oxygen is reactive and quickly combines with other elements, particularly to form water (H2O) or carbon dioxide (CO2). Oxygen is hence known to accumulate only if it is continuously generated, which happens on Earth by action of vegetable matter and photosynthesis.

Therefore, the discovery of sizeable molecular oxygen on the barren surface of the comet, 67P/Churyumov-Gerasimenko — just over four km long — raised questions that were difficult to answer. Konstantinos P Giapis and Yunxi Yao, at the California Institute of Technology, while developing special materials for computer chips, have discovered that high speed water molecules striking mineral surfaces can give rise to molecular oxygen. They report the finding in the journal, *Nature Communications* and they say the same process appears to be going on in the comet, 67P.

Earth, too, did not have free oxygen for a very large part of its history. The first forms of life that evolved did not depend on oxygen. They did use the sun's energy but they filled the atmosphere with methane. We still have some of these, in oxygen-starved locations and which break down organic matter to create "marsh gas". While there were also organisms — the cyanobacteria —


Konstantinos P Giapis

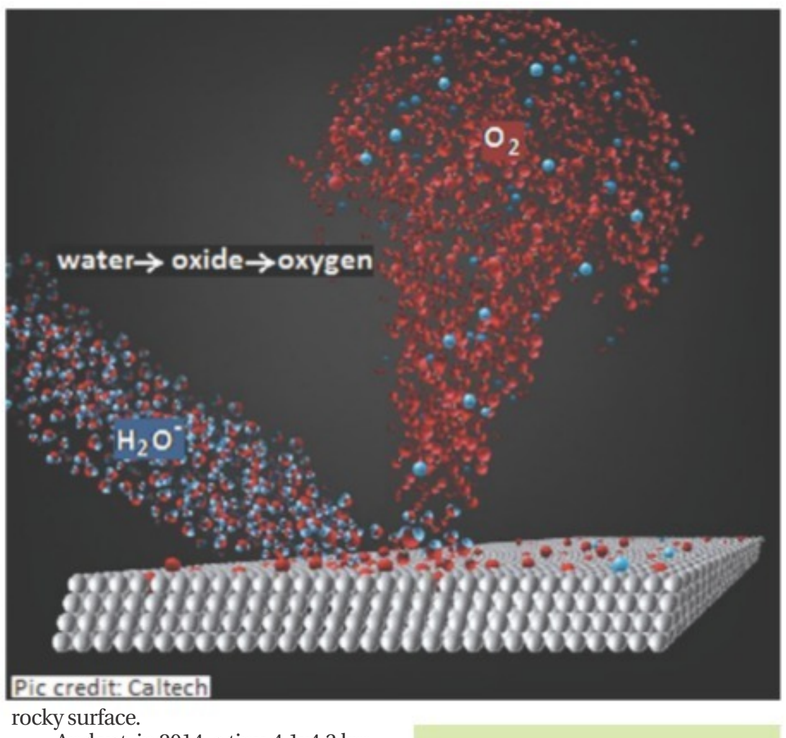

Yunxi Yao

which gave off oxygen, it promptly combined with hydrogen that was produced when methane decomposes. Methane, however, stays a gas at low temperatures and can get past the coldest part of the atmosphere and ascend to reach the extreme outer atmosphere. The light atoms of hydrogen given off by methane, at high altitudes, could then escape from Earth, which led to depletion of hydrogen.

When hydrogen levels fell, oxygen could accumulate. For millennia, however, oxygen got consumed in combining with free iron, to create oxides, which we see in the bands of iron ore in the Earth's crust. When all the iron got used up oxygen began to accumulate.

There was an explosion in vegetation and biodiversity and the existing life forms declined. Oxygen levels rose till they reached a balance of about 21 per cent of the atmosphere's content. The presence of oxygen also started using up hydrogen, which stopped the loss of hydrogen atoms out to space.

As finding oxygen in distant worlds is rare, the quest for life is focussed on finding other indicators, namely, carbon dioxide, methane, and ozone. Finding free, molecular oxygen, of course would be strong evidence of life processes. And along with chemical indicators of life, there is also the effort to find other signs, like smooth and undulating topography, as opposed to a



Pic credit: Caltech

rocky surface.

And yet, in 2014, a tiny, 4.1x4.3 km, barren, rocky comet, with barely any gravity, negligible atmosphere or anything Earth-like, was found to contain molecular oxygen, in abundance from one to 10 per cent, compared to the comet's content of water. As there was no question of the oxygen being from an organic source, it had to be proposed that it was of primordial origin, as thawing from a store, frozen from the time when the solar system formed 4.6 billion years ago. This explanation, however, is being questioned, as it in conflict with how the formation of the solar system is understood and because the oxygen could not have kept from combining with other elements over such a long time.

Giapis, professor of chemical engineering at Caltech, has been working on the effects of charged atoms and molecules, or plasmas, on the surfaces of metals, at the nanoscale. When molecules are exposed to high energy radiation like ultra violet light, groups of atoms making up the molecule, separate and float about as oppositely charged particles, in place of being together and neutral. The water molecule, H2O, for instance, would split as H+ + OH-, or as 2H+ + O-. When such particles contact the surface of materials, they are attracted to the region very close to the atoms at the periphery of the material. The ions then get attached to the surface and can form a thin nanolayer. When this happens, there is a change in the distribution of atoms and charges that the attached ion presents to other ions of the surrounding plasma and reactions that are otherwise not possible can take place or get accelerated.

Giapis and his colleague, Yunxi Yao report that the collision of high speed H2O+ ions colliding with silicates and iron or nickel oxides found on the surface of the comet could lead to release of oxygen atoms from the water molecule as well as from the surface minerals. They say in their paper that they have verified in the laboratory that accelerated water ions can participate in such reactions when they strike oxidised surfaces at high speeds to directly form molecular O2- ions.

When comets, in their elliptic orbits approach the sun, ice in the planet evaporates and forms a cloud or "coma" around the comet. The water molecules are then ionised by ultra violet light from the sun and accelerated by the solar wind. These are the high-speed water ions that strike the comet surface, for molecular oxygen to be ejected. The ejected oxygen can then be replenished by oxygen from the dissociation of fresh water molecules or from the surface oxides, the paper says. This process would continuously populate the coma of the comet with oxygen, and in time, there would be a steady level of oxygen, with generation balanced by consumption in forming fresh water or oxides.

This insight, of the same processes studied in a "down at Earth" materials science lab being active in fragments of rock out in deep space, widens the range of sources of gases and substances found in the cosmos. Not only does the quest for life need to be circumspect while assigning the discovery of gases like oxygen to biological origin, even our understanding of the geology of distant worlds would need to be reviewed.

The writer can be contacted at response@simplescience.in

The oxygen comet

The comet, 67P is a Jupiter family comet, from the Kuiper Belt, that was discovered by Soviet astronomers Churyumov and Gerasimenko in 1969. The European Space Agency launched the Rosetta mission to the comet in 2004 and Rosetta reached 67P ten years later in 2014. The space craft then entered orbit around the comet, just over four km at its widest and longest, and sent down a landing craft, Philae, which conducted surface analysis.

Philae unfortunately landed in a shaded part of the comet and had to wait some months before its solar panels started working. But the data it sent, based on battery power, kept researchers busy without a break.

Water vapour on the comet was found to differ from water on Earth in the composition of hydrogen isotopes. This ruled out the 67P class of comets as a source of the water on the earth. And then, the abundance of molecular oxygen was perplexing!

Matters of the mitochondria

Unravelling the mystery of DNA attacks in cells' powerhouse could pave the way for new cancer treatments

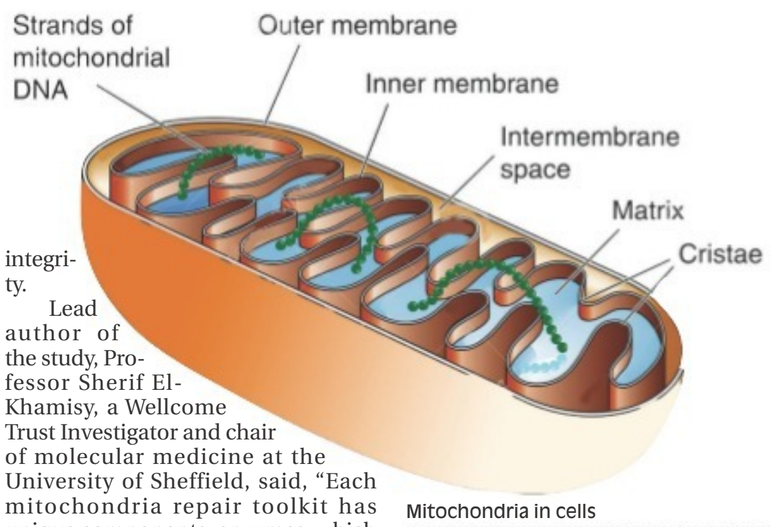
New research has unravelled the mystery of how mitochondria — the energy generators within cells — can withstand attacks on their DNA from rogue molecules.

The findings could pave the way for new treatments to tackle neurodegenerative diseases and cancer. The research could also have important implications for clinical advances in "mitochondrial donation" — known as the "three-parent baby" — used to correct defects in faulty mitochondria.

The five-year study led by scientists at the University of Sheffield, UK, published recently in *Science Advances*, reveals how the enzyme TDP1 — which is already known to have a role in repairing damaged DNA in the cell's nucleus — is also responsible for repairing damage to mitochondrial DNA.

Mitochondria are the powerhouses of cells as they generate the energy required for all cellular activity and have their own DNA — the genetic material, which they rely upon to produce important proteins for their function.

During the process of energy production and making proteins, a large amount of rogue reactive oxygen species are produced, which constantly attack the DNA in the mitochondria. These attacks break their DNA; however, the new findings show mitochondria have their very own repair toolkits, which are constantly active to maintain their own DNA integrity.



Mitochondria in cells

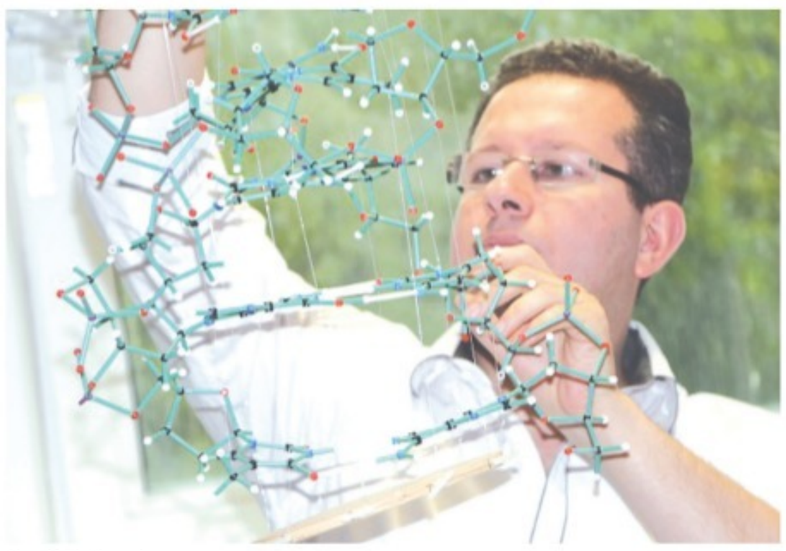
Lead author of the study, Professor Sherif El-Khamisy, a Wellcome Trust Investigator and chair of molecular medicine at the University of Sheffield, said, "Each mitochondria repair toolkit has unique components; enzymes, which can cut, hammer and seal the breaks. The presence of these enzymes is important for energy production.

"Defects in repairing DNA breaks in the mitochondria affect vital organs that rely heavily on energy such as the brain. It also has implications on mitochondria replacement therapies recently approved in the UK and known as 'three parent babies'."

Although much research has focused on how free radicals damage the DNA in the cell's nucleus, their effect on mitochondrial DNA is less well understood despite this damage to mtDNA being responsible for many different types of disease such as neurological disorders. Having healthy mitochondria is also essential for tissue regeneration, making it particularly important for successful organ transplants.

The team further identified a mechanism through which mtDNA can be damaged and then fixed, via a protein called TOP1, which is responsible for untangling coils of mtDNA. When the long strands become tangled, TOP1 breaks and quickly repairs the strands to unravel the knots. If free radicals are also attacking the mitochondrial DNA, then TOP1 proteins can become trapped on the mitochondrial DNA strands, making repair even more difficult.

Professor El-Khamisy believes the findings could pave the way for the development of new therapies for mitochondrial disease that boost their DNA repair capacity, or for cancer


Sherif El-Khamisy

treatments, which could use TDP1 inhibitors to prevent mtDNA repair selectively in cancer cells.

"Cancer relies on cells dividing very quickly. That means they need a lot of energy, so will have really healthy mitochondria," said Professor El-Khamisy, "If we can find a way to selectively damage the mitochondria in the cancer cells, by preventing or slowing its repair mechanism, this could be really promising."

The findings could also be important for new clinical advances such as the decision by the Human Fertilisation and Embryology Authority to allow "mitochondrial donation" — also known as "three-parent babies" — where mtDNA from a female donor is introduced to an embryo to correct mitochondrial defects.

"This research suggests that clinicians should assess the function of TDP1 and mitochondrial TOP1 before mitochondrial donation takes place, to ensure the success of this procedure," added Professor El-Khamisy.

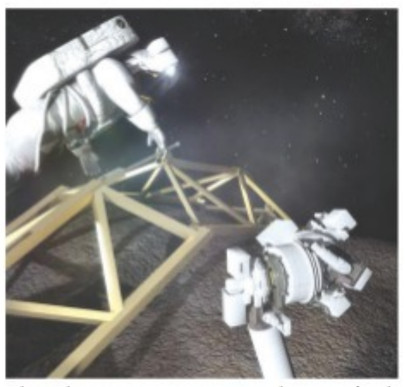
"Even if the new embryo has healthy mitochondrial DNA from the donor, it could still have defective TDP1 or mitochondrial TOP1 from the recipient, since they are both produced by the DNA in the cell's nucleus, so mitochondrial DNA damage could still take place over time, and cause disease."

Professor Allan Pacey, a fertility expert at the University of Sheffield's department of oncology and metabolism, said, "Given that the first UK licence to perform mitochondrial donation procedures was awarded by the HFEA last month, the publication of this study is very timely.

"It is important that we know as much as possible about how to identify healthy and defective mitochondria, in order to help those people with debilitating mitochondrial disease."

PLUS POINTS

Living on asteroids



The Chinese government plans to find, catch and land on an asteroid — before mining and even living on it.

Beijing hopes to be able to take the precious and rare materials that are thought to be inside of many asteroids by catching one as early as 2020, according to officials from China's space programme.

The country will launch its first spacecraft over the next three years or so, chief commander and designer of China's lunar exploration programme Ye Pijian told state media. But the project will be much broader than that — eventually using the asteroids as the base for a Chinese space station.

The reveal is just the latest ambitious Chinese space project. It recently revealed that it would look to build a base on the moon, potentially in collaboration with the European Space Agency.

The mission would involve landing a spacecraft on an asteroid and then using rockets to change its trajectory. If it did so successfully, the rock could be pushed into the moon's orbit — getting it ready to be mined and have the precious metals extracted.

Like Nasa, which announced a similar plan recently, China hopes that the value of the metals taken from the asteroid would pay for the expense of the ambitious mission. Nasa is also hoping to travel to an asteroid in the early 2020s, with two missions called Lucy and Psyche.

Asteroid mining has also been the focus of some private companies, who hope that there are trillions of dollars to be found in the space rocks. In 2015, Barack Obama made it legal for private citizens to own celestial bodies — opening up the ability to for people to buy and own their personal asteroids.

Andrew griffin/the independent

Ending a myth

Humans have a centuries-old reputation as poor smellers. Though we can see more colours than the average mammal, our noses are simply no match for the questing snouts of rabbits and hounds. Sure, the aromas of coffee and pie are great. But intelligent humans outgrew the need to sniff their way through life. Or so the thinking went.

In a review last week in the *Science* journal, John McGann, a professor of psychology at Rutgers University in New Jersey, US, argued that this is a flawed perception dating back to the 19th century.

McGann blamed pioneering French anatomist Paul Broca, who wrote that, given the comparatively small olfactory organs in the primate brain, "it is no longer the sense of smell that guides the animal". As for smelling in apes, humans included, "All that exceeded the needs of this humble function became useless."

Broca was hunting for the part of the brain that gave humans free will, McGann said, to separate us from animals. At the time, too, the Catholic Church in France was criticising Broca's work.

Human olfactory bulbs account for just 0.01 per cent of the brain's volume. (In mice, the fraction is 200 times larger.) Broca divided mammals into smellers and non- smellers. He included humans among the latter, along with dolphins, which lack olfactory bulbs entirely. The depiction of primate smell as a humble function stuck.

It is high time to end the myth, McGann said. Humans have just about the same number of neurons in their olfactory bulbs as mice, capybaras and star-nosed moles. And humans are about as sensitive as dogs at detecting amyl acetate, a chemical with a banana odour. We are better than mice at detecting a smelly compound in human blood.

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