Water when things get rough

There are many sides to plain old H_2O, says s ananthanaryanan

THE presence of water is the crucial factor in many of the wonders of our earth, including the presence of life itself. But water also exists in forms quite different from what living things are familiar with, to make possible other, non-life-related features of earth. These include different crystal structures when water is in the form of ice and also forms of liquid, when water is at high temperature and under pressure.

Christoph J Sahle, Christian Sternemann, Christian Schmidt, Susi Lehtola, Sandro Jahn, Laura Simonelli, Simo Huotari, Mikko Hakala, Tuomas Pylkkänen, Alexander Nyrow, Kolja Mende, Metin Tolan, Keijo Hämäläinen and Max Wilke, of Germany, Finland and France report in the journal, *Proceedings of the National Academy of Sciences*, that water undergoes structural changes at the molecular level, which makes it an aggressive solvent, at high pressure and temperature. These conditions exist deep under earth's surface and knowing how water behaves is vital to understand the movement of metals and minerals and the formation and composition of earth's mantle and crust.

Max Wilkie.

Wonders of water

Water is known as the *universal solvent* because a great number of substances (though not all) dissolve in water. This property is because of the structure of the water molecule. While water is H_2O, or two hydrogen atoms connected to one oxygen atom, there are peculiarities that make this combination unique. One is the balance created by the relative mass of the atoms — the oxygen atom is about 16 times heavier than a hydrogen atom.

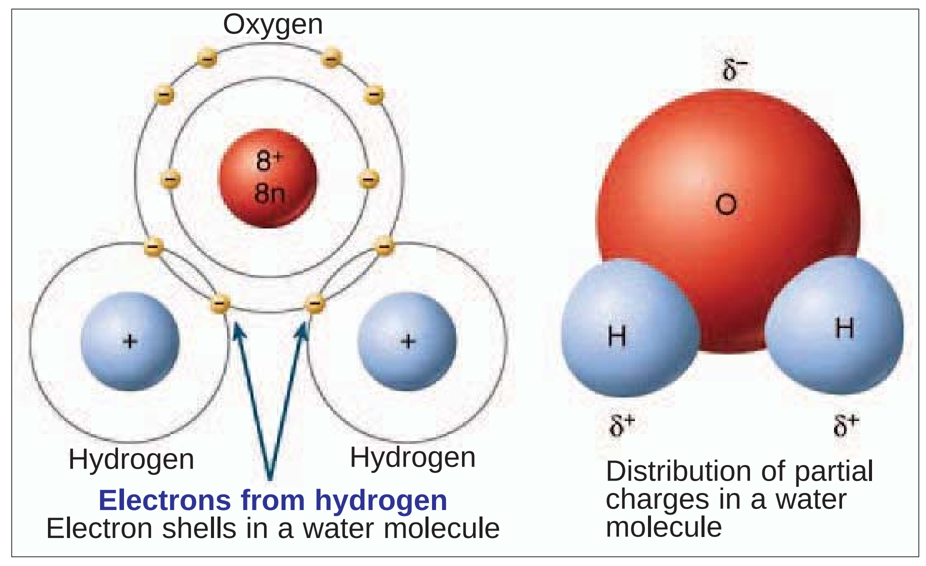
As the atoms join because the two hydrogen atoms share their individual electrons with the oxygen atom, which reaches a stable state with the help of the two electrons of the hydrogen atoms, the hydrogen atoms in combination are positively charged, while the oxygen atom is negatively charged. The charge makes the hydrogen atoms get attracted to the oxygen atom, but also repel each other. The result is that the hydrogen atoms are on opposite sides of the oxygen atom. But being directly opposite is an unstable condition and the hydrogen atoms can be a little nearer to the oxygen atom, but are kept that way because they are also nearer to each other, if the hydrogen atoms are a little to the side, shaped something like a shallow "V".

The result of this shape of the water molecule is that it is lop-sided, the two positive charges are to one side and the negative charge is to the other. The water molecule, when seen from a distance, is not an uncharged body, like a molecule should be, but is like a pair of separate charges — the two hydrogen atoms on one side and the oxygen atom on the other. This form of the water molecule has a powerful effect on other molecules. The separation of charges creates an electric field, which weakens the bonds between the components of other molecules. It is almost like molecules are prised open, like a clam shell, and materials dissolve in water. Water, thus, becomes a medium where chemical reactions can take place and water is the medium of choice for life processes.

Other properties, like low viscosity, which allows water to flow freely, and surface tension, which enables water to rise in the narrow channels in plants, have resulted in all forms of life on earth evolving to use processes that use water. An important condition for this use to be available is that water should be in liquid form. Life forms are, hence, usually found within the narrow temperature range when water is liquid, or the life form burns food to maintain such a temperature. For the same or similar reasons, life forms can be expected only in planets that have surface temperature where water could be liquid — or in *earth-like* extra-solar planets.

Self-organising

As water is, thus, a form of entities like pairs of charges, which are free to move as in a liquid, it can be expected that the charged-pair nature would affect the way water molecules orient themselves. The weak electric force between water molecules, called the *H-bond*, causes water molecules to form into small, ordered structures, which get less structured as one moves away from them, The H-bonds create a hexagonal crystal form when water freezes into ice, a form that is a little less closely packed than liquid water at four degrees Celsius.



Electron shells in a water molecule

Distribution of partial charges in a water molecule

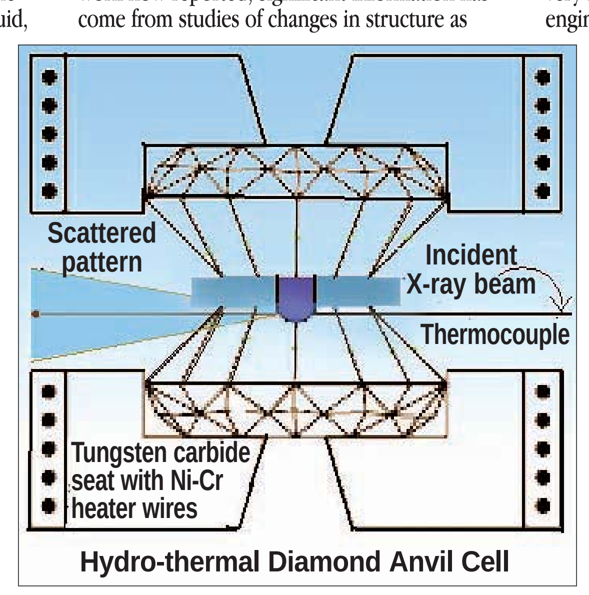
The result is that water expands when it freezes, an effect that has a profound effect on the survival of aquatic life and also in the weathering of rocks, when water that freezes in cracks causes rocks to split open. Ice crystals are known to take innumerable forms, depending on the process of their formation, but as ice is held together by H-bonds, it is a material with negligible mechanical strength.

The area of interest is how water behaves, at the microscopic level in the liquid and gaseous forms, under different conditions. Studies have been conducted by scattering X-rays or beams of neutrons, which are uncharged subatomic particles, by samples of water. The studies are inconclusive and the question of whether the structure of water is the same everywhere or whether there are patches of H-bond distortion surrounded by a regular structure is open. In the work now reported, significant information has come from studies of changes in structure as conditions change because of very high temperatures and pressures.

The nature of liquids is that they form a surface, above which the substance exists in the vapour phase. When the temperature is increased, molecules gather energy and leave the bound, liquid state, to enter the vapour state. So long as this process is going on, the liquid will not rise in temperature, but only change phase from liquid to vapour. But at a very high temperature and pressure, the surface separating the liquid and the vapour disappears and the liquid can be said to be in both phases at once.

This temperature and pressure is called the *critical point*, at which small changes in pressure or temperature can lead to large changes in the other as the molecules absorb or give up the heat of vaporisation. Above the critical point, the vapour cannot be liquefied by increasing the pressure alone and should thenceforth be referred to as a gas. The critical point for water is about 374? Celsius, when water liquefies at a pressure of about 218 atmospheres. And as a powerful solvent, water above the critical point is used for chemical processes, destroying waste, recycling plastic and processing biomass.

But the structure of water in these conditions has rarely been studied, despite its importance to understand geophysical processes, volcanic action, petroleum formation, even studies of the origin of life. For creating a water sample at high pressure and temperature, Dr Max Wilke and colleagues used a diamond cell, sealed with a gasket made of rhenium, a rare metal that has a very high melting point and finds use in jet engines. Water was contained in a half-millimetre wide and a tenth of a millimetre deep cell and electrically heated. The temperature was measured using a thermocouple and the density and pressure measured by observing a vapour bubble in the liquid.



Hydro-thermal Diamond Anvil Cell

The micro structure of water was tested using a scattering of X-rays and it was found that the structure evolved from being water-like at room temperature and pressure, to a gas-like structure at high temperature and pressure. Comparison of the results with what was calculated suggests that high temperature/pressure conditions created a uniform, or homogenous structure, rather than a formation of clusters of H-bonds. The results represent important progress for analysis of processes in the condition deep under earth's surface.

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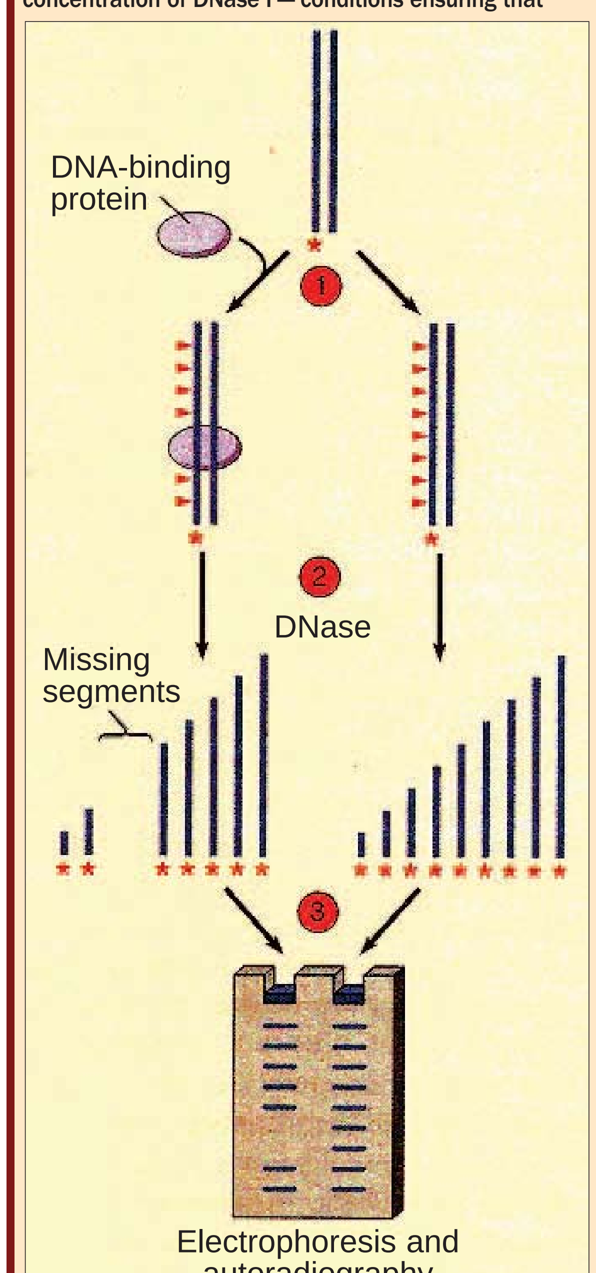
About the regulation of transcription

tapan kumar maitra **explains the process of identifying protein-binding sites on DNA**

THE initiation of transcription depends on the interactions of proteins with specific DNA sequences. In prokaryotic cells, the RNA polymerase *holoenzyme* directly recognises and binds to the promoter sequence at the start of a gene. In eukaryotic cells, certain transcription factors must bind to the promoter before an RNA polymerase can bind. And in all cells, the regulation of transcription depends on the interaction of still other proteins with specific sites on the DNA. Thus, the researcher seeking to understand transcription needs to know about transcriptional proteins and the DNA sequences to which some of them bind.

DM4 footprinting is one technique that has been used to locate the DNA sites to which specific proteins attach. The underlying principle is that the binding of a protein to a particular DNA sequence should protect that sequence from degradation by enzymes or chemicals. A version of footprinting outlined employs a DNA-degrading enzyme called DNase I, which attacks the bonds between nucleotides more or less at random. In this example, the starting material is a DNA fragment that has been labelled at its five-inch end with radioactive phosphate (indicated with stars).

In step (1), a sample of the radioactive DNA is first mixed with the DNA-binding protein under study; another sample, without the added protein, serves as the control. In (2), both samples are briefly incubated with a low concentration of DNase I — conditions ensuring that most of the DNA molecules will be cleaved only once. The arrowheads indicate possible cleavage sites in the DNA. In (3), the two incubation mixtures are submitted to electrophoresis and visualised by autoradiography. The control lane (on the right) has nine bands because every possible cleavage site has been cut. However, the other lane (on the left) is missing some of the bands because the protein that was bound to the DNA protected some of the cleavage sites during DNase treatment. The blank region in this lane is the "footprint" that identifies the location and length of the DNA sequence in contact with the DNA-binding protein.



DNase footprinting as a tool to identify DNA sites that bind specific proteins.

A newer approach, called the chromatin immunoprecipitation (ChIP) assay, is now widely used to study protein-binding sites in the DNA of eukaryotic chromatin. In the ChIP assay, cells are first treated with formaldehyde to generate stable crosslinks between proteins and the DNA sites to which they are normally bound. Next, the cells are disrupted to shear chromatin into small fragments, and the chromatin fragments are treated with an antibody directed against a protein of interest. DNA fragments bound to that particular protein will be precipitated by the antibody, and the sequence of the precipitated DNA can then be analysed.

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Beyond the pursuit of profit

In the third part of a series on the wind energy sector, aritra bhattacharya **wonders whether smaller, decentralised projects have any advantage over bigger, centralised projects using large turbines**

THE global wind power industry's thrust is on large turbines with capacities of one megawatt and above. As a June 2012 working paper from the International Renewable Energy Agency (http:/www.irena.org/DocumentDownloads/Publications / RE_Technologies_ Cost_ Analysis-WIND_POWER.pdf) notes, "The current average size of grid-connected wind turbines is around 1.16 MW, while most new projects use wind turbines between 2 MW and 3 MW. Even larger models are available, for instance REPower's 5-MW wind turbine has been on the market for seven years."

The same paper mentions that small wind turbines have a miniscule proportion in the global industry. "Small wind turbines' share of the total global wind power market was estimated at around 0.14 per cent in 2010 and is expected to increase to 0.48 per cent by 2020," it says. The scenario in India is no different, and the earlier part of the series explored how the wind power industry here has been focussing on large turbines and large wind farms. This is because larger wind turbines produce more economical power, says Kanchan Kumar Agrawal from the Centre for Science and Environment's Renewable Energy Team.

However, it is also possible to conjecture that smaller turbines produce less economical wind power as not enough money has been invested in research and development of smaller turbines. A report from the International Renewable Energy Agency notes, "Although small wind turbines are a proven technology, further advances in small wind turbine technology and manufacturing are required in order to improve performance and reduce costs."

But these advances will not come about unless suppliers invest money in R&D of small turbines. Anupam Boral, managing director of the Kolkata-based Gitanjali Solar Enterprises, which works on installation and maintenance of small wind turbines (small wind turbines are generally considered to be those with generation capacities of less than 100 kW), says that suppliers generally focus on R&D of bigger turbines as the profit margin in the segment is higher by as much as 15 per cent per megawatt. "Large projects are centralised and often involve huge volumes; big investors and suppliers crowd this segment not only because the profit margin is higher but also because the return on investment is much faster." He says that while large projects are centralised, small projects are decentralised and typically spread over a much larger territory (for every megawatt). As a result, the possibility of employment generation in small decentralised projects is much higher. For instance, while 10 people may get employment for a month in setting up a one megawatt-worth installed capacity in a centralised project involving large turbines, 100 people may find employment for over a year in setting up the same capacity in decentralised projects involving small turbines. Yet, large projects have ruled the roost in the Indian wind energy sector and have often run into foul weather in the pursuit of profits. The case of the wind farm in the Koyna Tiger Reserve is but one example.

Curious case of Koyna

The Koyna Wildlife Sanctuary in Maharashtra was notified on 16 September 1985 and comprised 423 square km, which included 14 villages. In Maharashtra, sanctuaries have three types of land – forest, government and non-forest private. As per law, once a sanctuary is notified the district collector is supposed to conduct a hearing in the areas where there is private land, to ascertain if people want to be a part of the sanctuary; in case they decide against it, the collector is supposed to ask for deletion of such land from the sanctuary area. In the case of the Koyna sanctuary, however, the hearing was conducted 13 years after the notification of the park, in 1998. People in the 14 villages expressed a desire that their habitats be denotified from the sanctuary.

Nana Khamkar.

Following this, the collector was supposed to send the request for deletion of those villages to the state government, which, in turn, was supposed to forward the same to the Centre. This because an amendment to the Wildlife Protection Act — operational on private land inside sanctuaries — in 1992 stipulates that deletion of land from a notified sanctuary cannot be done without the approval of the Centre. However, the state government sat on the proposal and did not forward it to New Delhi.

Further, in 2000 a Supreme Court decision made it mandatory for states to seek its approval for reducing the area of any notified sanctuary. The Maharashtra government, however, did not send the proposal to the Supreme Court either. Meanwhile, it allowed the sale of land in the 14 villages, mainly to wind power giant Suzlon — legal provisions allow for such land deals to take place once the deletion of private land has been okayed by the Centre and the apex court. As neither had been done by the state government, these land deals were illegal.

Suzlon, however, set up a wind farm in the purchased land and invited large corporations to buy and own windmills. Accordingly, corporate entities like Bajaj and Tata bought a number of windmills in the wind farm operated and maintained by Suzlon. It was functioning fine till 2010, when activists in the area pored over a map of the park — by then, it had been notified as Koyna Tiger Reserve — and found that the wind farm was functioning in contravention of laws.

Activist Nana Khamkar filed an RTI asking whether and how many windmills were operational inside the reserve. The reply to the RTI application stated that 235 windmills were operational in the farm. In 2010, he filed a petition in Bombay High Court asking for the removal of the wind farm, since the land on which it was located was purchased in violation of Section 20 of the Wildlife Protection Act; further, the setting up of windmills in an area that was still within a reserve was a violation of Section 2 of the Forest Conservation Act.

Bombay High Court directed the forest department to take a decision with regard to the fate of the wind farm. The department, in turn, ordered the eviction of 235 windmills and around 10 resorts from land that was still within the park.

Following this, the investors in the windmills, along with Suzlon, approached the high court and obtained a stay on the court's earlier decision; they argued that the petition was filed in 2010, while the wind farm was in operation since 2000, and a large amount had been invested in producing "green energy".

Following the petition in the high court, the Maharashtra government filed an application before the Centre regarding the deletion of the 14 villages from the reserve in 2010. If the Centre approves of the deletion, the matter will go to the Supreme Court, which will send it to the Central Empowered Committee for clearance. Knowing that the CEC will have a major role to play in the matter, Khamkar approached it a couple of years ago. He says he has learnt through reliable sources that the Maharashtra government sent an emissary to the Centre last week to request it to expedite the process and place the matter before the Supreme Court, which will then ask the CEC for its opinion.

"If the villages get deleted from the reserve, a heavy fine will be levied on the owners of the wind farm," says Khamkar. Pending the apex court's decision, however, the wind farm continues to be operational inside the reserve. Wildlife activist Rohan Bhate, who resides in the area, says the wind farms have caused considerable damage to wildlife in the area, and will continue doing so till the wind farm is evicted.

But what are the chances of the same? Khamkar is sceptical. "The case will take a long time — these windmill companies and the investors have immense lobbying power. Meanwhile, the wind farm will continue as is," he says.

The Koyna reserve case lays bare the manner in which large players in the wind energy sector have gone ahead with projects in contravention of laws, in collusion with state governments and the forest department. In fact, one of the problems with policy on wind power is that it allows diversion of forest land for wind farms. This despite studies that have shown that large windmills, that are typically set up on forest land, cause considerable damage to wildlife. In other words, the promise of green energy is countered by the amount of green it destroys.

Investors and suppliers in the sector, however, prefer to set up large wind farms on forest land because it comes without the perils of acquiring private land from unwilling owners. There are examples from elsewhere in Maharshtra and neighbouring Karnataka where wind farms have come up on land diverted from the forest department. That leaves us to ponder over not just the economic aspects of wind energy but also the social and environmental costs — not to forget the political climate that allows for such wanton abuse to take place.

Next week: What do locals gain?

The writer is on the staff of The Statesman, Kolkata, and this article has been written under the aegis of a CSE Media Fellowship