Inside the Weird Chemistry on Titan
by Professor Andrea Sella

The word ‘acid’ is one of those words that epitomizes chemistry. People immediately think of something horribly corrosive and dangerous. The second thing they think of is ‘the pH scale’, which quantifies the acidity of a solution, suggesting that there are levels of acidity.

To understand what chemistry there might be on Titan we need to look very closely at what acids are, and what makes them tick.

One way to define what an acid is, is to say that it is a substance that can let go of a proton, known to chemists by the symbol $H^+$.

Normally when we hear about protons we think of the Large Hadron Collider at CERN in Geneva where these subatomic particles are smashed together to uncover the deeper structure of our world. But to a chemist, a proton is simply a hydrogen atom stripped of an electron.

In other words, in chemistry, you can remove a proton, $H^+$, from an atom or molecule leaving behind an electron on the remaining fragment.

So, for example, you can take a molecule of water – $H_2O$ – and pluck off one of its protons leaving behind OH$^-$ which we call Hydroxide. And as electrons are negatively charged, and protons are positive, the hydroxide molecule now has a negative charge.

This process is called ‘acid dissociation’.

In chemical terms, we write this as follows:

$$H_2O \rightleftharpoons H^+ + OH^-$$

In other words, strange as it may seem, water is, itself, an acid, albeit quite a weak one.

So where does the proton go, given that there are plenty of other water molecules around?

What happens is that the proton forms a new bond with another water molecule and gives it a positive charge. We say the proton ‘protonates’ the water.

We write this like this:

$$H_2O + H^+ \rightleftharpoons H_3O^+$$

So, water can also accept a proton and therefore act as an alkali – or what we chemists call a ‘base’.

The crucial thing to understand here is that water (or almost any other substance) can actually act as ‘an acid’ or ‘as a base’ depending on the circumstances.

This has really important consequences...

If you dissolve an acid in water, because the water is so reactive, the acid will protonate the $H_2O$ making $H_3O^+$. And this puts a limit on how acidic the water will become. When you put a strong acid into water it will immediately react and make $H_3O^+$. So acids in water can never be more acidic than $H_3O^+$.

A similar thing happens with a really strong base.

If you dissolve a strong base in water, it will steal a proton from the water and leave behind a hydroxide $OH^-$. We can represent the base by the letter B and write this as:

$$H_2O + B \rightleftharpoons BH^+ + OH^-$$
So, there’s a limit to how strong an alkali you can make in water too – it can only ever be as strong as OH⁻.

You can see there are clear limits to how acidic or basic you can be here on our watery Earth – these limits are determined by the water itself! It’s easy to forget that water is a highly reactive substance that gets involved in the acid and base chemistry.

And that’s the reason why the pH range that you learn about in school is limited to between 0 and 14. That’s just as strong as an acid or alkali can ever be in water,

And that limits the kind of water-based chemistry that can be done here on earth.

Imagine now, that you are on Titan, where the ocean is made not of water but of liquid methane, CH₄.

Although the formula looks similar to water, there is a crucial difference: methane is lousy at giving up a proton so it makes a terrible acid.

It is also a spectacularly useless base because sticking a proton onto it (to make the bizarre CH₅⁺) is phenomenally hard.

*Meaning in Titan’s methane lakes we can theoretically extend the pH range, up to +40 and down to -20*

Why does this matter?

It matters because it means that the oceans of Titan might therefore provide a medium in which other substances could act as highly potent acids and bases, unrestricted by the methane.

We learnt recently that the Cassini-Huygens mission has discovered some large and peculiar molecules in the atmosphere. These will eventually rain down into the oceans. So, we might legitimately ask what happens if strong acids or bases are present?

*This is where things get interesting.*

Strong bases have long been used in chemistry labs here on earth to rip protons from organic molecules, allowing for a wider range of bond formation to be carried out. So perhaps in Titan’s lakes there are now options for building organic rings and chains.

Conversely, very strong acids are known to cause other kinds of organic reactions and even to promote the rearrangement of carbon chains by reconnecting some of the carbon-carbon bonds. These reconnection reactions are crucial, for example, in oil refineries where hydrocarbons are routinely altered to alter produce complex long chain molecules. Doing this can, for instance, improve the performance of fuel in our automobiles.

So, having methane as a medium may unlock all kinds of them chemistry that just isn’t possible here on our watery planet.

There is one big caveat, though.

Titan is very cold, which makes all chemistry very slow.

And liquid methane, ultimately, can – as far as we know – only dissolve a restricted range of substances.

But Titan has one thing that we chemists don’t in the lab: time.

So, the million-dollar question is: what exotic – and perhaps large – structures might be lurking in those lakes and oceans after billions of years of achingly slow chemistry?