Seven point four

Let's hope you score 7.4. Not out of 10, that would be too average. Let's hope you score 7.4 out of 300 million. That would be normal – chemically 'normal' in a technical sense, but also fresh, healthy, well tuned, full of life, energy and exuberance, and free from any nasty infections. Healthy, wealthy, and beautiful.

by
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I mean, of course, pH, the power of protons. Typically for science, nobody quite agrees on what pH actually stands for. The term was introduced in 1909 by Søren Peder Lauritz Sørensen, head of the Carlsberg Laboratory in Denmark, which was set up by the eponymous brewer. Appropriately enough, Sørenen is also remembered for being the first person to be photographed falling off a bicycle.

Sørensen said pH means *pondus hydrogenii*, but what did he know? The French say it means *pouvoir hydrogène*. In English it's usually said to mean the power or potential of hydrogen. They're all wrong. It really means the power of protons, or hydrogen nuclei. The proton was once an elementary particle, but later turned out to be just three quarks glued together with gluons. Nothing simple is ever simple to a physicist.

So what exactly is pH 7.4? It's a cipher for the number of protons in your blood, the acidity of normal, healthy blood. You really don't want to be pH 7, and forget about pH 8; neither is compatible with you continuing to be alive. Luckily, you're an exquisite machine for remaining at pH 7.4.

Neutral pH is designated 7, a curious convention. It refers to the proton concentration in pure water at 25°C. Most water is H_2O, but one in every 500 million molecules or so dissociates into a proton (H^+) and a hydroxide ion (OH^-). This gives a concentration of protons of 1 x 10^{-7} grams per litre, which is to say you'd find one gram of protons in 10 million litres of water. The pH value is derived from that negative exponent – pH 7 is therefore a proton concentration of 10^{-7} grams per litre.

Values less than 7 are acidic, so at pH 2 there are 10^{-2} grams of protons per litre. Values more than 7 are alkaline – at pH 10 there are 10^{-10} grams, and so on. That makes pH a logarithmic scale, meaning the gap between pH 6 and pH 7 is a tenfold step (from 10^{-6} to 10^{-7}). I have to say that it all makes perfect sense when you know the originator worked in a brewery.

Blood, strangely enough, is not neutral but slightly alkaline – pH 7.4 (so you'd need 40 million litres of blood for 1 gram of protons, or 300 million for 7.4 grams). And of course the temperature of blood is not the standard 25°C, but rather 37°C. The greater energy at higher temperatures means that more water molecules dissociate, giving up more protons. So neutral pH at body temperature is 6.8, not 7. Given the logarithmic scale, our blood has barely a fifth of the proton concentration of pure water at neutral pH, making us distinctly alkaline.

So why do we have alkaline blood? Many factors contribute, but my favourite relates to energy and power, specifically the oxygen carrier haemoglobin. The properties of haemoglobin depend on pH, by way of a phenomenon known as the Bohr effect, after the unfortunate Christian Bohr, the soccer-mad Danish professor of physiology and father of the famous quantum physicist Niels Bohr.

Poor Bohr senior was discredited by August Krogh, one of his own pupils and later a Nobel laureate, in a series of papers published back-to-back in 1910, known as the 'seven little devils.' Bohr stopped speaking to Krogh after their publication, and died of a heart attack the following year, at the age of 56. Krogh was mortified, as he had revered his teacher, even if he revered the truth more.

Nobody ever discredited the Bohr effect, though, and it's one of the most beautiful mechanisms in biology. The binding of oxygen to haemoglobin depends on the pH of its surroundings. In alkaline conditions, haemoglobin binds to oxygen strongly, whereas in acid conditions, it gives up its oxygen and picks up protons (and carbon dioxide) instead.

Because blood is mildly alkaline, haemoglobin binds to oxygen in the lungs. In the tissues of the body, however, active respiration makes conditions more acidic. This acidity induces haemoglobin to give up its oxygen, and pick up protons and carbon dioxide in exchange. The harder we exercise, the more acidic the tissues become, and the faster oxygen is released. So our ability to use oxygen, and switch up a gear in energy levels, resides in the poise of our blood pH. Lose your alkaline poise and you'll lose your energy.

But proton power goes even deeper still. One of the most difficult and brilliant Englishmen of the 20th century, Peter Mitchell, proved that, within the cell, respiration uses oxygen to unleash the power of protons.

Mitchell drove his opponents hopping mad, and was obliged to retire with stomach ulcers, eventually setting up his own research institute in an old manor house in Cornwall, financed in part by a herd of cows. From there, his revolutionary explanation of respiration won him the Nobel Prize. Deep inside the cell, he said, the flow of protons powers an electric circuit in the same way that the flow of water drives a hydroelectric turbine. The body is electric, and we are all proton powered. So let's hope you score 7.4. Your energy, power, and life depend on it.

Nick Lane is the author of *Power, Sex, Suicide: Mitochondria and the Meaning of Life*; *Oxygen: The Molecule that Made the World*; and *Life Ascending: The Ten Great Inventions of Evolution*