Harvesting light in a quantum world

SOME BIOLOGISTS STUDYING PHOTOSYNTHESIS ARE STARTING TO THINK THE WEIRD WORLD OF QUANTUM PHYSICS MAY BE NEEDED TO UNDERSTAND HOW IT WORKS.

Plants have been turning sunlight into energy for millions of years. What does quantum physics have to do with it?

Studying plants and algae has typically been the specialty of botanists, biologists and chemists. With advances in spectroscopy, physicists are now able to pick up their lasers and play with plants too. Spectroscopy uses radiation to measure properties of atoms and molecules. The field of quantum biology has blossomed into an exciting area of research and one of the most interesting opportunities is to learn how plants collect sunlight.

Plants are the original solar powerhouses on Earth — they have been capturing photons for millions of years. Insights into the underlying physics of photosynthesis could lead to a new generation of highly efficient solar cells. If we can improve the efficiency of solar cells by utilising techniques plants have developed, our renewable energy portfolio would be greatly enhanced and we could even reduce the impact of climate change.

However, physicists aren’t there yet. It turns out that energy transport within plants and algae is not well understood as it happens in an incredibly complex environment. Many
studies suggest that quantum phenomena may play a part in photosynthesis, indicating that non-intuitive, non-classical physics may govern fundamental processes that are responsible for life on Earth.

The complex electron transfer system that converts light into chemical energy inside chloroplast reaction centres. This is the heart of photosynthesis.

Plants and algae use light capturing molecules, called chromophores, to absorb sunlight. The Sun’s energy is then transferred to reaction centres. These enable the first chemical steps of photosynthesis, and are needed for the ultimate creation of sugars, which allow plants to store energy.

In 2007, a group led by Prof Graham Fleming published an experimental study, which claimed that quantum coherence plays an important role in energy transfer during photosynthesis. Quantum coherence describes the wave-like properties of particles. The study showed that energy transport acts in a quantum, wave-like manner, as opposed to behaving like classical particles. Instead of the packets of energy travelling to the reaction centre on a random classical path, quantum coherence allows it see all possible routes and choose the fastest one.

These coherences may be observed as “quantum beats” — variations in electronic signals between energetically excited molecules — through spectroscopic probing using lasers. By using the radiation from lasers, scientists can study how the energy packets are transported and determine if quantum coherence is present. The study suggested that quantum phenomena may be important in unravelling the mechanisms of photosynthesis.

Dr Ivan Kassal, from the University of Queensland, has been studying quantum effects in photosynthesis since 2008. He first became interested in this field after reading Prof Fleming’s paper.
“It was very interesting because it was about quantum effects in photosynthesis. I was working with quantum computers at the time and I thought I could have something to say about this,” explained Dr Kassal. Since reading this paper, he has delved deeper into the question of how photosynthesis happens, and whether quantum mechanics allows the plants to be more efficient at collecting energy. “Previously, it was thought that energy moves through photosynthetic complexes by hopping from one molecule to another like a particle. Now we know that it can also move like a wave,” Dr Kassal said.

Quantum phenomena usually require delicate and cold laboratory conditions to be observed. So it’s extra tricky to study them in plants, which are warm, complex organisms.

There have been many more studies of quantum effects in light harvesting complexes since 2007, and we are getting closer to understanding the complexities of energy transport in plants and algae. However, some are skeptical that non-trivial quantum effects exist in photosynthetic systems altogether. After all, quantumness is usually observed in ultra-cold and delicately isolated laboratory conditions—not so much in plants. Dr Kassal acknowledged that there are doubts about quantum mechanics existing in photosynthesis because biological systems seem to be “too hot and noisy”.

In addition, several studies of quantum photosynthesis have made overreaching claims about the relationship between quantum mechanics and evolution. Some studies say that plants have learnt to exploit quantum physics through evolution, but there is currently no evidence to support these statements. These claims make many scientists uncomfortable with the field of quantum biology and can result in pseudo-scientific adaptations. Dr Kassal
explained: “Some people have made claims that have been too ambitious in the past and I think that’s motivated me to be more precise.”

With this in mind, one of the questions Dr Kassal seeks to answer is whether quantum effects actually enhance the efficiency of plants, or whether this quantumness is just a by-product of the light harvesting mechanism. “Just because you see the quantum effects, doesn’t mean they’re being exploited—they could just be spandrels or artefacts of evolutionary processes,” he said.

“You have red blood, it doesn’t mean you’re taking advantage of your blood’s redness or that you’ve learned to do it over billions of years of evolution. It means that you happen to have haemoglobin, which works pretty great for oxygen binding and it happens to be red. So the question is: if coherence is present, does it actually have a role?”

Quantum biology may have the ability to make our solar energy systems more efficient.

Along with this question, Dr Kassal’s group is continuing to research how photosynthesis works, with the hope of applying their findings to artificial systems for energy production.

Applying quantum information and quantum optics methods to these systems is a possible route to measuring “quantumness” in plants and algae. Studying smaller, more isolated systems is also a promising way forward. “There’s some scope for studying smaller things to understand them better. I think some people have applied methods to very large complexes and signals get spectrally crowded and you can’t really resolve what you’re looking at,” said Dr Kassal. In other words, the larger the system, the more complex the
results. In order to pinpoint quantum effects, it is necessary to study smaller structures. For example, by shining a laser on smaller, artificial structures, such as two isolated chlorophyll molecules, scientists could identify the effects of quantum coherence more easily.

In addition to these avenues for research, more theories are needed to explain what we see in experiment. For example, do quantum effects actually enhance energy transport, or are they just artefacts of the light-harvesting structures?

Solving the puzzle of how plants and algae capture sunlight to sustain life on Earth would be an incredible leap forward for renewables, and the prospect of quantum phenomena being present in light harvesting is fascinating. While insights into the mysteries of nature aren’t easy to come by in complex systems such as plants, the possibility of creating more efficient solar harvesting technology is worth every effort if we are to go green and achieve progress in tackling climate change.