A quantum leap for scientists could help us harness solar energy

In the Darwinian drive for survival, living organisms have repeatedly beaten science to the punch. From mastery of flight by birds to the jet propulsion of squid and the sonar systems of bats, evolution has pulled off miracles aeons before humanity’s best and brightest.

But evidence is emerging that billions of years ago organisms began exploiting phenomena so extraordinary that even Albert Einstein refused to accept their reality.

Understanding how nature achieved its amazing coup now looks set to trigger a technological revolution. The phenomena are the focus of the most successful and baffling field of science: quantum theory. Since its emergence about a century ago, quantum theory has acquired a reputation for being extremely complex and extremely weird. Its inventors confessed that they never really understood it and, to this day, its fundamental principles are unknown. Even its origins are bizarre.

It was first invoked by the German theorist Max Planck, who was struggling to solve a technical problem about heat escaping from an oven. Much to his surprise, he found he could solve the problem easily – but only if heat is regarded as being not a continuous stream but as packets of energy he called “quanta”.

Other physicists – including the young Einstein – followed Planck’s lead and showed that the same trick solved other mysteries, including many linked to the properties of atoms. But the more they found out about quantum theory, the stranger it became.

Experiments showed that particles sometimes behaved like bullets and sometimes as waves. Then came the Uncertainty Principle, which showed that the more precise certain properties of particles were pinned down, the vaguer other properties became.

Despite being one of its creators, Einstein became increasingly disturbed by quantum theory and began seeking ways of proving its inadequacies.

Yet, every time, the “ridiculous” predictions of the theory proved correct.

Perhaps weirdest of all was the theory’s insistence that every particle is spread throughout the universe – until the moment it is observed, at which point it is compelled to be at a specific point in space and time.

Even today, physicists who accept Einstein was wrong about quantum theory concede they struggle with this.

The good news for the rest of us is that all this bizarre stuff only manifests itself in certain circumstances. At anything other than incredibly low temperatures and virtually perfect vacuums, particles behave perfectly normally and we can ignore “quantum weirdness”.

Or at least, that has been the accepted wisdom.
Now quantum weirdness has been found in a familiar place, in what seems to be another example of life exploiting anything that helps in the Darwinian struggle.

Forget esoteric lab experiments: quantum weirdness is at work all around you, in the leaves of every tree and plant.

We have all been taught that plants thrive by making their own food via the process of photosynthesis. It is trotted out in every biochemistry text: light energy from the sun is captured by the leaves and used to split apart water molecules, freeing their electrons to make carbohydrates.

This clearly involves particles, so it is hardly surprising quantum effects are involved. But the textbook accounts glide over something that demands not only the effects even Einstein accepted but also the truly weird stuff he rejected.

When sunlight strikes leaves, its energy must be sent as efficiently as possible to the sites where the water molecules are split. The trouble is, the sunlight strikes anywhere but the sites are only at certain locations. Yet as if by magic, virtually all the energy gets to exactly where it is needed.

The explanation, say physicist Jim Al Khalili and geneticist Johnjoe McFadden, of the University of Surrey, UK, is that plants are exploiting quantum effects. The professors are authors of Life on the Edge, a review of the evidence for quantum effects in living organisms that was published this month. They cite compelling new evidence that plants exploit the quantum property of being able to exist everywhere at the same time, until forced to adopt a specific location.

The plants themselves cannot pull off such a trick, of course: theory shows they are just too big and interact too strongly with their surroundings to leave the quantum effects intact.

But it is a different matter in their leaves. Here the sunlight creates unstable packets of energy called excitons and it is these that split apart water molecules – if they can find them before losing all their energy.

Textbook accounts claimed the excitons simply found the water molecules by wandering around randomly but this is far too slow a process and would lead to huge energy loss. That is where quantum weirdness comes to the rescue. It allows the excitons to travel through the leaf by all possible routes simultaneously and reach the water molecules fast enough to split them.

According to Mr Al Khalili and Mr McFadden, the discovery that photosynthesis, which evolved more than three billion years ago, makes use of such bizarre effects “has come as a huge shock to quantum physicists”.

Until now, they have regarded such effects as simply too delicate to be useful in everyday phenomena.

Having been taught this lesson in humility, technologists are racing to exploit it. Now the first results are starting to emerge.

Earlier this month, researchers at the Massachusetts Institute of Technology and Eni, an Italian energy company, revealed a quantum energy transfer system that could revolutionise the efficiency of solar cells.
Conventional solar cells generate power by turning sunlight energy into a flow of electrons – an electric current. The process of getting sunlight to where the current can be generated is, however, relatively inefficient.

In Nature Materials, the MIT-Eni team reported boosting the efficiency using an arrangement of molecules optimised to exploit the benefits of quantum weirdness in transporting energy. Taking their lead from nature, the team arranged the molecules the same way nature does: via genetic modification, specifically of a virus.

The research has sparked huge interest, though more work is needed to turn this into a real, working solar cell. Even so, we may well be witnessing the first in a host of advances inspired by this latest surprise sprung by nature on scientists.

Robert Matthews is visiting professor of science at Aston University, Birmingham, UK