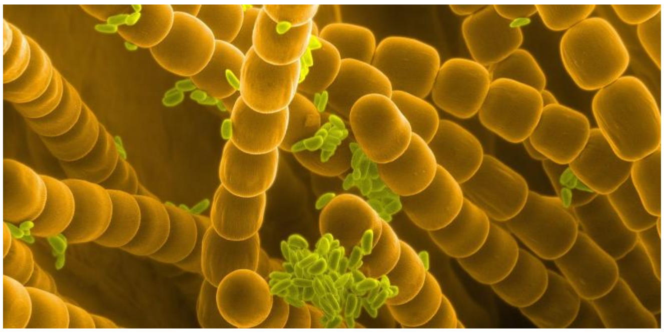
Does ecology reach all the way down to the subatomic scale?

16 August 2016, by Peter Fisher



Without electrons there would be no electron microscopes, and therefore no close-ups like this image of pollen. Credit: Heiti Paves/Wikimedia Commons, CC BY-SA

Imagine you could stop being human-sized for a while and shrink down to the size of a bacterium, roughly one-millionth of your current stature. At this scale, you would stop being bound by gravity and instead discover that viscosity is the dominant factor, making the air feel more like swimming through a gloopy swamp.

Hordes of your fellow bacteria buzz past, powered by reversible rotary motors that propel them at up to 20 times their body length per second. That's the kind of speed that, relatively speaking, you would need a motor to achieve in the human world.

Food is easy to find; nutrients simply land on your surface via molecular diffusion. Other aspects of bacterial life are perhaps more familiar: bacteria, just like larger creatures, are hunted down by predators and plagued by pathogens.

These Tom Thumb universes don't make a whole lot of sense to us humans, who are more used to dealing with things we can see and touch. Indeed, we were oblivious to the microbial world until Robert Hooke invented the microscope in 1665 – a feat made possible by the advent of high-quality glass and the emergent science of optics.

Life's full of surprises

From that awakening sprung a grasp of the sheer complexity of life. That's something we're still wrestling with today, as shown by the fact that an average teaspoon of water, soil or ice is teeming with millions of microbes that have never been counted or named.

This dizzying diversity is busily making a living in every conceivable nook and cranny on Earth. In your mouth there are up to 100,000 bacteria on each tooth alone. There's a veritable bacterial zoo feasting on our daily deposits on train and bus railings, seats and other paraphernalia – not to mention flesh-eating bacteria.

This is hard enough to get your head around, but stay with us as we descend into a much smaller, more complex and altogether weirder arena.

Smaller still

Down at the scale frequented by subatomic particles, viscosity doesn't get a look in – things are orchestrated by quantum principles where causality, locality and realism are out the window.

Here, at mere femtometres, or millionths of a billionth of a metre, particles like electrons aren't particles in the traditional sense. They can effectively be in several places (and move in several directions) at once and behave as waves – a property that paved the way for electron microscopes.

This might sound no more tangible or relevant than the squiggles on a physicist's whiteboard, but the evidence of its reality is there to see, both in the form of experimental demonstrations of particle-wave effects and in the range of modern technology that uses quantum effects such as atomic clocks or other practical, if spooky, uses.

Perhaps one day soon we'll even have quantum computers (just ask Justin Trudeau, although in truth he struggles with the details too).

Living processes at the subatomic scale

But what does quantum physics have to do with living things?

Whereas conventional microscopes brought the micrometre scale into focus (followed by the electron version, which extended resolution by several orders of magnitude), here in the 21st century we can peer down to the atomic scale of nanometres, or billionths of a metre, thanks to X-ray lasers.

This technology has already recorded some spectacular glimpses into the molecular processes that underpin some of life's most basic functions, like photosynthesis and light sensing.

Movies made from snapshot X-ray imaging (which can take a staggering 100 trillion images a second) show the inner workings of the molecular machine during photosynthesis – a process where magnesium atoms, surrounded by protein, split water and digest carbon dioxide as food in all green plants. Nature uses this same mechanism, in combination with electron transfer reactions, to generate practically all the oxygen breathed on Earth.

Similar movies show what happens when light hits your retina and engages with a photo-sensitive protein.

This amounts to more than idle curiosity – imaging in this way can provide insights into a wide range of biologically and pharmaceutically important molecules, which in turn can potentially help in the development of more effective drugs. And that's not to mention the implications for ecology in arriving at a fine-grain understanding of photosynthesis, the engine room of the plant kingdom and the myriad creatures that depend upon it.

These technologies lay bare the intricate connections between subatomic and ecological processes.

A whole new industry built on small

The rapidly developing field of nanoscience and technology – a further spinoff from quantum principles – has given rise to no shortage of prospective uses. This includes the promise of nanobiotechnology to develop new, more effective drugs for conditions such as high blood pressure, assisted by the view of these molecules afforded by X-ray lasers.

Then there's the more proactive bionanoscience which aims, among other things, to simulate biological mechanisms so accurately you can now take a virtual stroll through a cancer cell while it is tackled by drug-bearing nanoparticles.

We are thus entering an era of "molecular manufacturing". And on the horizon are "nanobots" – molecular-scale workhorses small enough to manipulate molecular processes within cells. Perhaps one day these will be sophisticated enough to deliver drugs to specific molecular sites or even carry out surgery.

The invisible force

These aren't designs with which humans can directly interact, not least because they're functioning in an environment we can barely begin to imagine given our metre-scale, commonsense reality. That also means that should these processes have a harmful flipside, we don't have much of a handle on how to deal with them.

Back up the size scale we have procedures like environmental impact assessments, product stewardship and toxicology testing. How do such concepts fit, if at all, with the advent of nano-engineered molecular structures? It's entirely possible that our e-waste bins at recycling centres (or even landfills) could one day find themselves full of intricately engineered nanostructures with unknown environmental consequences.

That's possibly fanciful, but there are nevertheless potential issues with mineral-based nanoparticles already found in cosmetics, paints, clothing and other products. Some have well-defined paths into the outside world, heading from our showers and sinks to sneak through sewerage treatment plants. What they might do having "gone feral" in waterways and soils is anyone's guess, although some indication may come from their big brothers such as fine silts or microplastics, whose surfaces can become carriers of both inorganic and organic pollutants.

These issues aren't currently writ large for the water industry. Even much-vaunted Class A wastewater treatment plants deal only with pathogens, taking little interest in nutrients, chemicals, microplastics or nanoparticles.

But nanoparticles' size, shape, surface area, clumping and behaviour in the wider environment make it difficult to conceive of how best to regulate them. Moreover, there have been few regulatory studies on nanoparticles in which hazard and exposure have been considered together, so it's difficult to provide a comprehensive risk assessment.

And these are relatively "inert" variants. The lack of knowledge could become more pressing if nanobots go feral.

Nothing just goes away

We should be advanced enough as a society to realise that everything we manufacture has to be accounted for. Nothing just "goes away" – even stuff that's far too small to see.

Unlike smog or litter, this is way, way down in that invisible world, making it difficult to form a political constituency around the issue.

Nonetheless, advances in our understanding of the profound connections between atomic-scale processes and biological molecules in that tiny, tiny world serve to deepen, if not transform, the way we regard ecological processes – and, by implication, "living things", no matter how invisible.

Source: The Conversation