Science is a Long Story: A Conversation with Tom McLeish, Part One

Tom McLeish FRS, physicist and Emeritus Professor of Natural Philosophy in the Department of Physics at the University of York, UK, in conversation with Dr. Samuel Loncar, Editor-in-Chief of The Marginalia Review of Books.

Introduction

As part of our Meanings of Science in the Modern World project, I had the pleasure of speaking with one of the world's leading experts in soft matter physics, academic disciplinary leader, and writer, Tom McLeish.

McLeish's publications reflect his interdisciplinary academic interests, which include science, theology, history, and theories of creativity in art and science. His most recent books include: *Soft Matter – A Very Short Introduction* (Oxford University Press 2020), *The Poetry and Music of Science* (Oxford University Press, 2019), and *Faith and Wisdom in Science* (Oxford University Press, 2014). In addition to giving public lectures in literature and science, he directs several large interdisciplinary collaborations and co-leads the *Ordered Universe* project, an interdisciplinary re-examine of 13th century science. His scientific research in soft matter and biological physics and cross-discipline collaborations have been recognized with major awards in the US and in Europe.

Our conversation was lively and illuminating, and his passion for everything from soft matter and polymers to Cappadocian theologians and the idea of resurrection was an evident delight. We begin with McLeish's journey into the scientific world, which in part was inspired by his grandmother, a botanist and lay preacher in the Church of England. This led to a rich discussion of soft matter, academic disciplines, the importance of science being in conversation with philosophy, and challenging the myth that the unexplainable was all magic until science entered the narrative.

Crossing Boundaries

SAMUEL LONCAR

You write so movingly—you made me so interested in polymers and things I know nothing about—so I'd love for you just to share a bit to begin about your own journey into the study of the natural world.

TOM MCLEISH

I honestly don’t know a time when I didn’t think I was a scientist. I must’ve been about two and a half years old. I don’t know where it came from, but I remember

just loving all aspects of the natural world: the stars, the plants, the bees, and, of course, I was very influenced by NASA in the 1960s when I grew up. You couldn’t really ignore the Moon Program: the sheer romantic, millennia-old dream actually realized of walking on our planet’s satellite, and I was seven years old or so when Neil Armstrong stepped out onto the surface of the Moon. So that was one important strand, but of course there were others too.

My grandmother actually was an important influence on me. She had done a degree at London University in the twenties, I think, on botany, but she was broadly scientifically interested. She gave me her grandfather’s field microscope when I was a child: it was a little brass microscope, which I later discovered is of the identical make with which Robert Brown made his investigations into Brownian motion. I still have this wonderful device. And I was pricking my finger and getting blood cells out and looking at them and fly’s wings and things. A bit later, of course, I got a small telescope at 10 or 11 years old and found Saturn with its rings. I’ll never forget the hair-on-the-back-of-the-neck-prickling discovery of seeing this wonderful, ringed planet hovering in the eyepiece under your eye.

But I should say my grandmother was also a trained lay preacher in the Church of England, which I later became myself. So it was clear in my upbringing from her that there was no conflict at all between science and religion. In fact, quite the reverse. So that was one important strand.

Of course, later I discovered that the science I really loved was called physics. I always describe physicists as the Winnie-the-Poohs of the scientific world. We’re bears of little brain. Complicated things confuse us. We leave that to the biologists and chemists. We like things lovely and simple.

SAMUEL LONCAR

That’s a lovely, humble view of such a rigorous field. I love Winnie-the-Pooh. The Winnie-the-Poohs of science?

TOM MCLEISH

That’s what physicists are. The other strand for me is my interdisciplinary passion. Whenever I have seen the fragmentation of the academic world—I remember thinking about this at school as well as university: the entrenched polarization of the arts and humanities, in particular of art and science—this made no sense to me, never has.

And as you may know, my own country, the UK, is one of the earliest of the G8 countries to specialize in education, something that I've been trying to inveigh against in the work I've been doing, in the educational policy work of the Royal Society more recently. We need to equip young people with both the scientific and quantitative skills but also the imaginative—the humanities and literary skills—they need to navigate the future. But I was very fortunate. My school was broad and flexible, and I was able to study French at ages 17 and 18, while I was doing my late high school science.

A French teacher (actually another Christian) was also passionately interested in Sartre, Albert Camus, and the French existentialists, so of course, I became passionate (of course you do, don't you?) for Sartre and Camus and the French existentialists. So that set me on the path. It showed me the value of the humanities and gave me an interest in the humanities discourse. I saw how important it is to keep that going alongside science because science also has its narrative and its story. So there are a few formative things.

As for polymers, I always wanted to be an astronomer. But before going to university, I took a gap year in industry. I wanted to know how science panned out in industry. I just got that bug too. And I happened to get a funded place at a company called Courtaulds that made artificial fibers, polymers. And it was a fascinating process. But they had no fundamental science whatsoever. It was all empirical. You try this: if doesn't work, you ditch it; if it works, you try it again, and see if you can sell it. That was the rule. And I remember thinking there must be a science of these extraordinary liquids—made of long-chain molecules. I knew that; I didn't know anything else.

Then at Cambridge, the Cavendish Professor, Sam Edwards, had made a career out of inventing what we now call soft-matter physics from quantum field theory, using its mathematical techniques and physical nsights, and working with this wonderful Japanese physicist and chemical engineer, named Masao Doi, to devise the first molecular physics theory of viscoelastic polymers. And when I was in Cambridge as a final-year undergraduate, I attended a lecture where Edwards announced: "Gentlemen, ladies, I do believe we have a first theory of viscoelasticity," and I remember thinking, "Oh, my word, I must be the only person here who knows that there's industry out there desperate for this. I could be in at the beginning of something really new for my PhD. Or I could be yet another astronomer." I'm not dissing astronomy, which is fantastic. And gosh, I always partly regret not being on board with the exoplanets and Hubble. However, it was lovely to be in on something new. So that's what got me into polymers and soft matter.

The Wonders of Soft Matter

SAMUEL LONCAR

That's incredible. There's so many wonderful themes there. Just to pick up on the most recent, you are one of the world's leading experts now in soft-matter physics. What is soft-matter physics? You've just explained that it's a very recent field that Edwards pioneered. Could you tell us a bit about why it's special and fascinating to you? What's enamored your mind for so long?

TOM MCLEISH

One of the special and fascinating things is that it is exactly what it says on the tin, and very often it is in the tin: jellies, soups, sticky liquids. It is the physics of softness, and of course softness is very subtle. Some of your readers and viewers today might have seen the demonstration of the rose, the softest of all petals, being dipped in liquid nitrogen, so that it's frozen. And then you lift the flower out—no chemical change, nothing; it's made of exactly the same stuff it was before—and tap it with a hammer, and the thing shatters like glass. So softness is not purely a function of material and structure. It's also a function, it turns out, of dynamics. That is what heat is. Temperature is the motion or lack of motion at the smallest length scale of the molecule.

So, it's the emergence of properties like softness, stickiness, foaminess, bubbliness. We have plastics, we have foams, we have biological tissue. The fact that their molecules can be, for example, long chains or networks, and entirely new properties emerge. That this is physics, not just chemistry, although, of course, it's inherently interdisciplinary, is itself very interesting. And it was Sam Edwards who realized that a super large molecule made of thousands and thousands of chemical units, at some length scale its properties just emerged from the fact that it is a string.

The tiny little beads on the string which possess the chemistry are good for local things. But the overall properties like its rubberiness—elasticity, just the stretching out of rubber—doesn't come from stretching chemical bonds; it comes purely from stretching out individual thermally excited strings that would like to be randomly sampling all possible paths, but as you stretch them, they are constrained to sample fewer and fewer of them. Let me just grab a little cable to illustrate this. So here's a long chain polymer, and it's just dancing around forming all sorts of conformations, but when I stretch it out, it's partly confined to just a few. And that's the statistical pressure that rubber and elasticity works on. The mathematics for this come straight out of quantum field theory: Feynman path integrals and all that, as Sam realized. So soft-matter physics is really born from the quantum field theory of the post-war years in terms of its method. [It also comes from] the chemistry of increasing kinds of materials, humanmade materials available to industry in the postwar years, too, and it's another example of how industry and academic science reciprocate in terms of knowledge exchange.

It's not that ideas come in universities, and we apply them in industry. It's much more nonlinear and complex than that. My own research later in soft matter, for example—my first big bite of a new puzzle—had to do with what happens if you take these long-chain molecules and branch them into tree-like or cone-like structures. After all, we've learned that part of their key physics is that two strings can't cross each other in three dimensions. That was a fundamental interaction, what we'd call a topological interaction. So it became obvious to ask, what happens when one changes the topology of the molecules themselves? And the answer is whole new emergent properties leap out, and that was fun to explore for quite a few years, in collaboration with chemists and engineers and computer scientists and industrial scientists, too. So that gives you an idea of soft matter, and the latest thing that's happening is, of course, that we are made, life is made, of soft materials. So you'll now find myself and other soft-matter physicists engaging more and more with biologists and together exploring how the physics of biological cells and biological matter works.

SAMUEL LONCAR

It's an extraordinarily exciting field then. You mentioned it comes out of quantum-field theory, so in one sense, it is itself a fruit of the latest science. Was there a previous interest in the problems, or was the conceptualization necessary for the issues that now make up soft-matter physics something that couldn't emerge until quantum-field theory and twentieth-century physics?

TOM MCLEISH

The interest goes back a long way. In the nineteenth century, we have the emergence of rubbers. Actually, rubber technology has been around since the Incas; it's been around a long, long time. And the science of rubber and the industry of how you turn latex— a viscoelastic slimy resin—into crosslinked rubber with vulcanization and so on—is technology more than a century old.

Fascinatingly, one really important property, which later became a real key to its physical physics, is that when you stretch rubber, it gets warm. And if you take a stretched rubber at room temperature and you relax it, it cools. So there's strange thermodynamics going on. It's called the Gough effect, after a man named John Gough who lived in the Lake District. And, very interestingly, he was blind from birth, so he had to develop his other senses, his non-sighted senses, in his exploration of the science that he loved, and I think it's really a wonderful thing that he discovered an effect that other people completely missed because it's a very subtle change of temperature. Anyone can detect it. Just stretch a rubber band on your lower lip, which is sensitive to temperature. This is what he would do. So the Gough effect goes back to the nineteenth century.

I should say that the notion that there were giant molecules was still being contested in the 1920s, and the German chemist who first promoted the idea that there were macromolecules was Hermann Staudinger. He was reviled by his colleagues because giant molecules, of course, have an indeterminate molecular weight. How many units are you polymerizing, 10,000 or 10,002? Molecular chemistry is supposed to be an exact science.

This is one of the Kuhnian socially constructed barriers to new understanding that had to be overcome in the early days. There's prior history of chemistry and material science. Maxwell was interested in viscoelasticity. The Maxwell model actually comes from the simplest possible mathematical model of a material which is a solid if you observe it at short times and a liquid at long times. So, it has a nineteenth-century history as well. But you're right that it needed both the chemistry and physics—the postwar mathematical methods—to reinvigorate interest.

There's one other historical aspect of the science here. You get the wonderful chemical physics that scientists like van der Waals were doing at the end of the nineteenth century. There were statistical methods behind the colloidal part of soft matter— in distinction to the long stringy polymers, there are also tiny round things, and they're the colloids. But all of that went on hold – the physics thereof at least, when quantum mechanics stepped onto the scene, because everyone had to do electrons, and everyone had to do Heisenberg and Schrödinger stuff. And all that quantum-mechanical stuff had to calm down for a few decades before people went back in the sixties to say, "Well, now we know a bit more mathematics than this. What was this fascinating program on complex fluids that that was going on before we all got excited about quantum mechanics?" That's slightly tongue in cheek, but only a bit. That's the potted history.

Natural Philosophy, Science, and the Extraordinary

SAMUEL LONCAR

As a philosophical issue, it's fascinating that the very field that you're in reflects the evolution and purification of what in retrospect was a very significant error in early modern philosophy. Softness would be what the early modern philosophers would have called a secondary property, right? Not a core property of intrinsic reality. And yet, it seems that what is so interesting is that this quality—a quality that is inherently, we would say, qualitative—in fact seems to be embedded in some of the most profound, fundamental, mathematically complex structures that we can now study. It's a very interesting evolution from the early modern mechanistic view to this now very dynamic view, which is statistical, although still highly, highly fundamental in its profundity of engagement with the structures of reality.

TOM MCLEISH

Yeah, absolutely. It's statistical; it's also emergent.

SAMUEL LONCAR

Could you say more about emergence? It's an exciting quality.

TOM MCLEISH

Having a chair of Natural Philosophy, I try to do some philosophy or just to engage with philosophers, as well as doing the science. Ever since I was at Durham, before my current appointment, I have become very interested in the philosophy of this thing, or these multiple ideas, called emergence.

And it's a challenge to one of these optional interpretive schemes of modern science, which is reductionism, the idea that there's a level of linked scale at which all the causal variables seem to operate with the fundamental variables. Yes, of course there are large, coherent bodies of structure in motion, like breaking waves, or like sheep, or like trees, that can be talked of and conceived of and analyzed in terms of themselves. But at the end, it all comes down to the atoms. Oh, actually, when I say atoms, it's not the atoms, but the protons and neutrons. Well, actually, no, not the protons and neutrons. It's the quarks. Maybe. We think.

You see the problem here. How many layers of this onion do you peel off before things become emergent? I like to tease my quantum-field-theory friends by asking them to show me the Standard Model Hamiltonian, which has 23 or 19 (I'm not quite sure how many) arbitrary parameters, and I show them the Edwards Hamiltonian of the physicist polymer, which has two parameters, from which all properties of polymers emerge. We don't need the quarks, thank you very much. Which of these is more fundamental? We can at least argue about it.

And after all, does it not seem rather strange that all irreducible causal agents might occupy the same energy or length scale? That's a rather arbitrary thing. There may be universes in which that is the case. We'd better go and look empirically at ours, hadn't we? Because perhaps there are irreducible agents at a range of length scales. I think the empirical observational data of our own universe point very clearly to the latter case.

So there are cases within quantum mechanics, there are highly demonstrable cases within statistical mechanics as well, of irreducible causal powers. That's maybe a little bit controversial to some people. It's not controversial to me. But there's an exciting literature on this. Certainly in practice, all science works as if a strong emergence were true. That's how we actually do things. When my biological colleagues work on membrane proteins, they don't talk about the electrons or the quarks or the field theory or the gluons in there. They talk about the membranes and the properties of the membranes and the properties of the proteins and Brownian motion of the subunits. And those are all you need to know to understand this extraordinary world of the soft matter of the cell, for example.

SAMUEL LONCAR

What you're saying is very significant. We've separated science and philosophy. I know you recognize the value of the philosophy of science to the practice of science, but you can see why some physicists or others wouldn't, until you start to get into these issues where there are empirically salient, highly relevant things in science that speak to deeply philosophical issues. And so about the reductionist program, you tell the famous anecdote of Laplace in your book, *Faith and Wisdom in Science* published by Oxford.

The Laplacian dream was of a scientific program that came out of Newtonian mechanics in which, by understanding the very simple fundamental structures of reality, you could if you had all of the information, all of the initial parameters, get a complete, deterministic picture of everything. And yet the picture that's actually emerged in science—particularly since the twentieth century, and in your own work and in your own field—tells us a much more dynamic, complicated, and interesting story. Is that a fair high-level summary of what's at stake here? There are different worldviews that have animated science, and soft-matter physics is partly a philosophical change in outlook about what the fundamental structure of the philosophy of physics might be.

Investigating the Stories Science Tells

TOM MCLEISH

Yes, I think that's true. It certainly informs the philosophy. And we see the observed reemergence of what I used to call (I might be swayed to call it something else) strongly emergent, as an irreducibly emergent, agent at high length scales. Now, of course, this whole program comes from the philosophy of mind. And this is where I think the physicists might make a helpful suggestion—we have made a suggestion or two, which I hope have been helpful to the philosophers of mind. You see, the motivation behind a non-reductionist philosophy of mind is, of course, that we don't experience our minds as being reducible. We don't experience our minds as being mere epiphenomena of matter. This is, by the way, an old discussion; this is not a new discussion driven by artificial intelligence.

My favorite debate as to how one tells whether mind is reducible to its matter or components in terms of thoughts—call it soul, if you wish—goes back to Gregory of Nyssa, one of the great Cappadocian theologians, and his elder sister, Macrina, who's also one of the great Cappadocian theologians, in her deathbed discussion, which is often translated *On the Soul and the Resurrection*. It should really be *On the Mind and the Resurrection*. And they go hammer and tongs about this. Interestingly, Gregory takes the view that everything is reducible to atoms, material properties—just for fun. He doesn't believe that, but he takes that view for the sake of debate. And Macrina takes the view that the mind is a causal agent: we make real decisions, we have freewill, and so forth. And she ends up by pointing out that we know this is true because mind has the ability effectively to do science, to reconstruct nature. So when we see the phases of the moon, we conceive not of a little penny that grows from a sliver into a round and back to a sliver again during the month, but of a sphere, illuminated by the sun in fully three dimensions. In other words, we do not merely record perceptions; we recreate the entire universe in model form.

So much for mind. But my suggestion from the physics is, look, if mind is a big problem, then what's more ethereal than quarks? Mind is a long way out there. If the universe has irreducible strongly emergent structures, then we might be well advised to look for them at length scales in between the atoms and mind. Simpler emergent structures—let's establish those with the physics that we understand. We don't understand the physics and chemistry and neurochemistry of mind yet. Let's do that.

So that's where I think I've experienced a very happy and integrated meeting of physicists and philosophers. In fact, this Durham Emergence Project, which the Templeton Foundation funded, brought physicists and philosophers together, not just for one conference, which is the standard way of doing it, but for weekly meetings over three years, interspersed by interchanges and sabbaticals, interspersed by major conferences and writing books and papers together. That kind of engagement across disciplines was interesting. Some of the philosophers of science said they'd never experienced anything like it. They never experienced scientists as tenaciously interested in talking to them for long periods of time. Well, hooray, I'm proud of that. I could say the same thing: thank you to them for talking with us with serious investments of time.

And out came a philosophy based not on nineteenth-century science or at best quantum mechanics, but right up-to-date stuff, buying into some of the emergent soft matter and emergent quantum field theory in condensed matter these days. So we had lots of very fruitful engagement, working towards a renewed natural philosophy, I think.

SAMUEL LONCAR

That’s very exciting. And I love the anecdote you give of Macrina, which you have in the book. So maybe we could use that as a way into some of the issues that you’re raising in physics and philosophy and the philosophy of mind. You give an example of people doing something like science 1600 years ago. That might surprise some people because of our image of science today. But your whole work and life has always challenged this idea. You were raised in a household in which the very idea of a conflict between religion and science would have seemed ridiculous because of the shared singular source of inspiration you had from your grandmother. So where do you see our image of science today? And how does your own work in this case challenge it? I mean, how old is science? How long have we been interested in science as humans?

TOM MCLEISH

When I was growing up, so as a very young scientist and then as an early career scientist, I had the coffee-table books or school histories of science that said that there wasn’t much going on before the seventeenth century. Before that we were in the middle of the Dark Ages, and it was all magic and superstition, and then suddenly Copernicus, Galileo, Kepler, and Newton appeared. “Nature and Nature’s laws lay hid in night / God said, Let Newton be! and all was light,” as Alexander Pope famously wrote.

I never believed this, and I didn’t believe it because I just don’t think things change that quickly. Rarely. So something’s been missed out. It smelt artificial to me from a very early age, but you have to do a bit of digging to discover that, yes, it absolutely is artificial, totally artificial. Of course, there have been changes in the scale, the depth, the style, in which we do science. No more, no less, there have been huge changes in the scale and style and depth and capacity with which we write, play, and sing music. But that doesn’t mean that there wasn’t any music before William Byrd or Monteverdi. Pick your favorite early modern composer.

In fact, we know from drilled bone flutes, that my colleagues in archaeology here in York know a great deal about, that tens of thousands of years ago, human beings were playing notes from our current harmonic scale on hollowed out bone and it’s very likely, therefore, that they had also discovered that strings have the same capacity. So what we now call science, by other names in the past, is as old as any other human cultural endeavor: music, art, telling stories, narrative, singing, painting, the works. . .

Part Two to follow.

Tom McLeish FRS, is a physicist, academic interdisciplinary leader, and writer. He is Professor of Natural Philosophy (Emeritus) in the Department of Physics at the University of York, UK. He has won awards in the UK, USA and EU for his interdisciplinary research in soft matter and biological physics, and also works across science and humanities on medieval science, and the theology, sociology, and philosophy of science. He is a licensed lay preacher in the Church of England, and is currently Canon Scientist at St. Albans Cathedral. As well as over 200 specialist articles, he is also the author of *Faith and Wisdom in Science* (OUP 2014), *The Poetry and Music of Science* (OUP 2019) and *Soft Matter – A Very Short Introduction* (OUP 2020). He regularly appears on BBC radio, including the morning prime-time religious reflection of current affairs, Thought for the Day.

Samuel Loncar is a philosopher and writer, the Editor of the *Marginalia Review of Books*, the creator of the Becoming Human Project, and the Director of the Meanings of Science Project at *Marginalia*. His work focuses on integrating separated spaces, including philosophy, science and religion, and the academic-public divide. Learn more about Samuel's writing, speaking, and teaching at www.samuelloncar.com. Tweets @samuelloncar