
For the Life of Science:

Philip Ball on Quantum Physics and The Writing Life

Philip Ball in Conversation with Samuel Loncar

Introduction

Over a few delightful hours last year, I spoke to the genial and generous writer, Philip Ball, a modern polymath who started off as a physicist, worked for 20 years as an editor at *Nature*, the world's leading scientific journal, and has written over 25 books, winning many awards along the way, including the William Thompson, Lord Kelvin 2019 Medal and Prize for communication of physics. I could not have imagined a better person to inaugurate our *For the Life of Science* series, which will help bring the joy, beauty, and power of science into conversation with culture, history, and the arts. We talked about his book, *Beyond Weird: Why Everything You Thought You Knew about Quantum Physics is Different*, which won the *Physics World Book of the Year* in 2018, his past and current projects, and what his writing and research process looks like.

If you've read any of Ball's remarkable books, you might have noticed something I found extraordinary, which led to the question that began our conversation. Ball has written books on subjects as diverse as the history of China (*The Water Kingdom*), physics, chemistry, biology, music (*The Music Instinct*) and Chartres Cathedral (*Universe of Stone*). In all of his books, he brings the highest quality scientific and scholarly research, often from vastly different fields, into a coherent, intellectually original, and exciting story. Besides writing popular books, he actively publishes peer-reviewed research, and has written scientific articles in fields as diverse as astrobiology, physics, chemistry, and biology. It is a remarkable and uncommon combination of breadth and depth, even among the many brilliant writers in the world of science.

I told him how special this seemed to me (it resonates with our vision at *Marginalia* to integrate knowledge and share it with the world, so we're delighted he's joined us as a contributing editor for science) and then asked him, in light of his work, how he saw himself, whether as science writer, scientist, or something else. From there, he took me on an incredible journey into his illuminating vision of science

and humanity, which I'm delighted to share with you. A more detailed discussion of *Beyond Weird* and Ball's interpretation of quantum physics can be found on MRB TV, our new [YouTube Channel](#).

SAMUEL LONCAR

First of all, let me say that is a delight and honor for me to be speaking with you! So, thank you.

PHILIP BALL

Oh, yes, thank you for asking me! It's a pleasure.

SAMUEL LONCAR

After reading a few of your books, and particularly *Beyond Weird*, it struck me that you seem like a lovely image of what an ideal scientist might be, so I was curious about your title, "science writer." It seems you have made, and are making, significant contributions to different areas of science and history, that you are engaged in primary research, but that you also bring to bear a remarkable depth of context to whatever issue you write about, drawing the best scholarship, not just in natural science, but in history or religion, into a single story.

So, I'd love to hear how you think about your identity in connection to the title "scientist" and "writer," since you seem to suggest that they are, ideally, one complete whole. And it's that unity of rigorous research and story-telling that I find so beautiful and striking.

PHILIP BALL

Thank you very much. First of all, that was a very gracious way of putting it! My work has not been put to me in quite that way before.

I think of myself as a writer, not even as a science writer. It always seems a little bit odd to me when I see reviews of my book saying, "The history of China by science writer Philip Ball." I think, "Okay, well, that's fine. If you want to think of it that way."

What I've tended to do—what I've been lucky enough to do—is to be able to follow my interest, and I managed to get myself into a situation where I can make a living doing that. It is an incredible privilege to be able to come across an interest and pursue it.

I came out of the sciences. I did a Ph.D. in physics, and I worked for the scientific journal *Nature* for years and years. But it became increasingly clear to me as I started writing more and more that actually I wanted to break out of the genre of science writing. And I think one thing that frustrates me about some science writing is that it really does seem to have a kind of self-imposed boundary that it mustn't stray outside of. I think scientists and some science writers—but I think particularly scientists—are very often rigorous in maintaining those boundaries and saying, “Well, I’m just a physicist. I’m not going to comment on this or that.”

As a writer, if I want to write about a topic, like invisibility, well, it’s certainly possible to write about that from a scientific point of view: What do we know about what it would require, in terms of the optics, to make something invisible? What technologies do we have to do that? But the topic of invisibility is not just about that. The subject as a whole is a *mythological* subject.

Invisibility goes back to myth. It appears a lot in the history of magic. And, to my mind, it brought up issues like the question of ghosts and spirits and apparitions and spiritualism during the nineteenth century. If I’m going to write about that topic, then not only can I include those aspects, but I have an obligation to include those aspects. Otherwise, I haven’t talked about the topic.

In almost any topic one talks about, even to some extent in quantum mechanics, there will be issues that come up that will move outside of the science. But there’s a risk in doing that, because it means that I have to venture into areas for which I have no training. And I’ve had to do that a lot in terms of history and to some degree in terms of philosophy and sociology.

But I think it’s a risk worth taking. It’s a risk worth taking seriously.

I think particularly when topics intersect with things like religion, the history of religion, theology, that those are areas where science writing and scientists have performed extremely badly. What I’ve always tried to do is to find out the best thinking in whatever area I’m researching and to make use of that.

Once I’d left academia, once I no longer had a departmental position, I thought I was leaving scientific research and going into something else. But opportunities have come up that have allowed me to go back into that to some extent. For instance, I’ve got a co-authored paper on an area of astrobiology, which was published last year and received a large amount of media interest, actually. And I just feel very fortunate that my co-authors invited me.

It is very nice that those opportunities still exist, but I have to be realistic. I’m not doing research. What I contribute to a paper like that is different from what it would

be if I were an active researcher. But it's very nice to know that there are some scientists who value what someone from outside can bring: a wider perspective on what the issues might be.

My philosophy in terms of writing is that if I'm lucky enough to be in this position where I can choose a topic and spend two years researching and writing about it, I might as well use that time to learn new things and to go into new areas.

There are writers who return to the same topic again and make that their speciality, and they're known for writing about astrophysics or evolution or something. But for me, it just feels like it's too good an opportunity to waste not to broaden my horizons with every book I write.

SAMUEL LONCAR

It's a wonderfully generous vision you are articulating, and I see your point that you are not any more in institutional academia. So I understand when you say, "I'm not doing research," you mean that you're not an active researcher in the manner of your colleagues with whom you co-wrote these papers. But at the same time, you're talking about the fact that you'll spend two years actively researching a subject.

In that sense, you are a scientist in the literal professional sense: you publish primary science in peer-reviewed journals, and you still serve actively as an editor in primary science. At the same time, you are obviously an accomplished professional writer on your own grounds, independent of your work as a scientist, and as a writer you work in history, music, and the arts as well.

That is different than being a "pure" researcher in the contemporary sense, but not because it's less than such research, but because it's more. Research that goes nowhere, that has no concern for its audience or its impact and assessment, isn't the same thing as scientific knowledge. Primary research that has no regard for the connections it has to everything else we know seems incomplete, like it isn't the fullest sense of true knowledge creation. What you're describing, then, is the completion, you could say, of what research is aiming at: communication and broad impact, where specialists and others can all benefit from your work.

Do you think your vision perhaps integrates our modern idea of a narrow, specialized natural scientist with the older idea of a scientist as a (natural) philosopher, where scientific precision isn't necessarily separated from a broad vision and clear communication?

PHILIP BALL

I can absolutely see your point. I absolutely see the point you're making historically. And I really like your point that the creation of knowledge is different from doing primary research.

They're closely related, but there's another step that has to come in order for that to become general knowledge. And one thing that I do see again and again is big gaps. It does seem to me that there is a lack of integration, even between different areas of science.

So, it is sometimes gratifying when a scientist says, "Oh, I hadn't heard about this other area that you've just written about and how it relates to mine." That's where I hope I can make some contribution in knitting things together. And not just within science, but also with science and the arts and humanities.

The normal conversation that often happens about science and the arts and how they relate is something that frustrates me because that, too, seems incredibly siloed and limited.

So the book I wrote about the cognition of music, for example, aims to correct this. There are plenty of books that talk about what's happening in the brain when we're listening to music, and a lot of them talk about which particular brain areas are activated, and there seems to be this fetishization of the names of the bits of the brain as though that explains what's going on. There are books like that. And then there are books on musicology, which make no connection to the cognitive literature, and books on musical performance.

But what I really want to do (because it's all about the same thing; it's all about how we make sense of music) is to bring those things together to try to talk about the cognitive science within the context of what we actually do with music socially and personally, and why it has the effect it does, and what its importance is in cultural terms.

That is absolutely is the kind of thing I'm aiming to do, and which I feel there is a lack of. So it's wonderful to hear you say that you see there is not just a value in doing that, but that there's an actual name for doing that or that it is part of a tradition.

Though, I hesitate to describe myself as a philosopher or historian because I know that there are people in both those areas who are experts. There's a training that you have to do; there's a way of thinking that that is needed and that scientists often

disregard. They think, “Well, anyone can learn a bit of history.” But there is a real discipline to it, and that’s what I want to take seriously and be humble about. And I ask the people who have that training for help and assistance and advice.

SAMUEL LONCAR

That humility, the recognition that you can only do what you do because of so many colleagues’ great work in diverse fields, captures the spirit of science, which I feel so strongly in your work.

By connecting scientific research that doesn’t get connected, you help us see what the discoveries in science are for. You bring them to life. But no one tells scientists or scholar to do this, and the academic system doesn’t always reward this, even as it needs it. We haven’t yet created an academic Chair, saying: “Here’s the research professor position in the integrative knowledge of culture and art and science.” But that’s what you’re actually doing—integrating knowledge for the public’s benefit! And if actual scientists find it helpful and musicologists and people reading your books, then shouldn’t that be the gold standard of what the term knowledge means?

PHILIP BALL

But I couldn’t do what I do without those specialists providing the primary material.

SAMUEL LONCAR

Absolutely, we need the primary material, but for your process as a writer, that primary research seems like it’s a beginning, not the end. So, you do the primary research of specialized academic articles, which is invaluable, but it isn’t your main goal. Certainly not relative to a book that integrates what we have thought about the subject, in myth, in history, in art, in our imagination, in our full humanity.

And in that sense, your writing process has significance for the general challenge of interpreting science and scholarship to itself and the public. For me, it connects to what we’re aiming to do at *Marginalia*: to help the public and the academy access the best version of what we know as a whole community, while at the same time trying to shape a new, more conscious version of whatever the latest results and discoveries are.

I see your process as an inspiring model for our needs today, a way to help people see the value and beauty of science. Scientific research has to get *re-humanized* by a full integration with the rest of what we know about humans, with what humans know and care about.

We know we tell ourselves stories; we know we evolved into human beings through stories and music and [language](#). In the end, would it be so surprising that knowledge has to somehow make sense to us once again as language, as a kind of story, as a kind of music?

PHILIP BALL

I suppose what occurred to me when you when you were saying that, Samuel, is that my process, certainly for the past several books, probably for some time now, is different.

I sometimes see other writers, particularly science writers, saying, “I’m looking around for a new idea; what should I write about next?” I feel like I’ve been lucky enough not to be in that position because I need something else to happen before I write.

What I need to happen is for me to be thinking about a topic and thinking there’s something here that needs to be said, and then suddenly realizing, “Okay, I can see now that I have something to say about this.”

It’s not that I’m going to talk about this area of science because I think people might be interested. I only want to write a book if I have something that I want to say about the topic that I’m looking at and that I hope will be useful. I can aspire to no more than that.

The book that I’ve just finished is about [minds](#). And you know, there again, it was a topic that came about through some AI research that I was looking into. And I didn’t know what to do with it. I wanted to write an article, but it never quite happened. I was wondering why I never wrote the article when I was visiting Harvard the summer before last, and then I suddenly realized, “Well, that’s because it’s a book! And it’s a book about this and that and that and that.” And all the issues came together. It was no coincidence that it happened at Harvard, because that was where all these people were who were working on these issues, which was fantastic.

The same is true for the book that I’m starting to write now. It came out of that visit too. I was visiting at the Department of Systems Biology at the Harvard Medical School for three months, and I came away with a big set of notes, a big, long document, and I kind of thought, “I don’t know what I’m going to do with this. Is this a paper that I’ll try to write for academic publication or something? I’m not sure.”

And then just a couple of weeks ago, I suddenly thought, “No, fool, it’s a book! That’s why you can’t figure out what to do with it!” And it’s a book about how life

works, how cells actually work. And in many different areas of biology that narrative is changing, so that is the ridiculously ambitious task I've now set myself, but I think I know what I want to say about it.

So perhaps what you're driving at is that it's only when that happens and I realize that I have something that I hope is worth saying and that I hope is going to help the researchers in these different areas bring ideas together—that that's when I will start working on a book rather than a magazine article, which is a very different sort of entity.

Perhaps that is saying the same thing that you're saying: that I'm waiting for that moment when I can see that there's a message. It's not just about trying to explain the science; it's trying to make sense of the various things that are going on.

SAMUEL LONCAR

Right!

And if there's something to be made sense of, and even what we're calling science is part of what you're using to make a higher kind of sense of that, then I think we could say, without any invidious intention, that the part you're playing in the world of writing and science is a distinct, though not separate, function than *mere* research. It is that *towards which* research is ordered, what it hopes to become, where you look at the different areas of knowledge and say, "What's the deeper music here?"

So, how did this way of working lead to *Beyond Weird* and your interpretation of quantum physics? What was the message that led you to get to a point where you thought, "I've got a book." When did you say, "Oh, this is a book"? And why? What are we not understanding about quantum mechanics and the story that led you to think I've got something to say about this?

PHILIP BALL

It was exactly that process. I think that was possibly the book where that process was most explicit in my mind. Although now that I think about it, earlier ones had that same trajectory. But with this one, I had been asked to write articles about different aspects of quantum mechanics. This was about four or five years ago now, when the area of quantum information and quantum computers was starting to take off. So that was one impetus.

But I was writing these articles and suddenly I thought, "Hang on a minute! The story we keep telling—we journalists, we science writers, and often the scientists when they're trying to popularize their work—that story is not the right one." It's

the one we've been telling for decades. *I've* been using for decades: the same old quantum metaphors. And it's wrong, or it's misleading, or is too simplistic, or somewhere along that scale.

And the reason for that, when I started to think about it, is that knowledge has moved on, even in this incredibly difficult, recalcitrant area of science. We've been struggling for decades, for almost a century, to figure out what on earth this theory is trying to tell us about the world.

Since the 1980s and 1990s, we've been able to do experiments that we couldn't do before, experiments that the founders of the field couldn't do. They were only thought experiments then, but we now have the technologies to do them. They've told us things that can advance the way we think about this field and shown us that we need to change the old metaphors and analogies we use.

To be perfectly honest, I concluded only with some reluctance that I needed to write *Beyond Weird*, because there were already a lot of popular books about quantum mechanics. You could very well ask, does the world really need one more? Since mine has come out, there have been half a dozen more, and there will still be more, I'm sure. And it's a very contentious area.

We don't have all the answers. And it's a challenging area to write about because it pushes at the boundaries of language and what language can do, which is something that Niels Bohr famously talked about and recognized. He recognized that the challenges are linguistic ones, to some extent.

SAMUEL LONCAR

Yes, you had an incredible quote in the book from Bohr: "We are suspended in language."

PHILIP BALL

I think that's an example of how it was and is: we are caught in language and have to confront that fact.

For all the mud that is slung at Niels Bohr these days for being a confusing and sometimes inconsistent writer, he had an insight that no one else at that time really had about quantum mechanics. All of these things made it a very challenging project to take on. I felt I had an obligation to do it, because otherwise it's going to continue. I still see that the same old metaphors are recycled. Occasionally, I try to nudge things along and change that record, but it's not going to be an easy thing to do.

I don't think I alone will do it. But I figured, *it's time to try to explain why it is that there is a different story that we can tell about quantum mechanics*. And one of the things that became clear to me quickly was that in order to do that we need to get rid of the way it's normally told.

Certainly, in popular books, the way it's normally told is historically, chronologically. And it's a good story—it's a great story—because it has these great characters, and it came out of nowhere and took everyone by surprise.

Of course, it makes sense to tell it that way. But the problem, as I saw it, was that what's fundamental about quantum mechanics isn't what was first recognized.

In fact, some have tried to make a case that the things that were first recognized about quantum mechanics are perhaps the least important about it. I mean, just the fact of the quantum, the fact that things are quantized, that energy comes in packets. In a sense that is definitely a striking fact about the world that no one anticipated and that deviates from what we're used to. We're used to things changing gradually. But that's more a symptom than anything else. That was a symptom that something in our description of the world was amiss, rather than a fundamental building block of the theory.

I figured I needed to abandon that chronology and to try to dive in at the level of what we now can say about quantum mechanics, what we now do understand about it, and to weave the history into that developing picture.

So that's what I attempted to do with *Beyond Weird*. I felt the book was sort of thrust upon me by this realization: Somehow we've got to change the way we talk about the subject.

SAMUEL LONCAR

And that connects, right, to why you want get beyond the talk of “quantum weirdness”?

PHILIP BALL

I think we often start off from this issue of quantum weirdness.

We say, “Well, you know, in the quantum world of the microscopically small, different rules apply, weird rules, where things can be in two places at once, and so forth.” And that's where we take it. And in fact, close to the beginning of the book, I have a list of, I think, seven or eight popular things that are said about quantum mechanics that are in fact misleading or plain wrong.

For instance, one of the weird things about it is that if you have a quantum particle, it can be in two different states at once, or in two different places at once, which, of course, makes no sense. A teacup can't do that, but a quantum particle can.

So this is one of these common metaphors we use. But fundamentally, I think it's misleading because so often these tropes that we have come down to us trying to say what the world is like, according to quantum mechanics. And the fundamental problem is that quantum mechanics doesn't speak about that, or it doesn't speak about that in any way that is obvious. What it speaks about is our *experience of the world of quantum systems*.

It seemed to me that a crucial thing happened in quantum mechanics when Erwin Schrödinger came up with the idea of a wave function to describe the behavior of quantum particles. Instead of being localized in one point, they seem to be spread out in waves. He came up with this notion of a wave function, but then he had to ask himself, "Well, what does this mathematical entity actually mean? What is it? What's it referring to?"

His first guess was that it's referring to the density of that particle somehow sort of smeared out through space. But then he realized that wasn't quite right. And the physicist Max Born said, No, actually, what it's referring to is probability, the probability that we will find this particle at a certain point in space. So we've got this smeared out wavefunction that goes all through space. And from its magnitude at any position, we can work out what the probability is that if we make a measurement, we will find the particle at that point.

This is the way the story is often told.

Well, that's kind of weird. Quantum mechanics is probabilistic. And that's all true. But really, what Max Born is saying to us, is the wavefunction is speaking to our *experience*. The wavefunction is not telling us anything obvious about what that particle is or where it is or what it is like. The wavefunction is saying, if we make a measurement on it, there is a probability X that you will find it in that position.

This is absolutely what we find. Max Born's interpretation of the wave function fits perfectly with all the experiments. So, if we set up an experiment to create a particular particle and a particular wave function, where we can make measurements on it again and again, we'll find it perhaps here in one experiment, and over here in another experiment. Then we do enough of them so that we collect good statistics, and we find, sure enough, the probabilities overall are exactly what the wavefunction tells us.

The mathematical machinery of quantum mechanics isn't pointing down towards a picture of the world, towards reality, which is what most scientific theories do. It's pointing up, to our experience of it. It's telling us *what will happen if we look*.

When I was trying to put this across in the book, I had a conversation with one of my science-writing colleagues who said, “You need to have a kind of slogan or one-liner to say what’s going on here.” And I thought, “Yeah, I do. But I’m not quite sure what that is!”

I went away and thought about it and realized that what this comes down to is the language we should use to talk about quantum mechanics is not an *IS* language.

It’s not the language about what the world *is* like, what this particle *is*, what its properties *are*, where it *is*, what it *is* doing. The language of quantum mechanics is an *IF* language.

So, quantum mechanics is saying, *if* we do this, *if* we make a measurement on this particle, we will find it in this position with a particular probability. And in this position with another probability. If we make the measurement in this way, we will measure this, but if we make it in another way, we’ll measure something different.

So it is a language of “ifness” rather than “isness.” And what it comes down to is this issue of knowability.

SAMUEL LONCAR

So if quantum physics isn’t telling us about what *is*, but what happens *if* we do things, how does that change what it says about what we can know?

PHILIP BALL

It really seems to be a *theory about what is knowable and what is not*, and about the fact that, weirdly, if I can use that phrase [*both laugh*], we have some choice over what that outcome is, because we have a choice about how we, or whether we, try to measure this property or that property. And if we measure this property, we’ll get some value, but then we can’t necessarily know anything about this other property. If we measure that other property, we can find out about that, but not this one.

So this is where it seems like the theory is somehow subjective, and that the observer can’t be removed from the theory. That’s the way we often talk about it. But when we talk about it that way, it raises the question of whether consciousness is involved.

But what it seems to me to be about fundamentally is *the fact that we can ask more questions about the world than the world has the capacity to answer*. That’s ultimately what quantum mechanics seems to be saying. And it goes against the

grain of science because we're used to asking questions about the world at ever finer scales, at ever finer levels of granularity, and always getting an answer. And quantum mechanics seems to be saying, "You can only do that so far."

The world is saying to us, "I'm not going to have answers to all your questions, not because there's only so much you can find out, but actually because there is no objective answer that can be given to all of those questions at once."

So you have a choice about which questions you can ask. And if you limit yourself to those questions, I can give answers, but I can't answer them all." So that really seems to be what the theory is telling us about the world.

SAMUEL LONCAR

You've taken all of the literature; you've read the stories; you've familiarized yourself with it from the inside, not just as a writer, but as a physicist, which is your original training. And what you've come out and told us is, first of all, the subjective interpretation means—tell me if you think this is fair, Phil—quantum mechanics is ultimately *anthropological* in its significance. It tells us something fundamental about the limits of what we can do and know in the world, about what it means to be human.

That seems to me like such a fundamental thing. We have got to return to the actual question of what it is we *as knowers* are capable of, and what we can really *say* (which are deeply philosophical questions, and they made me think of the *Tao Te Ching* and the limits on language and knowledge somehow implicit in the world itself). And I take it you're saying quantum mechanics gives us a very surprisingly specific picture about certain definite constraints on the human being that look quite different from the common, realist vision of science (science just tells us what's *out there*, independent of us as knowers) that most of us have.

Is that fair? Do you think that's an overstatement?

PHILIP BALL

I think that is fair. And I think that's what we still struggle with. That's what many physicists still struggle with.

I should say that the picture I've given is the one that we can realistically say that we have about quantum mechanics at the moment. Many, perhaps most physicists still cling to the idea—and they may turn out to be right—that there has to be an objective reality underneath all this that we can get to, that things are a certain way. There has to be something like that. This is the so-called realist perspective. Quantum mechanics doesn't give us that.

But there's a real struggle to try to find a way to wring that out of quantum mechanics, and I understand that impulse. And it may turn out that if we can see beyond quantum mechanics (there's no indication that we will yet), perhaps we will return to a realist picture where there's an absolutely well-defined world underneath everything that has no dependence on how we look at it.

That's the scientific model, and that's what people are looking for. But in my book, what I wanted to say is that at this stage, with all the knowledge that we have, in all the experiments that we have done, the world seems to be telling us that it's not like that. And certainly quantum mechanics as a theory is not like that. It's saying there is a limit, and it's this fact that it's not a limit on how much about the world we can know. It's a limit on what the information content of the world is. It is this curious thing, but for some reason, we are capable of asking more questions than the world holds answers for.

I certainly don't want to get into the muddy area of confusing quantum mechanics with consciousness. But there are resonances in that area, too: whether in trying to understand consciousness, we're actually looking to ask questions that the world won't actually turn out to hold clear answers for, and we have to make decisions about what it is that we want an answer to and accept not just ignorance but some unknowability or some undecidability about other areas.

When you were talking about the yin and yang, for instance, that was certainly the perspective that Niels Bohr took. He had this idea of complementarity. You have to make a choice. You can know one thing or the other. His idea of complementarity is that there are many ways in which there are two systems of knowledge that are incompatible with one another, and we just have to live with that. We have to make a choice about whether we're going to look at one or the other.

To some people—and I think even to me, actually—this was a bit vague. Bohr was almost defeatist about this, but I think that was his attempt to articulate these limits. And I think now we can do better than Bohr's capitulation to complementarity, to just sort of saying, "Oh, we have to accept these two incompatible things." I think what we really need to accept is just this unknowability about some aspects of the world. So I think there are resonances.

It's interesting to me that some of the people coming back to the questions of the foundations of quantum mechanics are looking again at the phenomenologists from the early twentieth century and the idea that perhaps where we need to start is from ourselves and from our experience of the world. And in a way, the weird thing about quantum mechanics as a theory is that it seems to insist that that's where we start from, from what we can measure, what we can know.

SAMUEL LONCAR

I think what you've done is shown that what we call science has given a compelling scientific answer to a question that scientists themselves have called philosophical.

You bring it out as an imminent conclusion of 100 years of physics. You stress that don't know what terms like "state" mean. We don't know what terms like "measurement" mean. We don't know what terms like "locality" really mean.

Beyond Weird changes a person's ability to say, "I always know where science ends and where philosophy starts." And the result is, apparently, a different way of thinking—not just about quantum mechanics—but about science. Something about the story science tells itself (maybe that it's completely separate from all philosophy?) isn't quite right. And it seems you're telling us science itself now says so.

PHILIP BALL

It says so in a very particular way. Another story that is often told about quantum mechanics is one that generalizes everything it's about to almost the rest of science. And, in fact, Bohr was guilty of this. He wanted to apply complementarity to psychology and sociology, and I think he got carried away with the idea. So science is able to be quite precise about where it is that our view of the world fails, quite precise about where it is wrong. Most of the time, it works fine. But when we really get down to it, at the most fundamental level, what is the description of the world that science provides us with?

That is where things become problematic. Maybe it's important to maintain that distinction. Certainly (and I don't think you're suggesting this), it doesn't throw the process of science into doubt in the way that it's generally practiced and as a practical tool, but it does seem to indicate that the philosophical underpinnings of science are more unstable than is recognized.

That speaks to this notion of *isness* and *ifness*. I was asked to talk at a meeting on the fundamentals of quantum mechanics shortly after I had crystallized that view but before the book was published, and I thought, "My God, am I going to risk putting this out in front of all these people?" And maybe they were being polite, but no one dismantled what I was saying. So I thought, Well, okay, maybe that's saying something.

SAMUEL LONCAR

So, quantum physics, perhaps we could say, at least nibbles at the boundaries of a strict science-philosophy distinction, without settling anything?

PHILIP BALL

In terms of this divide of science-philosophy, I think that the typical response that scientists will give is that they regard philosophical questions as ones that cannot be answered empirically. You can't come up with an experiment that will decide a philosophical question. That almost defines for them what a philosophical question is. And so I think that's why they feel either uncomfortable in going into areas that seem to them to be philosophical, or actually actively hostile about doing that, because it seems to them that philosophy is a different kind of area of knowledge that science doesn't speak to, shouldn't speak to, and that is kind of inferior because there isn't a way that you can adjudicate the questions it raises. I'm putting it crudely, but I'm sure you'll have come across scientists who take that view of philosophy.

So I think that's why the boundary exists. It's why passions run so high in areas like quantum mechanics, the interpretation of quantum mechanics, and in areas like the understanding of consciousness, because both of those topics have what seemed to be irreducibly philosophical aspects to them. And empirical science alone won't be able to answer those questions for you. This is the real problem with the arguments about the interpretation of quantum mechanics: that all of them are constrained by the fact that, ultimately, they have to deliver the same thing in terms of what the observable world is. If they don't, then they're not good interpretations. There's something wrong with them if they conflict with what we see. But if their whole aim is to be consistent with what we see, where is the gap to split them apart and to distinguish between them and to adjudicate between them. This is what makes scientists uncomfortable, and what makes passions run so high when we talk about it.

There are interpretations of quantum mechanics, if you call them that, that do suggest experimental tests. So, the idea is that somehow the collapse of the wavefunction, as it's called, is an objective physical process that you can observe, that can be used to pull out empirical questions which you can, in principle, address—though it's incredibly hard to do that. But that's rare, you know. Mostly they don't do that. That's certainly why the foundations of quantum mechanics are one area where philosophers have made significant contributions to the scientific debate, and where actually the scientists who are really serious and involved in the foundations of quantum mechanics, they don't have that prejudice against philosophy.

They actually recognize that philosophy is needed, and philosophers are needed, to help them with this. And I think the same is true actually in studies of consciousness. That too is an area where philosophers have made important contributions and where there's still not enough dialogue between them and

neuroscientists. But it's certainly happening; it's starting to happen. And I think there's a recognition there, too, that there has to be that dialogue; there has to be some meeting, and that scientists need philosophical help to actually just find some way of progressing.

I think the same may be starting to happen, perhaps, in areas of high-energy physics, at the extreme areas where it's beyond empirical testing; and also in areas of cosmology, where there is no obvious way of empirically testing. So, at those frontiers, there are people in science who don't want to impose those boundaries. That seems to be the fundamental problem: it seems to a lot of scientists to violate the empirical basis of science, which, as you have intimated, has a philosophy embedded in it. Of course, it does. And that's what makes the scientists uncomfortable: they have to recognize that.

SAMUEL LONCAR

Maybe a one idea of philosopher, then, is just a scientist under the aspect of their full humanity in the mode of conscious integration, and maybe a scientist is just a philosopher under the aspect of a focused, detailed specialist, who, as they specialize, has to temporarily ignore the larger horizon in which their work fits.

If that were the case, scientists could realize that philosophy (in this broad sense) is a mode of what they do professionally, even if they don't focus on it in most of their technical work. They don't specialize in integration, the way you seem to be a specialist in integration. But that integration into a beautiful whole is what we all need, and what you're doing. But I don't want to put this label on you! I'm just thinking about how the borders we establish can hinder, as well as help, us.

PHILIP BALL

I feel like I've spent most of my working life escaping from any job title or job description or job, even. I don't want a label, whether it's "philosopher" or "science writer" or anything else. But I'm defined by what I do in the end, of course, and you've helped me, Samuel, to see what it is that I do when I'm reading about science. The destination is different to the scientists who are doing the research. Where I'm heading is different.

One of the things I've been looking at that is going to feed into this next book, to jump into a completely different area, is how genes are regulated in cells. And the scientists who are trying to understand that—the cell biologists—they want to know: how does that happen? Because then we can understand how cells get their particular state and how genes are switched on and off. And that's clearly a fundamental thing about how life works. So they're zeroing in on that question. The end question is important, we know. What we wanted to find out is how it happens,

and so we were looking in more and more detail at the molecules and how that happens.

What I see happening in that area, to take one example in particular, is that I'm working in the other direction and thinking: "Okay, you're finding out what is actually happening amongst the molecules, and it's not what we thought was happening. It's actually something that is astonishingly different from what we thought was happening.

It makes no sense in terms of the picture that we have developed of how cells work, and you're scrambling around to find metaphors that in themselves don't quite make sense. For instance, somehow there's this kind of vague blob of all these different molecules that magically condenses and somehow cells get regulated out of that." What I'm doing is thinking: What's the destination of that thought?

It's not about how genes regulate. Their work is actually leading to a different story of the logic of how cells work, a different story from the one we've been telling ourselves for decades—in fact, ever since Crick and Watson. And I suppose I'm often thinking, "Why are you not also looking at that destination? Why is that not a question for you?" It seems to be the burning question for me. So maybe that's what is different about my work.

Maybe that's the integrationist impulse: to be trying to look back up from the details, rather than down into the details of this process that we know is important. And so we don't think about those high-level questions. We're just thinking about the details. And in a sense, that's what I felt I was trying to do with the book on quantum mechanics: to go down into those details and then find a different route out, to end up in a different destination that hopefully broadens our horizons or tells you something new about what it is that was going on down there. I don't know if that articulates it very well.

SAMUEL LONCAR

I think that articulates it beautifully, thanks so much, Phil!

PHILIP BALL

Thank you, Samuel, it was a pleasure.

*You can watch more of Samuel and Phil's conversation, getting into the details about quantum physics, on [MRB TV](#). This interview was supported by a donation from the Templeton World Charity Foundation, and is the first installment in our *For the Life of Science* series (*Science for Life* for short).*

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