Dave

Thanks for agreeing to speak to us. Yeah, we're here to talk about Quantum and I suppose the initial question is, as far as I'm concerned, you're part of the Centre for Quantum Science and Engineering. In terms of the research you actually do, what do you actually mean by quantum?

Richard

Okay, so what is quantum? Quantum is the study or use of very, very small objects, which most people will be familiar with as atoms and electrons, which form part of atoms. And when we have objects that are so small on that scale, the way they behave is described by something called quantum theory. And this has interesting and sometimes difficult to conceptualize results such as the particles, electrons, connectors with the particle or wave, depending on what it is we're looking to study or do with them.

Dave

So to a layperson, then, does quantum in that sense mean very small or is that too simplistic?

Richard

It does mean very small. And the reason why it's very small is that there is a fundamental constant called Planck's constant, which effectively describes the size of objects at which we start to see quantum behaviour emerging. And it just so happens that in the world we live in, in our universe, this constant means that things have to be on the nanometer size. You know, tens of nanometers typically before we start to see and observe quantum behaviour. It doesn't mean that we're not quantum objects but at larger scales, that quantum behaviour, such as the wave behaviour of particles, is kind of hidden away. So, yes, it does mean very small, but there's always some situations where bigger objects may display quantum behaviour under very special circumstances.

Dave

From my background reading, a lot of the excitement is around quantum computing, is that right? And what is quantum computing essentially?

Richard

Absolutely right. So there's been a lot of research and interest in quantum in the last decade, maybe 15 years, where something called Quantum 2.0 has emerged. And what Quantum 2.0 is moving towards is starting to use some of these strange properties which we find in quantum mechanics, such as entanglement, such as wave particle duality, etc., in a way which is more than what we've used previously. So your computer, which everyone has on a desk or in a phone, still relies on some quantum properties, such as electrons being able to tunnel through what are called barriers. Quantum 2.0 is doing one step beyond that. It's taking this dual properties of materials - of electrons, for example - and using that nature itself to manipulate information in a way which we can't do using standard computing.

Dave

In the video that you made for us, we talk about "Qubits." Could you tell us a bit more about those?

Richard

Yeah, so qubits are at the heart of quantum computing, as it were, and the analog with a classical computer - a computer on your desk that I've talked about - is that in that we operate using bits. So bits which are either zero or one, and we create logical gates and things out of those bits, but we only have those two options available - something is one or zero. In the quantum world, something can be one or zero - or a combination of those - at the same time. So what that means is that if we have a property which we're describing, it can take all the values between zero and one at the same time, whilst it's in its quantum state, we can operate on all of those values at the same time and then get the result out at the end. So what it enables us to do is address problems which we couldn't normally do using standard computing because we'd have to run the program for so long to cover all of the different variables and opportunities that the system could exhibit that we'd never get to a solution. So quantum computing lets us take this superposition of a property which gives us these qubits and start applying them to look at very complex situations.

Dave

It's interesting because obviously, as you said, traditional computing is based on ones and zeros. If there are now more states in the qubits than just those binary states, does that mean computer technicians - not necessarily programmers, I guess, at this stage – but computer technicians need to rethink the way they build computers?

Richard

Yeah, absolutely. So, a quantum computer isn't built like your standard computer. And one of the key challenges in quantum mechanics is that if we interfere with the quantum system, we effectively lose all the information and we no longer have this entangled behaviour. So that, at the moment, is restricting us to working on systems which effectively are isolated from the outside environment. There's many different approaches people are trying to take to make a quantum computer. Many of them involve using ultra low temperatures. So things like millikelvins - just a few millikelvin above absolute zero because at those temperatures, there's no thermal noise around which can decohere these states. There are some room temperature solutions we're looking at as well. Many of those involve photonics. But again, we can't interfere with the quantum object. That means look at it, it means measure it whilst it's doing these operations, and measuring it doesn't just mean us, you know, physically measuring something, it means interacting with its environment, and losing that information. It's also one of the strengths in cryptography, which is an example that many people have used early on, that if someone does interfere with the system, you know about it. And so you can tell if anyone has eavesdropped on your communication.

Dave

So, from what you're saying then, we're not there yet in terms of being able to point and say there's a quantum computer that we've made?

Richard

Well, we're getting there. So the question is, at what point does a quantum computer we've built do things a classical computer can't do? And in some very very specific cases, we have a quantum computer which can do interesting things, but it's not at the scale yet where we have what some people call quantum supremacy. So there are companies like IBM, who have a quantum computer which they've opened up to the public, to researchers, to access and use, and start playing with, to try and understand how you might engage, develop coding for quantum computing. So we have the prototypes there; they are showing some capability which we don't see in classical computers, but we're still not more powerful than a current supercomputer - but ultimately a quantum computer is going to be doing different things to what a supercomputer would do anyway.

Dave

Yeah, it's interesting to just explore that point, because as I understand it, the timeline of computing since the sixties or whenever – we had the massive mainframes, to now when you know you've got a computer in your phone, on your wrist or something. The line seems to have been speed of calculation, almost - obviously storage as well - we can store vastly more amounts of data, but the calculations have been quick. And I suppose as a layperson, thinking ahead, is it just a question of we will do things quicker? But you said we might actually do different things?

Richard

Yeah. There are some problems that we were never going to be able to solve with a classical computer, no matter how powerful it is. And some of these have real relevance in terms of security and finance, but some of them can be exemplified in things like the travelling salesman problem. So if you're trying to work out the best route for your salesman to travel across, you know, the UK to visit various sites, which way should they go, which is the most efficient way? Because of a vast number of different routes they could take it's impossible for a classical computer to ever work out this optimal route because we have to do it all effectively at the same time. And the superposition properties which we get from quantum computing allows us to address those problems. So that's a new type of problem we can solve using quantum computing, which is totally unavailable to classical computers and the simplest form of these are things like free body problems where free bodies are all dependent on each other in how they move. That's a very, very simple thing to do on a piece of paper, but incredibly complex to try and ever solve.

Dave

Is there anything specific that we can say we do here better than anywhere else or the cutting edge compared to other institutions?

Richard

One of the key problems we're facing, I think, in developing all technologies is the materials which we build them out of. Everything ultimately is built out of a material. And when we come to making quantum computers, but also other quantum technologies, the materials effectively limit what we're able to do. So here at Manchester we're internationally renowned for our materials research and some very, if you like, "non-quantum" properties of materials are actually vital for creating and enabling quantum technologies to work better. So one example is, earlier on I mentioned qubits may operate at very low temperatures. They need to be fairly isolated from their environment. Well, if we can make better materials, with better thermal properties, then when we put our quantum objects in the middle of those, they'll perform even better. So there's lots of associated and aligned research which is vital for us to get quantum mechanics to quantum physics to work in the middle. And in Manchester we have capability and skills on the materials side, but also we have the "pull" end of it as well. So we have computer scientists who actually were fundamental in developing our current computing technology – Manchester's well-known for that - who will be helping us as we develop these quantum computers in the future: how we're going to apply them, how we're going to improve them, what comes next. So we're able to have both the materials, you know, the physics in the middle, and then also more the application engineering side, all together in one site. And that's not something we should be shy of celebrating.

Dave

Absolutely. And I noticed, as well, from my brief research, that Richard Winpenny from the School Chemistry is involved as well. So it's very much a cross discipline function…

Richard

Absolutely. So, our Chemistry colleagues have been doing, you know, quantum chemistry for centuries. I mean, when you synthesize a new complex, you're bringing together atoms, using electrons to control how they interact and bond. And actually they are mini-quantum systems and in particular, some of the materials and molecules they make are able to control something called spin, which is a quantum property that electrons have and so if you like, they can make chemical qubits. And another approach is to see how we can couple these chemical qubits together in arrays to try and make quantum computers that way. Now that's another way of approaching the quantum computing side, but the fundamental studies they've done on those molecules over the decades are actually informing us on how our qubits we make in other materials should perform, should behave, should operate. So we're learning a lot from our chemistry colleagues and applying that work into the work we're doing in quantum.

Dave

What kind of real world examples – again, as someone who is not a scientist, not an engineer or anything like that – what kind of real world examples might we be looking at in terms of what quantum computing can give us?

Richard

There's many areas of application of quantum computing. Some of them are in, you know, the traveling salesman-type problems, optimization problems. Some of them are in security, making sure that your bank data and your communications are secure, and others are in the design of very complex systems. And some of those complex systems are going to be drugs. And if we're looking for personalized medicine, then in the future it would be great if someone has a diagnosis of some sort of illness, and we can take information about that person and that illness, combine it together and design a bespoke drug which targets exactly the need to help realise a cure or treatment for that individual. We can't do that at the moment. Personalized medicine is far too costly to roll out in that way. And also, some of the drugs we're developing – simply trying to synthesize those and model what you would need to try and synthesize them are beyond our current capabilities in computing. So those are the medical, if you like, examples as well.

Thinking about quantum mechanics. One of the things which is really good about it is that it's really good for engaging, you know, children and teenagers and thinking about the world around them because it asks the non-obvious questions. You can think how can a particle be in two places at the same time? And what do we mean when we say that, and what are the implications of how that might in the future be used? And we can talk about all these strange and weird things which go on in the world, and then bring it back and apply it to "and this is why we're learning this particular topic, because this is where it can lead you". So I think there are some great outreach examples we can do. And we go to, you know, science exhibitions of our scaled-up experiments and just try to give people a flavour of what we're doing on the atomic scale using larger objects. But of course, we can't do quantum mechanics using ping pong balls because they're too large; they're not quantum objects.