Episode 37, Quantum Shave and a Haircut

Dramatis personae:
- Ben Tippett
- Omair Taibah
- Katherine Brown
- ComicBookGirl19

The Titanium Physicists Podcast
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Ben: Oh, hello old friend, good to see you. Let's talk about this word fascination. It describes and unquenchable urge, which compels our hearts to quest, and be captivated. As long as there are elegant explanations to complicated phenomena, science will never loose its romance. Over the years, I've travelled the world, indulging in my fascination with physics, and now I find that a new hunger has woken within me, a fiery need to share these great ideas, with the people around me. So, I've assembled a team of some of the greatest, most lucid, most creative minds, I've encountered in my travels. And I call them, my Titanium Physicists. You're listening to the Titanium Physicist podcast, and I'm Ben Tippett. And now… *allez physique*!

01:11
[Intro song; *Tell Balgeary, Balgury Is Dead* by Ted Leo and the Pharmacists]

01:47
Ben: In classical computation, there are problems which are described as hard. There are problems which require exponentially more time to solve, the more complicated the problem starts out as. So, they are usually problems which require you, or the computer, to look at every single possibility so that you can compare their outcomes. My favorite such problem is called the travelling salesmen problem. So imagine you have a salesman, and he has several cities he need to visit. He doesn't know which order he needs to visit the cities, in order to make the shortest possible travel time. So, if there are three cities, there are six possible order you can visit the cities in; so you have to calculate the travel time for six different routes and then compare them to see which is the shortest. But, if there are four cities instead of three, there becomes 24 different order you can visit the cities in. And if there are five cities, there are a 120 different orders you can visit the cities in. So, computation time required to find a solution is enormous because you need to do one calculation at a time. Now, there is a type of computer which has the capacity to do all of the calculations at once. And it does so, by harnessing the weird power of the laws of quantum mechanics. These quantum computers might end up giving us, a way to solve *some* of the hard computational problems in efficient amounts of time.

Today, we are going to be talking about the subtlest and nerdiest of machines, the quantum computer. Now, speaking of things both nerdy and subtle, there is a lady on the internet, who has made a name for herself for her insightful and entertaining reviews of nerdy movies and books and stuff. She's the empress of geeks, she has her own YouTube channel, with hundreds of thousands of subscribers. She has cool pink hair, and a boxy robot friend. You can find a link to her videos on our website; it's ComicBookGirl19! Welcome to the show 19!

3:36
ComicBookGirl19: Hello!

Ben: Okay, 19, for you today, I've assembled two fantastic titanium physicists. Arise, Dr. Kathrine Brown!

Katherine: Hello!

Ben: Dr. Katherine got her PhD from the University of Leeds, and has just finished a postdoc from Louisiana State University. Now arise Omair Taibah!

Omair: Pi peep, Pi peep!

Ben: Omair got a degree in Electrical Engineering and Physics from King Fahd University of Petroleum and Minerals in Saudi Arabia. He's currently applying to graduate school and we met, when he sent me an email asking to do a show on this very topic.

4:08
Ben: Alright everybody, we're going to be talking about quantum computers! So, to talk about quantum computers, we need to start by talking about how quantum mechanics means that objects acts in different ways than we're used to. Omair, why don't you start by telling us about the double slit experiment?

Omair: So, let's imagine we have a cannon ball shooter, and we have one slit in front of it, and we shoot the balls through that slit. The other side of the slit, we can imagine a pattern, which is basically just straight ahead from it. Nothing will change the trajectory of the cannon balls. But now, let's imagine we have a box filled with water, and we have like a barrier with one slit, and right after that, two slits. So there are two barriers and when we make a wave from one end, the wave goes through one barrier and one slit, and it goes in a certain pattern.

ComicBookGirl19: Uh-huh.

Omair: Let's imagine, now that we have two slits. Each wave will go through one slit, and then on the other side of the barrier with two slits, we'll have a certain pattern that goes up and down, up and down, on the surface of the other end of the box.

ComicBookGirl19: Okay.

Omair: So, what happens is, in the cannon ball, we… we shoot objects; in water, we make waves. Now, we know that light is some type of a wave, and if we do the same experiment with two slits, it has a pattern similar to that made with water.

ComicBookGirl19: Okay, I'm with you.

Omair: So, now, let's do it with electrons. There was a time when we though they are objects, like balls. So, if we shoot then towards those two slits, lo and behold, we find, a pattern similar to wave. So, this made us think about electrons differently. They possess some type of a wave characteristic.

ComicBookGirl19: Okay.

6:06

Omair: So, if we cover one of the slits, so it's one slit, we find the pattern goes completely like the one we had when we shoot cannon balls. So this experiment tells us two things, the dual nature of electrons, it's an object and a wave at the same time; and the other thing that it tells us is that there is a superposition that the electron actually passes through both slits at the same time.

6:35
Ben: Right. So, the idea is that, like, if you take water, just regular wavy waves; and you put them through a double slit, and have a wall behind it, the waves will interfere with each other, they'll hit the wall with different phases depending on where along the wall you are, and so sometimes the wave will be really high and sometimes the wave would be really low. And, essentially, if you take an electron gun, and you shoot it at a wall with two slits in it; if you look one at time, the one electron will come in with a wave, but the one electron might come on really high up the wall, or right in the middle. And so if you shot a whole bunch of electrons through, the sum of electrons will end up interfering with each other and you'll see these fringes, so it'll look just like an interference pattern on the back wall. And the deal is, you say, okay, maybe one electron is interfering with another, the way two water waves interfere with each other.

ComicBookGirl19: Okay.

Ben: So the deal is, if you cover up one slit, if you shoot one electron, you'll see it travel essentially along a straight line. But if you open two slits it can pass through, what happens is, the single electron will end up somewhere else on the wall. It won't follow a straight line, instead it will end up in one of the fringes. It will just kind of show up in the middle or way up high or something. So, the question is, what has deflected this electron? And the answer is, somehow the electron splits into two pieces, one of the piece goes through the upper hole and the other piece goes through the lower hole and then they recombine on the back wall; and the location they'll end up recombining is defined by these interference fringes.

8:02
ComicBookGirl19: Okay, so it slits into two pieces, right? So these two pieces, they come back together on the back wall? Are they like magnetized back together? How does that work?

08:13
Katherine: It's important to note that the electron doesn't split in half and one half go through one slit and the other half go through other slit. The way we think of it, and it's not intuitive and it won't be, is the whole electron is going through both slits at once.

Omair: Yes.

ComicBookGirl19: Okay.

Katherine: If you do an experiment to begin looking at it; if you put a little detector at each slit to work out which slit it's going through; and you begin firing, you fire a single electron, you wait a while, you fire another single electron, you'll find your distribution have a pile of the electrons opposite one slit and a pile of electrons opposite another slit. So, if you observe which one it's going through, it behaves exactly like you're firing a cannon ball through two very big slits. There really isn't an intuitive answer, I'm afraid.

ComicBookGirl19: That's what I've been hearing. I was told about the quantum computer over dinner one night, and, I guess I should just tell you guys what I know about it. Which isn't very much, because I really appreciate physics, and especially quantum physics, but it just always goes over my head. So, what I heard was, regular computers were binary and they only have ones and zeros, there's only two different things. Whereas, I heard a quantum computer works on 32 different levels, instead of just two? Like a binary computer? And I also heard that it was made in a company in Canada and that they just started building parts and seeing what works. They didn't know how they were doing it, they just were like, oh well… let's see if it works. And apparently they built it, and it works, but they don't really know how it works.

9:50
Ben: Umm…yeah, there are some things you got right 19, and some things that, eh, doesn't quite line up.

ComicBookGirl19: Okay.

Ben: So the first thing you said was that the difference between a quantum computer and a regular computer is that, in regular computers, they have bits, right? All the information is stored as 0's and 1's. And in quantum computers, things are stored in these kind of quantum packets, called qubits. Quantum bits. And the thing is, these qubits obey the laws of quantum mechanics. Specifically, they obey the law of superposition.

10:23
Omair: In qubits, remember the analogy of Schrödinger's cat?

Katherine: So we've got a cat; and we've locked him in a box; and we can't observe anything in the box. And also in the box, there's a particle so we've for a quantum system. And what we have is, after say 10 minutes in the box, the particle has exactly 50% chance to decay. So, as far as we know, the particle is in a superposition of decayed and not decayed. It's both at the same time. Until we observe it, it's impossible to say if it's decayed or not. It's somewhere between decayed and not decayed. Also in the box is a vat of poison, and if the particle decays, it hits the vat of poison, released the poison and kills the cat. If it's not decayed, the poison's fine, still locked in its little vat, and the cat's alive. So, what you've created here is kind of a large scale quantum superposition. You've created this cat that's equally alive and dead.

Ben: So the idea here is that, so if we're going to talk about qubits, all things in quantum mechanics are kind of described in terms of certainties. They're described… when we're not observing the system; the system acts like all of these possibilities are essentially happening. It's kind of like when we're talking about an electron going through both slits at once; there were two possibilities: the electron goes through the top slit and the electron goes through the bottom slit. And if we can't tell where the electron is in the intermediate time, technically, the two different possibilities evolve independently of one another. Uh, as if they were both the only one kind of existing, right? So the electron possibility that goes through the top slit, goes through the top list; the electron possibility that goes through the bottom slit, goes through the bottom slit. And then when it hits the back wall, those two kind of interact. So, in quantum mechanics the deal is, we have these qubits and one of them is 0, and the other is 1; and we can evolve the system independently of one another, instead of having to do each calculation, a set of calculation with the starting bit being 0, and a set of different calculation with the bit being 1, we can treat the system like it's both and do them both at the same time.

ComicBookGirl19: Okay. So the quantum computer, essentially, you're creating two different realities?

Ben: Yeah.

ComicBookGirl19: At the same time?

Ben: Well for every different qubit, there are two different realities.

ComicBookGirl19: Okay.

Omair: So, if we have two qubits, that's four realities, basically. If we three, that's eight different realities that we are calculating at the same time.

12:53
ComicBookGirl19: Okay. So, how many qubits are in a quantum computer?

Ben: Ha-ha! That's an engineering question.

Katherine: I think it's important to make clear, if you imagine your qubit is in either 0 or 1, although you're in superposition of 0 and 1, so 50% 0 and 50% 1, you're never in half, you're always in 50% 0 and 50% 1. I know that's really counterintuitive example, but you're never in some number between 0 and 1, you're always in some probability being 0 and some probability being 1. And you only have the two states, you don't have… the things in between don't really exist. It's very discrete.

Ben: It's kind of like, imagine you had a friend, who was very cowardly, and you know that he was kind of a subtle thinker. And so, you asked him whether he was going to vote for republicans or democrats. So in his head he might say, well the republicans have this advantage and the democrats have this advantage, and they would weigh the two options. And if you could rip open his head, it would say 30% republican and 70% democrat. But, if you ever asked him his opinion, are you going to vote republican or democrat, he'll never say 70% democrat, 30% republican; he'll ways say democrat, democrat, democrat, democrat, republican. So the only way you could gauge he's 75% democrat is that you just have to ask him over and over and over. I mean you have to let enough time go by, for him to go back to his, you know, some state where it's mixed; and them you ask him, and it's always going to be one or the other; but if you ask him enough times, if you do enough trials, you can get a sense of what the statistical layout is like.

ComicBookGirl19: Okay, okay. I understand. That makes sense.

Katherine: I know it's a bit early to be answering this question but… to how many qubits make a quantum computer, and I think it's a bit of a debatable question at the moment. D-Wave, the Canadian firm, have 514 I believe, roughly quantum things. Its might be slightly different from that, but around 514. And, they can solve at least one problem, but their quantum computer is not a fully generalized quantum computer, or at least at the moment, we don't believe it is. So you can't solve all these problems people want to solve, on a quantum computer, on this D-Wave machine. For a fully generalized quantum computer, that can solve any quantum algorithm, the best people have is somewhere between about… at least I know they've had 10 and they might be on 15 now… and they've used it, I believe, to factor 21, but they were cheating. So, they were cheating because it's easier to factor something when you know the answer; which sounds really obvious but you can do a simpler calculation if you know the answer, and they used the fact that they knew the answer to do a simpler calculation. And, another paper demonstrated actually, using this cheating technique you can factor using coin toss. But, at the same time they are showing you can do all these gates, and they do have a universal machine, even if it's too small to run particularly useful algorithms.

15:50
Ben: So the deal is that when you want to make a quantum computer, there are a variety of techniques that you can use to build a quantum computer. Essentially, when you want to build a quantum computer, you need to take advantage of some quantum aspect of something you can engineer. Quantum computing is kind of like you're doing experiments with Schrödinger's cats. If you observe the system, your cat goes from being 50% alive – 50% dead to either being 100% alive or 100% dead; you collapse the wave function. So, on the one hand, if you're interacting with the system too much, you'll interfere with the quantum superposition; all of the different possibilities won't evolve the way you're expecting them to, if you pole the system too much. So it's fairly fragile. But on the other hand, you need to interact with the system a little bit, because, if you don't interact with the system, then you're not doing really any computation. And in quantum computation what you're doing is you have all these qubits, and you're kind of evolving them in an appropriate way, to do a computation. And, so you need to manipulate the system without poking it too hard. Though, it's a very fragile problem actually, when you're poking too hard and you interfere with the system it's called de-coherence.

ComicBookGirl19: Well, it's it like… like I said I was told that, the people who built the computer, that supposedly works, they don't really know how to explain it exactly. They don't even know exactly how it works. Is that… is that a true statement?

Katherine: They aren't telling the public how it works; but certainly if you buy one of the machines, it comes with full circuit diagrams about what it's supposed to do. Two have been sold. One was sold to Lockheed Martin and is currently at USC. Umm, USC have done some work characterizing it and at the moment, they say that it's probably operating on a quantum level, but they're not convinced by the idea that it actually gives the speed up. So, they're not convinced that it's actually better than your laptop. Actually they were comparing it to algorithms run on your laptop so we're not even talking compared to a super computer. And the other one was bought by NASA and Google, and that's more recent so other people haven't had the chance to work on it yet.

17:58
ComicBookGirl19: So we don't even know, for sure, if the quantum computer works? Or is it an actual quantum computer yet?

Katherine: No, we don't. I would imagine the people at D-Wave have a very good idea of what their machine is doing. Part of the difficulty is, and when we talk about quantum computing with you, we talk about a model of quantum computing that's very much like your classical computers. So, in your classical computer, you imagine your bits of 0 and 1, and you're doing gates on them. So, AND gates, OR gates, NOT gates; and in your quantum computer you have a different set of gates for their equivalent of AND, OR and NOT. But, what they're doing in their model of quantum computing called adiabatic quantum computing, which is actually been proved to be universal if they have a full adiabatic quantum computer, which we don't know they do. If they did, it would be universal, barring the fact that you can't do error correction yet. But people are working on that. What happens in adiabatic computing is if you make a system very, very cold, it goes into its ground state of energy. So, it has the lower possible energy levels possible. So, I'm trying to think how to explain that…

Ben: Okay, there's this thing called Heisenberg's uncertainty principle. And the deal is, if you're talking about a particle, you can't know what the momentum of the particle is, and know it's location to arbitrary accuracy. The deal is, the more you know about the momentum about the particle; the less you know where it is. So there's a fundamental constraint on how much information you can know about a particle. So if you confine a particle to a little region; like you put it inside a box, you've got a little shoe box, and you take an electron and put it in the box and you close the box. Suddenly, you know a lot about where the particle is. You might know exactly where in the shoe box the particle is, but you know the particle isn't outside the shoe box. What this means is, you're also constrained about how much you know about the particles momentum. So the natural consequence of this is, any time you take a particle, and it's constrained spatially in any way, it's going to have some minimum amount of energy associated with it. There is always going to be a minimum amount of momentum that you can assume it has, just by virtue of this Heisenberg principle.

20:06

ComicBookGirl19: Okay, so electrons never stand still…

Ben: They never stand still, they're always wiggling a little bit.

Katherine: If you look at a hydrogen atom; you have a proton in the center and you have an electron orbiting the proton. We used to think that the electron was always orbiting it, and it could take roughly any position orbiting it. But what we found instead was it was actually in a set number of levels; it was either in level 1, level 2, level 3, level 4, and this represents how much energy the electron has. And, if you give it more energy, it could go from level 1 to level 2, but it could never exist between level 1 and level 2, you had to give at least enough energy to get up to level 2. And, so the ground state is when the electron is in its lowest possible state, say level 1, and we can extend that up to really large systems. We can imagine a system of lots of electrons, or a lots of different systems, and they all down so that they're in their lowest possible energy levels. And, what happens in adiabatic quantum computing is that you can take your computer to lowest possible energy level for the standard interactions for your computer. So your computer has an equation that's natural for it, there's a natural set of interactions between your qubits in your computer. And you can take it to the lowest possible energy level for this set of interactions. If you then very, very, very slowly, with very little energy, begin slowly trying to change the system, so it's kind of simulating another system, you can do this and keep it in the ground state, so you can find the ground state of your other system. And, the D-Wave machine, we know it can find the ground state of its system, and it can do that very well. And what, they hope it'd be able to do is be an adiabatic quantum computer so that you can slowly apply energy and change the ground state to the ground state of a different system. So you've got your hydrogen atom and you slowly apply energy so it feels like it's acting like a helium atom. So that's the idea; you try to change it to act like another system.

ComicBookGirl19: Okay.

Katherine: And if they can do that, then it will be a universal quantum computer, so it'll be able to do all the problems we want. The problem is, even if we can do that, at the moment, it's not fault tolerant. What that means is one error and your computer gives you a completely random answer. It can't cope with a single fault. And we don't think that there's any form of error correction, so if there's one error we have to just start again, we can't get rid of that error. In the circuits based quantum computer, where we are further behind, we've only got these 10 qubits, we do know how to define whether is a system is fault tolerant, and how to correct and error, so that's the advantage of that system. So, D-Wave have done a lot of things that are very promising, but they are not at the point of having this universal quantum computer where you can go out and solve the factoring problem…

Ben: Okay, so we mentioned at the start that computer science classifies different problem based on whether they are hard or not, and a hard problem is one that dramatically increases the computational time as you incrementally increase the difficulty of the problem. So, I started out by explaining the traveling salesmen problem which is probably not… you probably can't use a quantum computer to solve it any more efficiently than a regular computer.

Katherine: Traveling salesman is one that we definitely can't actually. I think they've proven it impossible.

Ben: So, when people first started talking about quantum computers, it wasn't clear that they were any better than normal computers. And then somebody came up with a way, there is this one really famous hard computational problem – this factoring problem. So when our computers, you know we're on a secure website or something, we're trying to do secure communication, our computers kind of encode all the information, in essence, there is a really big number that's exchanged. And this number is two prime numbers multiplied together. If I ask you, which two primes multiplied together give you a certain number it's tricky, right?

ComicBookGirl19: Yeah.

Ben: It gets increasingly difficult. So, for instance, uh… a six, not that hard, it's 3 and 2. If it's 10, not that hard, it's 2 and 5. If it's 34, you start having to go through all the primes before it, to see which ones multiply together to get that one. So essentially, it's kind of like the traveling salesman problem, it's computationally really, really difficult. It takes a ton of resources, and the higher up the number gets, the larger the number of possible primes that you need to look at that can multiple to get that one.

Katherine: Okay, so what they need is a system of cryptography where the bank, say, can release a key which you can use to encrypt the data but you can't use to decrypt the data, and that's the idea behind the encryption using prime. The idea is you use this big number that's the multiple of two prime numbers to encrypt the data, but you can only decrypt the data by knowing what the two prime numbers were. So that's just putting in context where it's coming from.

Ben: So, the deal is, with the quantum computers that were shown in the nineties, that you can use quantum computers to crack this problem in non-exponential time limits. In essence, the larger the number doesn't dramatically, dramatically increase the computational time required to figure out what those two prime numbers are. So, if you've got one of these working universal quantum computer, all this cryptography we're using is, in essence, just bunk. If somebody gives you a really large number, you put it in your quantum computer, and it takes advantage of the fact that you can use the superposition principle to calculate multiple possibilities at once, and then it spits out your answer and it could tell you what the two primes are. Without having to wait, you know … you entire lifetime.

ComicBookGirl19: Right.

25:42

Katherine: So, what you'll be relieved to know, given that, if this problem was solved, bank encryption wouldn't be secure anymore, it's D-Wave machine isn't believed to be able to solve the factoring problem. And I haven't heard any claims from D-Wave that they can.

ComicBookGirl19: So, alright. One questions I have is, I was helping put together a computer, because I have little hands. Seeing what goes into a regular computer, what kind of parts go into a quantum computer? Are they same type of parts? Are they completely different type of parts? Like, what is on the inside of this?

Katherine: So, in a quantum computer, it depends on what you're using. For example, you might use an *ion*. An *ion* is an atom with one electron missing, so it's got a charge. And it's sitting in a magnetic track. The magnetic track uses a magnetic field to trap the *ion* in place. And your quantum computer would be a row of these *ions* all trapped in place. Where it's different from the classical computers, is that in the *ion*-families, your little qubits, your *ion* would never move. You'd use lasers, so you can imagine now it's very different from your classical computer because these tracks aren't small, they're massive, probably taking up a large portion of a table, if not more for one qubit. And you shine lasers on them, to move them up or down and interact with each other. Another alternative, and it's the one which both me and Omair have the most experience with, would be the idea that you use a single particle of light, so a photon, is your computer. In this case, your operations will be done using wave-plates that change properties of the photon. To some degree they're a bit like the glasses used in a 3D cinema, which have polarizers. So you can use things like that and the photon will then travel at the speed of light through your computer going through all these different types of plates. When you see them physically, they look like this sheets of glass but they actually all do something. The photons are very difficult to interact with each other, and to do that, you use detectors. So you have to generate the interaction using these detectors. And the detector, it's very difficult to make, and they're fairly big things; normally to get good results, they have to be cooled down to 2 or 3 Kelvin temperatures.

So the quantum computer might look like that. Some quantum computers are basically those diamonds, the diamonds made of carbon atoms, but sometimes they're not very good and you have a little arrow in it; and they can build quantum computers using these arrows in the diamond. So, at the moment there are very different ways that they look, short of some work being done in Bristol University where they've got the photons on small chips, your quantum computer is significantly bigger, is taking up lab tables which are the size of fairly big dining tables, it's probably being cooled to 2 or 3 Kelvin…

ComicBooksGirl19: You can get shit that cold?!

Katherine: … yeah, your quantum computer is probably very, very, very cold. So, obviously, you can't touch things at that temperature. You're probably using lasers to control it, unless you're using a quantum optical system. So, you're going to be having a lab bench with masses of equipment and lasers. The D-Wave machine is a chip, but it needs to be cooled down, so when you see that machine, it's basically inside what is a giant fridge, which is a black box that says "D-Wave" on it, and apparently, deep inside it a tiny little chip that does all the calculations.

ComicBookGirl19: Okay, your computer has to be in a fridge to use it. So, what the hell kind of operating system do you use? What…what do you… put windows on there, I mean…

29:13

Katherine: Up to my knowledge, D-Wave have their own programing language. Some people I've collaborated with, have come up with one for your gate based quantum computers, which is called Quipper. But, you're probably still very close to, you know the idea of applications, so where you're programming on the level of the architecture of your computer, you have no higher level things to help you.

ComicBookGirl19: Okay, so you have to code everything in yourself.

Katherine: Yeah.

ComicBookGirl19: Well, I'm never going to use one of these quantum computers then, because I can't do any of that. Okay, so NASA bought one and Lockheed Martin bought one. So, what are they going to do with these computers, what problems do they need these computers for. I mean, are they just testing it really to see, or are they actually going to be using it to help with ridiculous problems?

Katherine: I'll answer your question in two bits. So first, you say you'll never use one, but you have to remember we're still vaguely at the stage where, if you go back to valve computing, so classical computing before they invented the transistor; and you'd never use a valve computer because it's big and doesn't have a good system to run, but that doesn't mean that it's never going to have a good operating system that runs, it just doesn't have one at the moment, because we're still at the very basic valve stage.

ComicBookGirl19: Right, okay. Well that gives me hope then.

Katherine: Lockheed Martin gave the computer to USC, the University of Southern California, and they've been characterizing it. I don't know if they intend to use it for anything else. NASA and Google do have some plans but we're not sure what they are at the moment. So, there will be some studying of it. And, one thing you can do one a quantum computer is that you can get an improved, unordered search. You can't get the wonderful improvements of factoring, you can't get the exponential improvements. You can only get quadratic improvement. But it has the advantage that you don't need a universal quantum computer, they can be done on simpler computers. So there is the possibility that Google might be looking to it for that reason. But that's not coming out of Google, My old boss, Johnathon Dowling, feels that's what they're likely to be using it for. But this isn't something that I've heard from NASA, Google, or D-Wave themselves, it's just idle speculation.

ComicBookGirl19: Okay, so besides D-Wave, is anyone else trying to make these guys? Or are they kind of the only game in town?

Omair: I've read about Mike Lazaridis, former CEO of BlackBerry (RIM) investing in the University of Waterloo; and I've read about Toshiba, I think they're trying to do one. I think there are a lot of teams that are trying to make one, but there are many ways to approach how to make a quantum computer and each way has advantages and disadvantages. No one knows really which one would be viable for commercial quantum computer.

31:53
ComicBookGirl19: That's something that I really enjoy about the idea of a quantum computer that there isn't just one way to do it, that there's a million different ways to do it, and that's what I find really interesting about all this. I don't know, there's so many different ways to do one thing, just… it's really

cool in my opinion. Uh... well like, how … how close do you think are they to making a universal quantum computer that really works? Like in your guesstimation… how many years will it take to where we can have a real one that works?

Katherine: These sole model that Bristol and several other universities, they are universal in the context that if you had a 10-bit quantum computer you'd have a universal 10-bit quantum computer. So you've got the universal computing, you just haven't got the size that you need. It is going to take a while, I think before we have something, that can do something that your classical computer can't. And at the moment, we don't think D-Wave have that, and I think it's going to take a long while, and it's going to take a lot more than the 1000 qubits that they have. Part of the disadvantage is quantum systems are a lot more prone to errors than classical systems. And you can get around this…the simplest error correction is the idea that you can encode one qubit in three qubits. So, you can use three qubits to represent your one. And that, continuously, you can… at the next level, each of those three qubits can be represented by three, so you use nine qubits to represent your one. And in fact, one of the most famous uses seven. But what you find is each physical…logical, so each thing you're processing on has got to be encoded in hundreds, thousands of physical things, to get our error rate down. So that's the big problem with building it is, you can't get your million qubits and compare it to a million qubit classical computer. You need to be doing this error correction all the time…

ComicBookGirl19: So a quantum computer is kind of like a person because they can be wrong sometimes.

Katherine: Yeah, ha-ha.

33:46
ComicBookGirl19: Okay, so what types of problems, say NASA, what types of problem would they solve with this computer? Would they start solving like crazy space flight problems and things like that? Or would it be more…

Katherine: So, the most famous one is the one Ben mentioned, which is factoring. You also get some improvement on sorting and unsearched database. Simulating a quantum system is believed to be a big one. They'll be able to simulate other quantum systems, make simulation… superconductors better. In idle speculation, what I think might come out… there might be improvements in simulating fluids. I believe that might be the case. But there's no proof of that yet. There's a lot of abstract mathematical problems they can solve with improvements. I means there are problems which do have, particularly you'd want to look for these ones which have the exponential improvement as we explained with factoring. Because they're the problems that your classical computer won't be able to solve even if you get more powerful classical computers. Anything with a less than exponential improvement, your classical computer is going to keep improving for a few years so there's a chance your classical computer will get there. But writing the algorithms is difficult, because… so what we back and we said is on your quantum computer, you can process all these options at the same time. So, if you're running at zero-one-two-three, you can run zero-one-two-three at the same time. As soon as you do a measurement you collapse into the state of either the answer for zero, one, two or three. So, it becomes very difficult the write and algorithm because you have to think very carefully how you're going to get the data out. So, I think with bigger improvements on data extraction procedures now, some very good ones… it'd be nice to get more to give you a wider variety of data you can extract.

ComicBookGirl19: So… so, wait. We're not even smart enough to ask the right questions to this computer?

Katherine: Aye. Yes, that a way to put it

Omair: Ha-ha. That's a nice way to put it, yeah.

ComicBookGirl19: That's really interesting.

Ben: Yeah, that was fun. Thank you Katherine, thank you Omair. You've pleased me. Your efforts have borne fruit, and that fruit is sweet. Here's some fruit. Katherine you get a cumquat...

Katherine: Om, nom-nom-nom nom.

Ben: And Omair, you get a quince!

Omair: Yom, yom-yom-yom nom.

Ben: I'd like to thank my guest, ComicBookGirl19. Thank you, ComicBookGirl19!

ComicBookGirl19: Thank you so much Benjamin. Thank you Katherine and Omair, you guys were really helpful.

Ben: This was a fun discussion.

Katherine: If you want to know anything more about quantum computing, my former boss, Johnathon Dowling, has just published his book, *Schrödinger's Killer App: Race to Build the World's First Quantum Computer*, and I can tell you it's incredibly funny. So, check it out.

36:26

Ben: Alright, hey tiphyters, listen. I know you love the show, and I love hearing from you. If you'd like to interact with the titanium physicists, there's a variety of ways. Why not follow us on twitter at @TitaniumPhysics, or you can join our Facebook group. If you'd like to hang out with us and socialize, why not join the online form, The BrachioBoard. It's fun place where the fans of Brachiolope Media Network gather to chat about science and things. Or, if you'd like to send me an email directly, to ask a question or propose a topic, email me at barn@titaniumphysics.com, or if you'd like to tell me nice things, email at tiphyter@titaniumphysics.com. I'm always happy to hear nice things. Okay that's it for the main part of the show. Remember if you like listening to scientists talk about science, you might also want to listen to other shows on the Brachiolope Media Network. Like the Weekly Wienersmith, where Kelly and Zach Weinersmith talk about academics about their research. Or Science…Sort of, where we talk about science in the news. Or Technically Speaking, where they talk about engineering. Editing support for the Titanium Physicist podcast is provided by a gentleman named John Heath. Thanks John, you're doing a bang up job. The intro song to our show is by Ted Leo and the Pharmacists, and the end song is by John Vanderslice. Until next time my friends, good day and remember to keep science, in your hearts.

37:40

[Outro song; Angela by John Vanderslice]

38:37

Ben: And so, it's kind of illustrative here to start with Schrödinger's cat. It's kind of an overused metaphor. When we got your quantum mechanics textbooks as undergraduates, they had these beautiful golden embossments in the front, they're in fake leather covers. And on the front, there's a striped cat, and it was alive and playful. On the back, it was asleep and the deal was that it was Schrödinger's cat, and the back cat was dead. It's delightfully overused, the Schrödinger cat joke. So the deal is, Schrodinger was interested in how the macroscopic works was different from the microscopic world. It was different in demonstrating how, they we talk about quantum mechanics is a little bit absurd. So he said here's a macroscopic object; it can look at things, it's alive, it's conscious. It's a cat, and we put it in a box. If that box is isolated from the rest of the universe, if we can't observe it, if we can't interact with it, then we have to treat the physics… what happens inside the box, according to the rules of superposition. So, there are two different possibilities. One where the atom decays and the cat gets poisoned and dies, and the other where the atom doesn't decay and the cat stays alive. So, functionally, until the open the box, the cat is both alive…there's a possibility where it's alive, and there's a possibility where it's dead. So both possibilities are existing simultaneously until you open the box, and see for sure.

40:08
ComicBookGirl19: Where does this number 32 come from? Because when I was talking to this guy, he was tell me… you know the binary, then he was saying the quantum is 32. Is that because it's 10 qubits? Is it like from that? Like you were saying, that the computers have 10 to 15 qubits right now. And is this 32 different… I don't know, where does that number comes from? Do you guys know what I'm talking about?

Katherine: Never heard the idea of 32 levels, or anything like that related to quantum computing. Umm, it might be a 32 times speedup. They might have been, one of the D-Wave articles might have been promising that. On a… on particular problems. I'm wary of constant speedups any way, but we could go into that later so you can understand what I mean, but, no I've not heard the number 32 mentioned, particularly, especially in the field.

ComicBookGirl19: Okay, okay. I was wondering… the reason, the reason I bring it up is because… in the qabalah there are 10 spheres of consciousness, where there's like 10 spheres here and they're connected by 22 pathways and that allows 32 different states of consciousness. And I was wondering if there as any sort of connection there. Because I know that quantum physics is a really weird world and I love the place where… you know science and philosophy, religion, consciousness, weird stuff like that, like things get really weird in there. So that, that's why I'm asking. Cause I was wondering if there was any sort of connection…

Katherine: Uh… there are some people in the field who believe the brain might be a quantum computer, particularly Roger Penrose. There are a lot of arguments against it, which I would say I disagree… which makes me on instinct disagree with him. If we look at when we're trying to create our quantum computer, what we need is a system that's very isolated from its environment. It's also very cold, we're cooling it down to liquid nitrogen, or even colder sometimes. And what we have in our brain is a very noisy, messy environment. So it seems very unlikely that you could get quantum coherence maintaining in the human brain; umm… just because of the physical conditions you need to create quantum computer… what we need to create quantum systems. There are some people investigating quantum biology but it's still a very vague field and there is still a lot of work in it that is more idle speculation than science; it's not actually backed up by science. Again, because we get to this problem that it's very hard to understand how a quantum system can exist in this noisy, hot environment because that ideal for de-coherence. When we're trying to create an artificial quantum system, we can't create system that operates on a quantum level in a noisy, hot environment [something something]. It would be quite good because it explained why our world operates on kind of classical level and not a quantum level in the big scales. But, I'd be very, I'm very cynical about the idea of quantum consciousness. But, if you do want to read that, I think Roger Penrose is the main person who understands quantum mechanics, who is pro it.

43:53
ComicBookGirl19: Okay, so everyone always wants to talk about artificial intelligence and robot uprising… so would and AI, would it be, like you can actually make like a robot that feels something, with a quantum computer, would that be even more dangerous terminator robot? Or would it be about the same dangerous terminator robot?

Omair: Uh, there is quite a speculation about that when it comes to quantum computers, I've read about, about when some point quantum computers will reach to unity with humans and…

ComicBookGirl19: Yeah, yeah. I'm definitely interested in that sort of stuff and like Ray Kurzweil and all these crazy futurists stuff that he's always talking about. It's like I was saying, like quantum computer, it sounds like a person in a way, you know, it could be wrong and it can, you know chip out certain things and you know whatever. So would that be more of an environment where, you know, and AI could actually learn to feel and do things like that, versus like on a regular computer.

Omair: The things is, in AI, in computer learning, in classical computer, we know exactly how we do it. The computer actually learns little by little. In quantum computer, we just don't know, we just, the algorithms we ave very limited, specific problems.

Ben: I think one way to think about it is that, if you want to build a robot that's as smart as a human, you need to make it really fast at computing, the feelings will be in the software. But quantum computers are more than just really, really fast normal computers… they're good at solving different questions. It's like you said, we don't even know what kind of questions it would be good at answering. But it's good at… the type of questions where you need to ask it to do a whole bunch of computations at the same time, to suss out all the different possibilities, rather than try to figure out the linear type of computing that we normally use our computers for. So it's not clear to me that a quantum computer would be any better at emulating a person with feelings, unless you wanted to make a computer that was really uncertain and unreliable…

ComicBookGirl19: But, but that's most people. I don't know…

Ben: Ha-ha.

Katherine: Uh, I'll answer the questions in two parts. Firstly, I think the idea of all the quantum error correction algorithms, except for one, have come from classical error correction, so people… once upon a time, classical computers were as bad as quantum computers and people were developing error correction for them. On the second point, I think with the AI, that's fairly interesting you pointed out. It's that years ago, people used to say once we have a computer that solves chess, we have an intelligent, thinking computer. Uh… we now have a computer that can beat a world expert in chess, yet we wouldn't consider it an intelligent, thinking computer. So what we find in, at least this is certainly what's got answers suggesting, and it seems to be reasonable true is that we keep changing our requirement to find a computer as an intelligent thinking machine like human beings. Um, I'm not sure at what level that's going to change. Obviously, you… it sounds possibly slightly sad, but you can see transcripts of people hitting on an AI that's basically functioning at a very low level. And there's some transcripts even in one of the books I'm reading, that yes, when we have a computer that we can't distinguish from a human being in conversation, which is the idea of the Turing test, when we do have that, which we're like… I think we will have, are we going to define that as an intelligent thinking computer, or are we going to be like we are now with chess and say "well of course a computer that can play chess isn't an intelligent, emotional machine."

48:06

ComicBookGirl19: Well, if I can have a conversation with it, then it… yes it's alive. I will treat it as a thing, I don't care if… But I'm also very sensitive towards robots, I guess. I don't know, I grew up with Data from Next Gen, and I always felt bad for him. He's just like you, he's just not made out of… flesh, okay. Well this is another question, a question for you guys, all three of you. What are you most excited… like what about the quantum computer excites you? Like, what are you pumped about?

Omair: Well, to me, I really like quantum communication, which is fairly related, actually really related to quantum computing. And that's what excited me personally, the most because…

ComicBookGirl19: What is quantum communication, what is that?

Omair: That's a whole new… new tangent. But basically it's using the same concept of quantum mechanics to communicate between different locations or different computers.

ComicBookGirl19: But it's like a communication between different…

Omair: Yeah... just imagine it as telephoning network, just using quantum computing.

ComicBookGirl19: Well do you think everything's going to go over to quantum, like 200 years in the future?

Omair: I never thought of that, to be honest.

Katherine: At the moment, I'd probably say no. But then there's a large list of quotes by people in the early computing field saying how no more than two people will ever want a computer. So… I don't want to be one of those people. At the moment, the advantages that quantum computers give are very specific and often scientific problems. And we have incredibly powerful classical computers. But, that's speaking from a very early stage, so I don't know what we'll be able to do in 200 years of time.

ComicBookGirl19: Okay Ben, what do you think?

Ben: Hmm, what do I think? It seems to me like it'll be just another important tool in our analytical tool kit. We might be able to use quantum computers to make better quantum computers, ones that don't require you to free them down to nearly absolute zero. You might be able to use them to make better materials. High temperature superconductors; and then all sorts of things will become really efficient. Energy transmission, energy storage… who knows, this might be the key that unlocks a whole bunch of really cool technologies.

ComicBookGirl19: Okay, I thought it was interesting, Katherine, you said that one of the quantum computers uses diamonds… and I think that's really interesting, the idea of using crystals and crystalline structures to store data, you know versus what we have been using. Do you think that, that is something that's going to become, like we're going to see that more at some point? Are people going to start utilizing crystals and shit for computers?

51:04
Ben: Well, a semiconductor is just a crystal. Computers are already full of crystals.

ComicBookGirl19: I want like, superman crystals. You know what I'm saying? Let's say there's a crystal, and you plug it into something and then it goes. Is that ever a possibility? This is just for my personal happiness.

Katherine: Unfortunately, the diamond system isn't that simple. You're trying very hard to isolate a particular defect or fault in the diamond. I've never seen one, so I'm not a 100% sure what it look like though, unfortunately isn't plug and go. Though, I also love the idea. It would be shiny.

ComicBookGirl19: I know, it would be much more accessorizable. It'd be way cuter… Broader strokes. Like, what does the quantum computer mean for humanity? What does… what does it mean on like the bigger scale?

Ben: One application for quantum computing might mean that we that we are more efficient because it can do all sorts of calculations simultaneously. It can solve all sorts of problems potentially, where we're currently really inefficient. Finding things, and how best to do things in what order. And so, you know, maybe… maybe it'll be the trick to us being a society that's less mean to bike couriers or something.

ComicBookGirl19: So…like so, okay. So this is what I'm here for. I'm hearing that the quantum computer could solve world peace. Like we got problems, we got logistical problems of how to feed all these babies, cause people keep having babies, it's crazy. Too many people on the planet. So you're telling me that quantum computer could *potentially* help up figure out how to… like logistical problems for like a world, like if you… like on a humanity scale versus like "oh, how do we take care of our people in a city?" you know, it'd be like "how do we take care of the world's people?" It could do stuff like that potentially?

Ben: Maybe… those are, those tend to involve computationally hard problems. So it's possible that the quantum computer might be able to solve it.

ComicBookGirl19: Okay, okay. Oh, okay. Alright, I'm in. I like the quantum computer even more now. Alright. Anything else, any… any other like weird stuff that you guys can think of that could help us, like how could a quantum computer help humans evolve, I guess. I guess that's a better way to put it.

Katherine: I think, if you go back to the 1920's and ask them to imagine life today, you'll probably not going to get anyone even managing to imagine that you can carry around your phone and look up information instantly on it, and access information from around the world. Nearly all academic journals, although being paywalls, you can access from your phone. The fact that you access to, maybe all of human knowledge, in your pocket; I don't think they could imagine that. And in a way, I don't think we can imagine how the world will change with quantum computing just like we couldn't imagine how the world changed with classical computing.

54:14

ComicBookGirl19: Going back to earlier, I do think it's interesting that you know, futurists and stuff are always predicting that we're going to merge with technology, at some point that just seems like an inevitability at this point, I'm just really interested to see how the quantum computer could work into that? Because I feel like, I don't know, I feel like because it's weird, I don't know, like humans are weird, and brains are weird, and consciousness is weird and if anything is going to mesh with us, it'd be something else that's weird, and the quantum computer sounds really bizarre.

Katherine: One things I like… I don't actually know if you could do this with classical computing, and it may be possible, is what they're working on in quantum computing is the idea of cloud computing, where the central computer doesn't know what calculation you're doing. So you still have… although you're using a central computer, at a centrail location, run by someone else, you still have complete privacy on what you're doing, what task you're doing, and what you're using your computer for, and what data you're sending.

ComicBookGirl19: I like it.

Katherine: And I think that's a useful application, but there may… I don't know enough about classical computer to know if there's a classical way to do that. But I do like the idea that you can have… cloud computing at the moment, I don't like the idea that the central database… the person at the base knows exactly what you're doing. So that's security, but there may be applications for that in classical computing as well. I couldn't say, but that something I like.

ComicBookGirl19: So it'd be kind of like a mother brain, but except having like a hive mind thing, we'd still all be separate. Okay. See that… that seems efficient. Like Ben was saying earlier, it just seems like it could make us a bit more efficient. And, hopefully help us to think of more interesting, creative ways to solve these dumb problems that we have in our society.