Episode 56, What “In Tangles” Meant
Dramatis personae:
- Ben Tippett
- Ken Clark
- Katherine Brown
- Dan Harmon

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Ben: Never be afraid. There's nothing which is known which can't be understood. There's nothing which is understood which can't be explained. For over 50 episodes now, my team and I have brought you to the very frontier of knowledge in physics and astronomy. And still our mission goes on. To present you with your birthright: an understanding of the Universe. I've traveled the world seeking out a certain type of genius. Masters of not only their academic disciplines but also at explaining their research in understandable ways. And I've bestowed upon these women and men the title of Titanium Physicists. You're listening to the Titanium Physicists 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]

01:46

Ben: I want to tell you about a different world... hold on, hold on. You know what I mean by "world", right? I'm using the word colloquially. The word we use in movie trailers. So, the dystopian world of Mad Max is different than the dystopian world with the kaiju in it in Pacific Rim. They're different from each other in the same way as my world is different from a kid in Cambodia's world is different from Victorian London. The word "world" in this case refers to a set of rules, kind of, that everybody around us is playing by. Even if two people are born in the same geographic place at the same chronological time they might end up living their lives in very different worlds. You know, like the hit 1980s sitcom "A different world". So, I want to tell you about a different world. Oh wait, wait, hold on. You know about emergence, right? Emergence is a property of systems. Ants are a classic example. Each individual ant is pretty simple, it's not thinking too hard about what it's doing but a colony of ants? Each ant interacting with the rest of them, leaving chemical trails and stuff, you end up with a colonies of ants that are smarter than each individual ant. And it can explore and defend itself, the colony can. It can reproduce and outsmart the middle-aged man who is trying to keep them from living in their walls. This cunning isn't a property of the individual ants, it emerges when enough ants begin interacting with each other. Emergent properties show up in a bunch of physics, which is pretty surprising if you think about it. The way we study physics, by its nature, we attempt to be reductionist. When we study a system and try to explain its behavior we try to do so in terms of underlying simple laws. The fewer special cases there are, the fewer underlying laws, the more universal those laws are, the better. Allow me to elaborate with a pretty classical case. Individual particles, atoms and molecules in gas or liquid, they have their motion defined by Newton's laws. Each one moves pretty much in a straight line with the same speed and momentum until it bumps into another one and they exchange some energy and some momentum and then they head off in different directions in straight lines. Fine. But at the macroscopic scale, the jar of water or whatever, that liquid is going to obey its own physical laws - the laws of thermodynamics. We describe the liquid in terms of its current temperature or pressure or entropy and how these terms change over time. Actually, yeah, entropy is a great example because the law of entropy says that entropy in your jar of liquid can only increase over time. And that's a really weird one because all of these thermodynamic laws are emergent from the smaller Newton's laws that each particle has to obey. And it's really weird because entropy can only increase in time and that's weird because all of the Newton's laws for the individual particles are time-symmetric. The particle can gain energy or lose energy and it's an amazing example because we end up with a macroscopic law - a law on a macroscopic level - which has very little to do with the laws that the individual particles have to obey. The fact that you have emergent laws shows a lot in physics. Because some physical laws can be emergent, you end up with a rule that - essentially - you have to expect that physical laws will be emergent. And this means two things. Firstly, going up in size. If you understand physics at one size scale, it won't necessarily give you a good sense of what kind of laws they'll obey at a much larger size scale because new laws might be emergent from the behavior of the small laws. And secondly, going down in scale. Even if you understand fundamental laws of physics at one scale, it's foolish to think you can guess the physics at the smaller scale because the laws that you think are fundamental at your scale might just be emergent laws which come about from some much weirder, more fundamental laws at the small scale. So, I want to tell you about a different world. A world which lives at the same time and place as our own but where things obey very different rules. There's no cause and effect as we know it in this world, nothing is anywhere specific and nothing might even have something in it. It's very strange. This is how our world behaves at the size of an atom. It's the world of quantum mechanics. The laws of quantum mechanics are actually pretty simple but they are different from the laws at our usual, Newtonian scale. In fact, the laws of our scale, like the fact that an object has a specific location and that you can't make something from nothing, are emergent laws which come about from lots of quantum systems interacting together. It's very, very strange. In fact, the usurping of laws of our world at our size scale by these other laws at smaller scale is actually pretty romantic. People have fallen in love with the idea that the laws of classical physics have been usurped. And people can kind of get carried away interpreting what this mean. To quote Professor Farnsworth from Futurama "As Deepak Chopra taught us, quantum physics can mean anything can happen at any time for no reason". Now, one of the strangest quantum laws involves an effect we call entanglement. Where the state of two unobserved particles are related to each other and what happens to one particle can affect the other particle. This effect is wonderfully simple mathematically but it sounds very, very strange when we describe it in words. Does it mean that everything is connected? Does it mean that people can be psychic? Today, on the Titanium Physicist Podcast, we're going to talk about the quantum entanglement. My guest today is an expert in cause and effect and how we relate to the world around us. He writes for television shows and his writing is notable for its unique perspective. His humor is based around exploring the absurdity of the human psyche without reducing it to caricature. At times both sorrowful and hilarious. He's the co-founder of Channel 101 website and he wrote the movie Monster House and was a writer on a Sarah Silverman program. In 2009 he created and wrote and produced the hit TV show Community which was on the NBC and is currently running on the Internet on the Yahoo! website. And in 2013 he created the hit cartoon Rick and Morty. He's a star of his own hit podcast, Harmontown, which even had a documentary made about it. Absolutely amazing, welcome to our show, Dan Harmon!

07:55

Dan: Wooohooo! Thank you Ben. That was quite an introduction. Both to me and to all physics.

Ben: Yes. [laughs] So, Dan, for you today I've assembled two fantastic Titanium Physicists, old friends. We haven't seen some of them for a long time. Arise, Dr Ken Clark!

Ken: Whoosh!

Ben: Dr Ken did his PhD at Queens University in Kingston, Ontario and is currently an assistant professor at the University of Toronto, where he's an expert on neutrino detectors and dark matter. And arise, Dr Katherine Brown!

Katherine: Oop boop boop boop boop!

Ben: Dr Katherine got her PhD from the University of Leeds in quantum computing and a Post-doc from Louisiana State University. She's currently a trainee patent attorney at Boult Wade Tennant in the UK. Alright everybody, let's talk about entanglement.

08:38

Ben: Okay, Dan. If you've got any questions to start us of?

Dan: I have a thousand questions. But I don't know if/ I mean, you guys could easily just start since a thousand questions is kind of the same as having no questions because I could just ask, no necessary order, what does "observation" really mean? I've been hearing that since, you know, the ninth grade about these principles in quantum mechanics. Like, I remember science class where you make observations about a candle. Write down a hundred things about this candle. Like, in quantum mechanics what does it really mean to observe something and doesn't it just sound suspicious? This idea that stuff that works mathematically/ you know, this idea that you observe one thing ant then the math works out for the other thing all the time but you can't do it any other way/ Is that raising red flags for anybody? And how does a physicist observe a particle?

Ben: Alright, Katherine. What do you mean by observing?

09:37

Katherine: I think that's actually a really difficult question. It's sort of almost just some kind of interaction. So, generally when we're talking about it, we're talking about an interaction where we can gain some informations; a typical way of doing measurement might be to use light to measure the state of something, you know. Send a photon in and see what you get out. Obviously, there's lots of things of doing measurement. But going back, hardness to the problem is when we talk about quantum mechanical system and we could talk about nearly any single-particle system. So you could have this state of an electron, states of a proton, states of a photon or single particle of light. And so how you choose how to measure each one, depends upon what system are you trying to measure. When we talk about observing we mainly talk about getting a result. So we're trying to measure whether a particle has a property called spin, whether it’s up or down or whether a photon is horizontally polarized or vertically polarized. But, it kind of gets a bit wider because obviously these little particles making up quantum systems are interacting with the environment. And when they interact with the environment, you could then do some kind of measurement on the environment and find out your result. So that would also be an observation because you've found out your data. So, really observation is any way of finding out a result of this state of the particle.

Ken: Any way that we determine information from a system is an observation.

11:05

Ben: The thing about quantum mechanics that people really had to get their heads around is that to a greater or lesser degree, because we're trying to measure quantum information involving really subtle things about, say, atoms. Since we're discovering this information using things that are about the size of atoms, in many different ways doing the measurement will change the system. I'm

Canadian. Imagine somebody's turned the lights out in a hockey ring and you're asked to figure out if there's a puck bouncing around on ice and whether or not that hockey puck is travelling in any specific direction or what's it doing. And you lean over the boards and you have your own hockey stick and you kind of waving your hockey stick around trying to detect this hockey puck. If you manage to detect the hockey puck, that observation is going to change where the hockey puck was going. You can gain some information but in doing so you're changing the system. Even more so for particle physics when you're trying to detect where a particle is in detecting it you essentially bumping it to see if it's there. And in bumping it you can change what it's doing. So even in the classical sense the reason observation becomes a big thing in quantum mechanics is that the act of observing is going to interact with the system, thereby changing it.

Dan: And is that correctly called the Heisenberg Principle or is that/ are we misusing that when we/

12:29

Ben: That's a great example because in the humanities often people will refer to this effect - the fact that you change a system when interacting with it - as being the Heisenberg Principle, right? Let's say, you can't take an anthropologist and land them on an island and have that anthropologist discover how the people on the island are interacting with each other because in doing so you've got this white person with all their fancy gear going around, perturbing the system. So/

Dan: Using hockey metaphor, is this on an island/

12:57

Ben: So, it does get used in that sense. In quantum mechanics proper Heisenberg Uncertainty Principle kind of/ it's a different effect. There's something kind of interesting which is that in quantum mechanics doing the observation doesn't necessarily just change the system. Doing the observation might force the system to define itself. The moral of the story is that it's more than just perturbing the system that we have to worry about. It's that interacting with the system you get rid of this quantum uncertainty. We're gonna spend quite a bit of time today talking about it.

Dan: Got it. So actually it first time I've ever heard if put that way that uncertainty is actually a valuable part of this little quantum biosphere. That quantum mechanics needs uncertainty to function. And that because of our emergent existence, we take our giant eyeballs and we put them into the quantum world and we immediately disrupt uncertainty because we're creatures of certainty and therefore we're fucked forever as far as knowing everything.

13:57

Ben: Yes, to some degree. But it's not just our eyeball that's doing it. It's the fact that to see it with our eyeball, we're bouncing photons off it and that's making it decide what kind of state it's in. So yeah, it's a quantum mechanics, the rules of quantum mechanics are kind of founded on a type of uncertainty. And so perturbing the system changes the system by getting rid of that uncertainty. But/

14:19

Katherine: In answer to your other question, I think, when you're asking is quantum mechanics real, that's kind of a philosophical question so I don't know many people in the field who committed to particular kind of philosophical idea of how it works. So, you do get the idea that the maths works out and we know it agrees with experiment but I don't think we're saying reality is as this as such. It's more of a notion that we need a philosophical idea to explain/

Dan: Right

Katherine: Why the maths works out. And if we found some simpler maths that worked out, we'd be quite happy to move towards that idea/

Dan: Sure.

Katherine: I don't think we're making a stronger commitment to this idea as maybe the ether was. But I think it's also worth remembering that it's uncertain when the people are making a claim of "This is how it actually is" rather than "This is a good way of giving us a mathematical results and data".

Dan: Right. 'Cause even when we thought the Earth was the center of the Universe, we actually got some good data out of that enough to, you know, we were studying how the planets related to each other. Until we did get enough data to subvert things. And you guys are deciding "Okay, let's work by this quantum model. It's all theory and we like this model. We can start to/ because math works maybe we could somehow use those numbers to one day actually prove, you know, any of this stuff". Which would be a paradox, it sounds like, because a proof is certain.

Ben, Katherine, Dan: [laugh]

15:58

Ben: I think the thing that's really surprising is that in quantum mechanics there are a variety of really strange things that sound like it's kind of a story that we're just telling ourselves in between the frames. And then these stories we're telling ourselves are consistent but not necessarily true. What we've seen actually in more recent history is that a lot of the really strange things that we attribute to quantum mechanics are verifiable. So, you know, entanglement is one of those where you're like "isn't this just a mathematical predictive model that's just consistent?" And it's like "well, it's more than that". It's more than us not knowing the framework of quantum mechanics where there is this uncertainty that drives everything. It's consistent with the experiment in a way that other arguments that are based on the classical physics aren't. We'll talk about those. Right now we're pointing out the peak of the mountain we're gonna climb.

Katherine: Yeah.

Ben: But you're gonna find out that this mountain is actually a very satisfying place to climb. There's more to it than just philosophy.

17:01

Dan: It wasn't my intention to make you guys sell me on quantum physics. I'm sure you've all thought about this a lot. [laughs]

Ken: You know what, I'm gonna give this quantum physics a shot.

Dan, Ken, Ben: [laugh]

Ken: I think this may not be bullshit. Not entirely, anyway.

17:16

Katherine: I'm thinking, certainly when I was doing the day job. You did the maths, you did the equations, you worked things out. You rarely thought about what it meant in terms in what was happening in the real life. Or you did by the end when you got your measurements out and you saw the result. But the in-between what was actually happening was not something you really gave much thought to and whether it was/ well, the many worlds theory is the common theory of quantum mechanics or the all the more mathematical which is Copenhagen interpretation. You've never gave any thought to which philosophy you're using.

Ben: Okay. So let's get on with explaining entanglement. So, when we started and you asked/ and you were like "isn't it weird that, you know, the mathematics say that knowing one thing about one particle over here can affect another particle". And, at its heart, it's not weird at all. At its heart, entanglement is kind of a consistency condition. Like, imagine you and your brother are going to different sides of the world. You're going to the North Pole and he's going to the South Pole, because you really like winter and he really likes summer. And your mum decides to pack you each a lunch box. And you see on the counter before she packs your lunch box there are two apples - there's a red apple and a green apple. And you don't know which lunch box she put it in she might have put it in yours, she might have put it in your brother's. You don't know which color it is. But you know you have one of the two apples. So, you go to the North Pole, he goes to the South Pole. If you open your lunch box when you're up at the North Pole you see you have a red apple that means that your brother's apple has to be green. No matter where he is or what he does, for consistency, 'cause there's only two apples to choose from - one red, one green - because yours is red his has to be green. Does that make sense?

18:59

Dan: Oh, yeah. Well, that makes perfect sense. I mean, entanglement has always been proposed as so much more magical than that. As if we would both have red apples no matter what. [laughs]

Ben: Yeah, yeah, that's right.

Ken: And then, just to clarify, you know it's cold at both poles, right?

Ben: Not, well/

Dan: I was gonna say, are you guys so much smarter than me that you know that it's summer on the South Pole? [laughs]

Ben: I know that it's summer on the South Pole when it's winter on the North Pole.

Dan: Your brother likes summer so much that he doesn't care if it's summer on the South Pole.

Ben: He likes two things: summers and penguins.

Dan: He's a theoretical weather enjoyer.

Ken: Yes, right, I like that.

Dan: Season enjoyer, sorry, not weather enjoyer.

Ben: Yeah. He's like "this is as cold as summer gets, I'm gonna try it."

Ken: [laughs] Okay. Sorry, go on.

Ben: So that's at the heart of what's entanglement. And you're right - it doesn't seem that much stranger. But the deal is, entanglement comes from when we plug other ideas in quantum mechanics into this fact that you essentially have/ if you have the red apple he's got the green apple. To discuss that any more we need to discuss about superposition. Hey, Ken. Talk about Schrödinger's cat.

20:06

Ken: Oh, but/ I mean, you already heard of Schrödinger's cat, right? With this experiment.

Dan: Right, the/

Ben: It's not an experiment, nobody's done this experiment

Ken: Actually, this theoretical experiment, yes. But let me qualify here: I hope no one's actually done this experiment in real life.

Dan: Yeah, viewer at home: this is not a thing to do. Yeah, what I understand about Schrödinger's cat is/ it's a way of taking the quantum world's kind of strange properties and showing how strange they would express themselves in real life. As if you could somehow create the machine that actually could create a mechanical process from a state of some quantum particle. That's why Schrödinger's cat is both alive and dead at the same time through our lack of observation because that's how weird things would be if our world was a quantum one?

Ken: That's exactly right. And you hit on the core of it, which is, you know, you put a cat and you close the box and then you don't know if this atom or whatever has decayed to release the gas or shock the cat or whatever horrible thing you want to do but the point is exactly what you said. Before you observe it, the cat is both alive and dead so there's this superposition of alive cat state and dead cat state. And the way you resolve the quantum mechanical issue is you open up the box. And so then hopefully you see alive cat state. What we say is, the wavefunction collapses so the probability that the cat is dead essentially goes to 0 and the probability that the cat is alive is now a 100%. You know, you've proven that the cat is alive here with your observation. And of course that ties back to what we were talking about earlier about observation changing the system. In a quantum mechanical way you have changed the system by resolving it so that the cat is alive. But before you open the box - yes, superposition of states. It's both alive and dead at the same time.

21:55

Dan: So when you say "superposition", is the definition of superposition/ does that mean both of its "alive" and "dead" states are at their respective superpositions or is the cat in the superposition of being both alive and dead? I'm not sure what superposition means.

Ken: Yeah, that's a really good question. So, the superposition. The reason that we use that is 'cause we talk about probabilities, right? So, we say that there are two different kind of probability states. One in which the cat is alive and one in which the cat is dead. And we have this superposition of those two states together, so that the cat is both alive and dead. So I guess kind of your second explanation is right. The alive cat and the dead cat are both kind of existing in the same place. In this case there's an equal probability of both. So that/

Dan: Okay.

Ken: So that it is both alive and dead, equally probable because of the way you designed the experiment. And then you open it up, you open up the box and the cat jumps out at or whatever and you say "Okay, now there's only one state that's possible", which is alive cat.

Dan: Okay. So we refer to an entity's superposition when we're talking about like an entity before observation, basically. Its sort of, like, root existence

Ken: Yeah, exactly.

23:06

Ben: Okay, so. At any observation it's either going to be one or the other, right? But then between observations it's formally mathematically both. If there's a 50% chance that it's alive and 50% chance that it's dead, we say that it's in superposition of being in the state of being both alive and dead. 'Cause that's what the particle is, right? The particle is either decayed or not, any time you check in particular. The way the system evolves when you're not looking, when nothing's interacting with it is as if part of it, probability that the particle's decayed, there's some probability that it hasn't decayed and then the system continues evolving like both had happened. And then when you measure the system, the system chooses which of the two it is, randomly.

Dan: Got it. A good mnemonic device you could use is... in Lethal Weapon when the bad guys shoot Mel Gibson's character, they don't know he's wearing his bulletproof vest, as they peel away and Danny Glover lifts Mel Gibson up and he says "Now we have an advantage, because they don't know I'm alive", the hero cop is in a super position to deal out street justice.

Ben: [laughs]

Dan: When the bad guys have not observed that he is either alive or dead.

24:17

Ken: If Erwin Schrödinger had seen Lethal Weapon I'm sure he would have used that because that's awesome. [laughs]

Katherine: I think the key thing to note is there is not just a lack of information. It is actually a different state because when you're talking about the Lethal Weapon example, he is alive, they just don't know. But the quantum superposition is different in the fact that you/ it's more than don't know. It actually is both at the same time. And that's quite a key difference because otherwise you're just in what we call a classical mixture. And so it's just something you can represent classically. Which is why it's so hard to think of an example because the reality we react with is classical and you can't think of anything that behaves exactly but/ yes, it's more than just not knowing.

Ben: Katherine, do you wanna talk about quantum computers, briefly?

25:12

Katherine: Well, they work on a combination of superposition and entanglement so I didn't know whether it was worth leading to with explained entanglement. But the basic idea with the quantum computer. So, why you can get speedup is because you can be in two states at once.

Dan: Oh, right.

Katherine: Your bits on your computer can be both 0 and 1 at the same time so you can run a calculation on both options at the same time. So, 0 and 1.

Dan: This is a theoretical thing, right? The idea of a quantum computer, it doesn't exist, right?

Katherine: They do exist. To some degree.

Dan: Uh-oh. Somebody's working for MI6.

Ben: [laughs]

Katherine: Only very, very small ones, so only D-Wave have a bigger system but it has certain limitations to what calculations it can do. For a completely universal system, they probably exist at around 15 bits which doesn't do any particularly useful calculations, as you can imagine. Because imagine your laptop as having only 15 bits rather than how many it has. But they're not theoretical in that sense. They do actually exist and you have computers that can do calculations, they're just too small to be practically useful other than this D-Wave system which does particular calculations but the disadvantage is that as soon as you do the measurement you end up forcing yourself into 0 or 1 so you can only measure one option at once. And so the way you get around that is you have to very particular calculation. So you might do the calculation on "do 0 and 1 give the same answer?" and you can get a result for that with a single measurement. And you can scale this up, so you could scale up, using entanglement so with 1 bit represents obviously 0 and 1 and with two bits you could represent 0, 1, 2 and 3 so it scale/ I mean, you can keep scaling. So when you have two bits entangled you can do questions on "Do 0, 1, 2 and 3 give me the same answers or not?”

27:16

Dan: So, when we talk about this business of observation and lack of knowledge and both things being true until observed, it's very important to know the layperson hearing this it can sound to us as if our observation makes things happen. And that's not really the way you guys are looking at it, it's more like/ it seems like a magic trick but this thing is in/ it can be/ the cop flying through the air who's been shot, who we don't know if he has a bulletproof vest on or not - there's an equal chance that he put it on or didn't put it on. And say this shotgun shoots him and he's flying through the air and that cop in a quantum world, if that's a quantum cop, is both alive and dead. As he's flying through the air, he's in a superposition. He lands, his partner runs over to him, lifts up his shirt and observes that he had his bulletproof vest on the whole time but his partner didn't make the bulletproof vest appear there. Because we're talking about Schrödinger's cat is both alive and dead and when you open the box, you're not making the cat do anything. Your observation isn't affecting things.

Ken: Yeah, that's exactly/ yeah, you've hit the core of this whole thing, right there.

Ben: The system is entirely statistical until the moment you/ right, so it/ the bulletproof vest has a 50% chance of being there or not. The guy lifting the shirt forces it to choose whether it's there or not. But he doesn't have any say over which one it's gonna be and/

Dan: Yeah, okay. Got it.

Ben: And what's more, he's not the only one who can/ it doesn't have to be, say, a conscious observer. In quantum computing one of the big problems is, you get this nice state - it's 50% 1 and it's 50% 0. You want to do calculations with it. You know, if it's too warm or it interacts with something else, the external environment interacting with it could force it to decide whether to be 1 or 0. And then the decision will have already been made.

29:31

Dan: This is so terrifying and fascinating from a writer's perspective, this idea of these computers that are going to evolve that, like humans, are capable of thinking two things at once but in order to preserve that power they need to be protected from all observation and all environmental, like, interactions so they like have this shamanistic existence and they're like these untouchable, like, deities that just tell us what to do because they've thought of two things at once and I'm terrified. I'm sure you guys love it, you eggheads! You love it!

Katherine: The main reason I think there's a lot of interest in it is, one problem it can solve considerably faster than your standard computer is factoring numbers. Say, you have the number 15, dividing it down to its prime number factors so that would be 3 and 5 for 15 which is actually a very, very difficult problem for a computer to do but it isn't difficult for quantum computer. There's quite an easy problem. And for the moment that's the key problem behind most of web security. So, the fact that we can't factor is why a lot of web security works. So once it's hacked or once we have this full scale quantum computer, the current use of web security would be ineffective. Luckily, there have been new methods of web security that won't be solvable by a quantum computer so hopefully it shouldn't be too much of an issue, we would just switch over but obviously that's why there's a big interest in this.

31:01

Dan: Well, in a world where the corporations have quantum computers and also the pirates have them, does this just average out? Does a quantum computer hack another quantum computer just as much as our current world? Or are you saying that once we enter the world of quantum computing, like, the idea of hacking sort of might become antiquated?

Katherine: I think there's quantum cryptography that's a slightly different thing. Cryptography works on problems that are not equal. So there need to be two sides to a problem. So, multiplication - multiplying 3 times 5 to get 15 is easy. But going from 15 to 3 times 5 is quite difficult. So most cryptography works are one of those problems where one half is easy and one half is hard. I don't think as yet we believe quantum computers other than quantum cryptography systems will actually make a better security system. So the fact that they can hack classical security, they're not going to also come up with better security system. It's things like/ and I know there's been a bit controversy over them because I think there been found backdoor algorithms to them but I don't know. I don't follow much about the leaks but things like elliptic curve cryptography I think are the ones that won't be solvable by quantum computers and they can be run on a classical computer. So, your normal computer will have a system that the quantum computer can't hack.

Dan: Just from a sci-fi perspective here or a Jason Bourne movie perspective, like, the first government that comes up with a quantum computer that can actually work on these things, would be a super hacking machine in a world where no-one else had one of these things. Whereas, like you said, that computer is also not gonna come up with better security system. But it would be a skeleton key essentially to traditional encryption.

32:56

Katherine: It would be a skeleton key, particularly if you don't let anyone else know you've got one.

Dan: Right.

Katherine: So that they don't switch to something you can't hack.

Ken: I'm kinda getting terrified too now, to be honest.

Dan: I have like eight movie ideas from this conversation.

Ben, Ken, **Katherine:** [laugh]

Dan: I'm gonna make like eight hundred thousand dollars next week.

Katherine: The key thing to understand is although the quantum computer can process every state at once, it can only ever give you one answer at a time. So it might be able to process 0, 1, 2, 3 but it can only tell you the answer for 0, 1, 2 or 3.

Dan: Hm.

Katherine: And that's where designing algorithms for quantum computers gets very difficult.

Dan: Doesn't that seem like such t-up for such a crazy sci-fi premise? Because they're talking about a machine that is capable of thinking incredibly deeply in a way that it can't share with you and then it just arrives at one thing?

Ben: Yeah.

Ken: Isn't this very Douglas Adams, I mean... the giant computer that said 42 and that's a/

33:57

Ben: I mean, that's the problem. I think/ to spill it out in slightly simpler terms, imagine you had a/ you're running a routine called I have a mouse and a maze and the maze branches. So, you put the mouse at the front and then the hallway branches into two and each of those hallways branch into two more and each of those hallways branch into two more, okay? And let's suppose that you have a quantum mouse that's capable of existing in a superposition state. So, you put the mouse in at the top of the maze and then you close it and you isolate it so that the mouse is allowed to do its work unobserved. It reaches the first split and part of it goes one way, part of it goes another.

Dan: This is identical to a scene in that horrible movie with Nicholas Cage, called Next in which he's like a Las Vegas psychic that can actually sees five seconds into the future or something like that?

Ben: Yeah, right.

Dan: And there are those set pieces where he does exactly that - you split into multiple Nicholas Cages and show him like one of them gets shot and so he shakes that off and, anyways.

35:02

Ben: that's right. So, imagine when the mouse ends up at the, you know, 64th bifurcation - one of those mice, one of those hallways ends in cheese. You know, like, hooray! And you wanna figure out which hallway ends in cheese, so you're gonna open the thing and hopefully the mouse if it found the cheese, it's gonna squeak. The deal is that okay - so it's bifurcated, so one of those 64 mice has found the cheese. But when you observe the system, when you open it up to see which mouse it is, suddenly those quantum mice decide to be in one of the 64. And which one it ends up in is entirely random. So, you'll have to do the experiment 64 times -ish to find out which one the mouse is in because the rest of the time the mouse is gonna decide to - "decide" - to be in one of the other non-cheesy end states. And that's why quantum computing is really, really difficult to do because, as Katherine said, you need to figure out how to phrase the question so that you don't have to do the observation over and over and over to find the one, single one that works. 'Cause that's no better than just randomly trying it. So you need to phrase your question in a way that'll give a meaningful answer reliably.

36:12

Dan: Well, what do you mean by that? I just wanna be clear on that. You have to phrase your question like in a case of the mouse cheese box, like, is there a way to prevent the problem you've just described by, you know, by setting up the experiment differently? Or, so that you can take advantage of that 64-bit quantum thinking on your mouse box?

Katherine: The sample question would be, you have the maze with the 64 cheeses and you could/ the one question that they could solve reliably in one observation would be in a case where you know that there's either 32 cheeses and the other 32 have no cheeses or there are 64 cheeses. And they can solve with a question like that they could solve using just one mouse going through the cage. Are there 64 cheeses or are there 32 cheese and 32 no-cheese.

Dan: Right, okay. So if we think more statistically than factually, you can take advantage of these things right away.

37:16

Katherine: And you could also have the scenario with, um, where it can distinguish between 64 no cheese and 64 cheese is one option and 32 cheese and 32 no cheese is the other option. So, you/

Dan: This is pretty interesting.

Katherine: There are some problems you can solve and other ones that you can't. How to do the measurement is actually one of the biggest issues in quantum computing, it's one of their biggest challenges I'd say.

Dan: We're finding out that the Universe is made out of all these spinning Dungeons and Dragons dice, like with 20 sides to them, and we know that that's the nature of it and we can understand that because if we stick our finger into it, we can stop the die and go "okay, that's 17" but we can't control the dice. Which leaves me thinking that if we figure out how with our cavemen brains to subvert dice by hitting them with a gazelle femur or we have to like evolve up to this new level of thinking where we can accept the idea that things have superpositions. Which is kind of like/ I mean, social consciousness is/ that is a sign of emotional maturity and social maturity is when you stop insisting that someone is either a good person or a bad person or that they're racist or sexist or that you know and start, like, understanding that it's possible that they're just an individual human with all kinds of strange random things going on. And that your direct observations will affect those things and get a result but all people around you are in a superposition of being either good or bad or both. Neither here nor there. And we kind of struggle right now as a society to you know, to rise to that. We're having riots and tear gas exploding everywhere because at the point we're in we need to start getting that we're all people, that we don't have a predetermined values or we're gonna perish.

39:09

Ben: Mhm. Yes.

Ken: Yeah, wow, exactly.

Ben: Hey, do you wanna hear about the

Ken: Do you wanna hear about entanglement, Dan?

Ben: The quantum mechanical analogue of that.

Ken: Yes.

Ben: So, entanglement is one of those things. Essentially it's a consistency thing. It's like the lunchbox. So, in the case if it was a quantum lunchbox what'd happen is you wouldn't say "Hey, there is definitely one apple in this it's either red or green". You would say, "The apple in this is a superposition between half red and half green and when I open the lunchbox, it's gonna decide to be red or green". And then so when I open the lunchbox, it doesn't just tell me "Okay, it's a red apple". It also determines that the apple in my brother's lunchbox is green.

Dan: Right.

Ben: Right?

Dan: Okay.

Ben: That's super weird. Because your immediate reaction is, say, well - you know it was never a superposition. It was always red. And my brother's was always green and I'm just figuring this out. I'm just discovering the truth.

Dan: But that's not a good way to survive. Like, that's not a proper way/

40:11

Ben: Yeah, right. I mean, if you do this with opinions, you're still six years old. Things are complicated, like you said. So, the trick is that people say "No, it was probably the one. The reason we need statistics to describe what's happening in this quantum mechanical systems is because we have incomplete information." So it's just like you saying "Well, there's a 50% chance that it's a red apple, 50% chance that it's a green apple. Fine. My sense is that it's either one or the other but I have to treat it like it's both until I measure it". Okay? So that's what Einstein guessed. That's what he was always saying. He was saying "God doesn't play dice. There is an underlying reality to all of this and we just don't have complete information about that underlying reality and that's why we need to treat it as statistical". And that argument makes a lot of sense. Sometimes it's referred to as a hidden variable argument, as in there's some information in there that I don't have a grasp of. And it's that missing information that's the reason I need to treat things statistically. And so my statistical arguments work really well but it doesn't really tell me what's going on under the covers.

41:19

Dan: You know, we do this all the time when we're breaking stories at Community. Like, we because I've always been obsessive about codifying story process and so it happens all the time where we, we have to take a step back and we have to go "Okay. Look, I'm not sure if this story is about Annie or Britta - two characters in the show. Let's move forward along this story process and assume it's either of them". Because what's more important is what happens from one moment to the next to a human being. And then we start to/ we decide later on whether this is happening to Annie or Britta. In order to get unstuck in a writing process you have to become less sure of everything but you can't just as a writer stand back and say "I don't know, anything" because that makes you a bank teller. You're not gonna write anything. What you've got to do is proactively say that everything. You know, you have to move forward, assuming everything is true, in a sense. At least in a couple of instances. Like, multiple characters are going to have this happen to them. Either this is the episode where they get snowed in or attacked by killer bees but in either case Pierce is going to learn to be less racist and why would that be. And therefore you deduce, you figure out over time whether it should be killer bees or an avalanche based on other stuff too. Because there's/ and it's because, as you're saying, it's because we don't know enough. It's because there's more to it right now and there's an unknown variable out there. And maybe if we knew that, we could pour a perfect story into a bottle and just take all the creativity out of it. But physicists are having to think a little bit more like, you know, Boy Scouts, being prepared for everything as they make their calculations because there is stuff you guys can't currently measure and by the time you measure it you have affected it so you have to start thinking very practically. Which happens to be very zen to outside viewers because it appears to us that you guys are saying multiple things are true at once which seems very spiritual and strange and not at all like physics.

43:47

Ben: So the question is: is it that it was always one of them and we just weren't sure or is it the case that it was both of them at the same time until, at the end, we do the measurement. And that's the question people struggled with for a long time and the answer is going to blow your mind. So, the deal is, Einstein's big thing was relativity, right? His law was nothing moves faster than the speed of light. I'm sure you've heard. So, Einstein, Podolski, Rosen together wrote a paper. It's called the EPR paradox. And so Einstein said okay - let's suppose you got this particle but we could just as well talk about lunchboxes with apples in them. So your quantum mom decides to put one apple in one, the other in the other and so because she's quantum mechanical we treat it like it's a superposition of both. Fine. So one lunchbox has a superposition of red apple and green apple, so does the other one. You go way off in the Andromeda nebula light years and light years away, you open your lunchbox - it's a red apple. Now, Einsten, Podolski, Rosen said: "According to this interpretation of quantum mechanics where it's both at the same time, where it's a superposition, this means that somehow the information"/

Dan: Something is moving faster than light.

Ben: Yeah.

Ken: You got it.

Ben: The information that you've got - you open a lunchbox, it's a red apple and then it sends a faster than light telegraph, maybe back in time, to the other lunchbox saying "you have to be a green apple". It's called the EPR paradox because, you know, the argument that this is what happens is consistent with how we talk about quantum mechanics but information travelling faster than the speed of light, that's entirely taboo. And so he said "Hey, what's it going to be?" It was a convincing argument for a long time but then a guy named Bell came along and thought kind of hard about it. Hm. How should we describe it for/ let’s talk/ let’s get off this EPR train and talk about quantum cryptography just for a second. We mentioned it before. The deal is that we can use entanglement to build a cryptographic key.

45:48

Katherine: Add quickly that the only provably secure method of cryptography is to develop a key between two people that you only use once and which is the same length as your message or longer and then throw it away when you're finished.

Ben: So, imagine you're trying to e-mail your password to your bank account to your partner who lives in Switzerland. How do you send those numbers to your partner without somebody intercepting them and then breaking into your bank account themselves? One tried and true method is - you come up with a number 10111, whatever, a whole bunch of numbers. You have that number, your partner has that number but nobody else other than the two of you have that number. So you're going to use that number to change the information you send him. You're gonna add that number to it or subtract it or something like that, multiply it - who knows? So the end is - you send him a number that isn't actually your password and then he has the uncoding key that he can use to decipher it and find your actual password. And then if somebody intercepts it on the way through, they've got nothing. So, various problems with that. We were talking about internet security before. Essentially that's what happens - you both have a number, you're encoding your information with that number, your buddy's decoding it and then anybody who intercepts it would just get garbage numbers. So, there's a way to use quantum mechanics entanglement to do it. What you do is, you say "Okay, I'm gonna have a machine that spits out entangled particles". It's gonna send me one of the particles and it's gonna send my buddy a particle. And the rule is, just like with the apples, if I measure my particle and it's a 1 then when he measures his particle, it's gonna be a 0. And vice versa. And the deal is that as long as the two particles are entangled, I'll do my measurement, I'll get a list of 1's and 0's, he'll do his measurement and get a list of 1's and 0's and those 0's and 1's will be opposites of one another. Every time I get a 1 in my chain of numbers, he'll get a 0. And so I can use mine to encrypt the information, he can use the fact that he knows all about it to decrypt it. It's very secure but the fantastic thing about this has to do with the fact that nobody can intercept these two numbers, right? The deal is, okay, suppose we've got essentially a train of numbers going out to my buddy in Switzerland, a train of numbers coming to me, those particles are entangled. Let's suppose Katherine decides to spy on me because she wants all my lucrative physics podcast money. She intercepts the train coming towards me and she measures each of those numbers. In doing so, she gets a list of numbers but she sends the train on to me, which is fine, when I do my measurement, the numbers, since kind of they're no longer coupled together particles.

Dan: They've been observed.

Ben: They've been observed.

Ken: Exactly.

Ben: And that means that when I try to observe them, they might still be random numbers, they might still be a random strings of 0's and 1's but they're no longer, because they've had a chance to do whatever, they've been interacting with things, they're no longer entangled with the train going to Switzerland and so my 0's and 1's won't match up with my buddy's 0's and 1's.

48:48

Dan: Well, wait. What I thought would happen is that Katherine's numbers would be the same as the ones you've got when you looked at them too but you would have no way of knowing that they've already been observed by Katherine or that Katherine therefore, she would have the mirror reflection of the other quantum apples heading for Switzerland and therefore she would have the encryption key.

Ben: The thing is that Katherine might have a set of numbers, I'll have a set of numbers, my buddy in Switzerland will have a set of numbers - they'll no longer match up.

Dan: Oh, so they only match at the moment that Katherine measures them and then they keep on and then you measure them and then they give you a different random die roll and/

Katherine: My measurement would stop Ben's numbers matching up. So before you send your data using this key, Ben and the guy at the Swiss bank account would send a small amount of numbers between them and see if their numbers match up. If their numbers don't match up, they'll say "okay, this key doesn't work, it's been hacked, we won't use it".

Dan: Aaah.

49:48

Katherine: So, they do the test at the end to see whether I've stopped their numbers matching up. And if I have, they say "Okay, this is a bad key now, we shouldn't use it".

Dan: Interesting. So, as you said, Katherine, quantum mechanics aside, just in pure cryptography theory, you said the only perfect unhackable cryptographic method is, as you described, like, one key that equals the length of the message - two people have it and then you throw it away after you're done with it.

Katherine: I wouldn't say it's the only non-hackable one. It's the only one they've proved is non-hackable. Which is a slightly different statement. Because the others as far as we know it are not hackable but they might be.

Dan: Right. The only theoretically perfect one. Not that we necessarily need it. So, the idea is that we're sending superposition apples to Switzerland and to Ben and if Katherine did intercept the train headed to Ben, she makes the apples' superposition pick red or green in each case, thereby the apples heading for Switzerland are now contaminated but no one would know that by looking at them, right? No one's gonna know except that when the train gets to Ben - not to Switzerland but to Ben - what are we doing, we're looking at the apples and we're/ are we able to/ how are we able to test to see if the seal's been broken?

51:13

Ben: So, it works for apples because Katherine will check the apples and write down if they're red or green and then close the lunchboxes and I'll open them and the red one will still be red, right?

Dan: Right.

Ben: It doesn't work for quantum mechanical particles because Katherine will close lunchboxes and then they'll go back to being a superposition.

Dan: Okay. Are they still entangled? Are they still/

Ben: No.

Ken: Yes, that's the key.

Dan: Okay.

Ben: So, the moral of the story is: she messes up the entanglement and then so the keys that we're using do not match.

Den: Oh, so if we were at war, Katherine could sabotage your entangled communication line because that would just make them not function. But she could never actually intercept any messaging.

Katherine: The key thing to understand is when you're sending the apples, you're not sending a message. You're just sending a random list of red and green. So you're sending the key that is gonna be later used for the message. And because you can tell whether the key has been hacked you can decide not to use it.

Dan: Right. This isn't the message, this is the key.

Katherine: This isn't the message, the message is gonna be sent later using the data from the apples.

Dan: Got it.

52:18

Ben: So the question is, is this really the case? Like, is it the case that it's truly just a random number or is it like Einstein maybe suggested. There's some underlying reason why the numbers all match up and that there's some hidden mechanism behind it and it's just law that one's red and one green the same as like if your mum just packed your lunch and you didn't know what it was. And then comes Bell, we mentioned his name earlier. Ken, tell us about the Bell thing.

Ken: Yeah, so we're in the mid-60s. This guy Bell proposed that there aren't any hidden variables essentially. That the problem is in the quantum mechanics is incomplete. That there's actually no problem here. And he did it by setting up a really cool system where he could actually/ it's an experiment that actually students in my fourth year lab do. Where they generate two photons, essentially, that are entangled, because they're generated in the same process and then they measure their polarization. So, light has a polarization which has a direction. They essentially set these two photons, they set them out two different directions and they use different detectors to measure them. And then they look and see how often those photons get like the same results, so each one was polarized in the same direction or if they get different results. And Bell, his whole theory was, that you can use this system essentially to test whether there are variables that we don't know or whether the process is just random. It's just literally random numbers. And so he did it and many people have done it since and the students continue to do it to this day and most of the time they actually find that it's really just random numbers. They do this whole experiment, determine this whole thing and find that at the core of things everything is based on random numbers. And there's not something going on we don't understand. In the case of the students, I don't know if they get that results just because they want to get that result but it has been repeated a lot of times and we're pretty confident now that there aren't these hidden variables that we just haven't found yet. Quantum mechanics is an adequate description of a system as a whole. Which is cool. Which is a pretty neat result to be able to get from this relatively simple experimental setup.

54:22

Dan: Uh... yeah, I guess. I mean.

Ken: [laughs]

Ben: I guess to put it in context, the question at hand is, okay - are these, like two spinning dice, where it's actually spinning and if I knew all the information about how it was spinning, I could tell which number it was gonna land on. But I don't, so I treat it like it's gonna be/ you know, it could be any number. Is it like that or is it literally a statistical object where it's one thing on one day, another thing another day, entirely random. And what this test says is that at the lowest level in terms of particles, how they interact, there's no knowing what they're gonna do. It's truly random. Random is the theoretical bedrock of this. There's no us saying "well, if I knew more about how the dice was working, I could figure out what number it was gonna land on", there's no underlying mechanism for why one turns out one way and the other turns the other way. It's just an entirely random thing, which is crazy because it means that yeah, literally, us studying one particle will change the superposition in the entangled particle, even though they're far apart.

Dan: I still don't get why Bell's test proves absolute randomness. Because it bounced off of my layman head as just being "Oh, Bell developed a way to roll dice over and over and over again" and then there's always a different number. How do we know that that means actual randomness as opposed to something that we're not seeing yet?

55:46

Ken: Yeah, that has nothing to do with your understanding and everything to do with the explanation. Because the math gets incredibly complicated on how actually the measurements are done. It involves looking at like different measurement systems and things like that. So, I kind of intentionally glossed over a lot of details about why it actually means this. So that's on me, not on you.

Dan: But suffice to say, Bell created a method of proving that, well, I don't know. I mean it seems like such a jackass thing to say "Bell created a method to prove that there's no unknown variable". I don't accept that. I refuse.

Ben: I know, right? Bell's inequality is all about, it's not a test to say "is this random?" It's a test to say "okay, if there is an underlying variable, you do this test over and over and then you kind of metacompare your answers". And if there is an underlying variables, when you do your tests and you add together all the numbers just right, you end up with a number. And that number's either above the threshold or below a threshold. And if it's below a certain threshold that means that there is an underlying mechanism. Whew. That's a bad explanation. Moral of the story is/

Dan: I mean, if we're looking for a correlation that we have yet to detect, I don't understand how a test could test for it.

57:00

Katherine: Bell's inequalities say that any list that you can imagine, so they assume a property of locality, which is what I do over here can't affect what's happening to you faster than a light signal can reach you. And they assume certainty as well, so if you make a measurement you get a certain result - you can't have randomness which is the people have decided is not true from Bell's inequalities. And so they say, if you have these properties, if you can imagine measuring the particle and you have locality and you have certainty, then if you're measuring the particular property of that particle, there must be certainty, so this must always come out as this. And it must be local so that means you are the particle that Ben's measuring if he makes that measurement, it must come out as this. And so it assumes that you have such a list, you know, if I measure this property of the particle and Ben measures this property of the particle, we must get these results. And it then calculates what would happen between my results and Ben's results if we did these measurements and find a particular number limit on what number you'd expect to get out. And what you find is you can get a number higher than that which suggests that you can't make such a list, because/

Dan: I see.

Katherine: Any way of making that list would give you this number or lower and you've got measured a number higher. So it can't possibly be described by this list. I'm not sure if anyone wants to clarify what I just said a bit.

58:31

Dan: Yeah, I mean that's as clear as I've gotten so far. It almost sounds like it's some sort of sticking a big long stick into a pit of randomness and seeing if there's a bottom and there isn't, meaning that there's true randomness. So you're using on the A-side, you're actually choosing certain things position-wise and measuring the relationship between that and the second result, the B-side. And there's nothing about the relationship between A and B that has ever suggested any kind of certainty even inexplicable certainty, it's always, like, functionally random.

Ken: Yeah, I guess it's like rolling D20's and if you keep rolling them, you know just by random coincidence how many times they'll line up. But if they're not completely random then you'll get a different ratio - they'll align up either more or less depending on what you're doing. So it's that kind of thing. And you can qualify "okay, it was complete randomness that judged how many times they lined up" or "wait a second, I don't know what was going on but something else was going on because they lined up more than they should have or less than they should have".

Dan: Got it, got it. Okay. That makes sense. There's a way to test for true randomness the way there is a way to test for true levelness of a table - you don't have to know how the table works or why the tables are level but you can put a bubble on a stick and see if the table's level. And so you can also take a system of dice and make sure that there's not something hinky going on with one of the dice because you can measure relationship between die rolls over time.

60:08

Katherine: I have to be careful with it. There isn't a test for true randomness because they can't determine whether computer randomness is true randomness or not. That's quite key point in maths. What there is a test for is determining that you couldn't make a list that had the properties that would give you this effect that we get from quantum mechanics. And therefore it appears random. But once you have a list of numbers there's no test to test whether they're truly random.

Dan: Got it.

Katherine: I think that's certainly a key point that most computer scientists would want to emphasize.

Dan: So we are mammalian species bound by Newtonian and thermodynamic laws that as we have gotten smarter and smarter have managed to look deeper and deeper into the matter that we're made of until we've finally found out that it's all a bunch of crazy random Matrix numbers.

Ken: Yeah. That pretty much sums it up.

Dan, Katherine: [laugh]

Dan: Well, what are you guys gonna do with the rest of your careers?

Ben, Ken, Katherine: [laugh]

Katherine: I work in patent law now, so... [laughs]

Dan: [laughs]

Ben: Well, that was fun. Than you, Katherine. Thank you, Ken. You've pleased me, your effort have borne fruit and that fruit is sweet. Here's some fruit. Ken, you get a superposition of mango and blueberry.

Ken: Nom nom.

Ben: All right.

Dan: [laughs] This is insane.

Ben: And Katherine, you get a red-green apple.

Katherine: Nom nom nom nom nom.

Ben: And Dan, because you requested, you can have the pair of the red-green apple, so the green-red apple.

Dan: Nom om. Nom om

Ken, Katherine: [laugh]

Ben: All right. I'd like to thank my guest, Dan Harmon. Thanks for coming on, Dan!

Dan: Thank you! Mine was red!

Katherine, Ken, Ben: [laugh]

Ben: Everyone, you should listen do Dan's podcast Harmontown. It updates more often than my podcast and you watch Community. It's on Yahoo! Right?

Dan: Yeah, absolutely.

61:59

Ben: Well, wasn't that fun? That was really fun. I really enjoyed making this episode. Okay. So, it's announcement time. First, Question Barn. These episodes are really fun to make so if you have some questions, you'd like barn the bunny to answer, email them to tiphyter@titaniumphysics.com. I've got a big pile of questions to go through. They're really fun to make. Okay. Next: good news, everyone! Patreon campaign is going well, we're getting the transcription train going again. This is all pretty fun. So, we are accepting your donations. You can either support us on the Patreon website or you can send us one-time donations using PayPal through our website. So, on that note, this particular episode of the Titanium Physicists has been sponsored by collection of generous people. I'd like to thank the generosity of Tony, Sam and Ed Bougue and Operation Longboards. I'd also like to thank Robin Johnson, madam Sandra Johnson, Mr. Jacob Wick, Mr. John Keese, a Mr. Victor C., Ryan Close, Peter Clipsham, Mr. Robert Halpen, Elizabeth Theresa, and Paul Carr. A Mr. Ryan Noule, Mr. Adam K, Thomas Sharay and Mr. Jacob S. A gentleman named Brett Evans, a lady named Jill, a gentleman named Greg, thanks Steve, Mr. James Clawson, Mr. Devin North, a gentleman named Scott, Ed Lowlington, Kelly Wienersmith, Jocelyn Read, a Mr. S. Hatcher, Mr. Rob Aberzado and Mr. Robert Stietka. Well, that's it for Titanium Physicists this time. Remember that if you like listening to scientists talk about science in their own words, there are lots of other lovely shows on the Brachiolope Media Network. Science... sort of is really fun, it's got scientists talking about science in the news and explaining thins; and, oh boy, Collapsed Wavefunction is about chemistry; there's loads of fantastic shows. So please, check out the Brachiolope Media Network. The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. So good day, my friends. And remember, till next time, keep science in your hearts.

64:19

[Outro song; *Angela* by John Vanderslice]

65:04

Dan: I just wanna know what you picture when you go "boop boop boop". Are you being pieced together or you are blowing up as a series of bubbles or/

Katherine: I wish I could say something but I just had to think of a sound.

Dan: [laughs] Yeah, I was/ that was a good sound. Way better than that stupid "Whoosh".

Ken: Oh, I agree.

Ben: Ken Clark's "Whoosh" is a pun on the fact that his name sounds like Clark Kent's.

Katherine, Dan: Aaah

Ben: Yeah.

Dan: Dangers of being a guest on a podcast you've never heard. Coming in here not knowing the funny jokes and/

Ben: I've never explained Ken's "Whoosh" sound to anybody. I'm really surprised it's first time we did it.

65:58

Dan: I don't wanna derail you guys but I'm so curious whenever we talk about this stuff, cause all I read about in books, "Oh, Newton found this then Einstein found that, blah blah blah". We romanticize it, as you were saying in your introduction, like we just turn it into this biopic. I just/ I've never understood what it is physicists actually, like, spend the bulk of their time doing. Like, do you guys/ is it really just math? Do you sit and stare at numbers? Do you try to, like, figure out/ I just don't even/ Like, what does the average physicist spend/ If they're theoretical cause you need to get specific about the type of physicist. Like, is there someone who just sits there and just stares at a blackboard full of numbers or is that some just movie trope? Like you're trying to solve an equation, as if it's a crossword puzzle or is there/ I mean, I know there's actual lab work when you get into like smashing particles together, 'cause I've seen that on TV but I just/ I've never understood. I know there's so much important work being done and I don't understand what it looks like. If you were actually/ if you were to spy on it.

Ben: It does depend. And it depends/ assume you're a theoretical physicist. And it kind of depends on your approach to things because there's all sorts of things that theoretical physicist could do. We mentioned before another of these different echelons of/ in my introduction there were kind of different echelons or size scales that we understand how the Universe works, right? So we know that at the very, very large scale General Relativity is the thing. On the very small scale Quantum Mechanics is the thing. One of the things physicists try to do is they try to kind of bootstrap their way up. They try to discover how one theory is consistent with another theory. Like, is there a way we can explain how the small laws all add up together to get one of those big laws. Another thing a person can do is they can/ Like, I was one of the more mathematical types of physicists. Sometimes they do stare at equations. And they say "I know a way of interpreting these equations. I know a procedure we can do to these equations. Let's do that procedure and see if we can find anything new". Or we might say "You know, when I imagine these things swirling around each other, I imagine that such and such an effect happens. Let's see if I can find that effect in the mathematical equations". But in addition to that you can/ the types of theoretical physics you can do is to say "Well, they're building a great big detector over in Switzerland. I want to see if we can detect this one type of particle or this one type of effect". And then you can do work to try. You plug in numbers instead of just working with bare equations, combining equations, you start to chart. You plug in numbers to see if you can sort out what kind of effect would be detectable. So there's all sorts of/ There's every type of physicist under the Sun. We're looking at equations every type they can, to be honest.

Dan: I think I could imagine that/ if I could just use television production as a metaphor, if I asked the same question about a person that makes TV. You could peek in and see somebody behind the camera, shooting a scene with an actor and it would look physical and it would have this process to it and this 9-5 schedule and all the stuff. And you could also peek in on an equally important thing where there's just a guy sitting there, being frustrated and might literally be just looking at a blank whiteboard. And there might even be a person sitting somewhere, you know, thinking about the thinking about it, which I have done for a long time. Like, thinking about how stories should be structured and sharing that information with other writers and then having them peer review me. And people trying to execute those things as you say with experiments and see how they work out and blah blah blah. So, I guess I could/ I guess it's too/ Yeah, you would have to ask somebody really specific that came for a dinner party "What do you do for nine hours a day?" and they could physically describe but you can't just ask that about a physicist.

Ben: Yeah, no. I think your comparison is apt. Because there really is all sorts of room for, you know. Somebody could just say "Hey, we saw this weird plot thing happen on reality TV. Is that a good plot? People seem to get excited about it, let's write that into our next script", right? There could be people who metathink how to put together plots and there could be people whose job it is only to take scripts that other people have written and, like, erase stuff that's bad.

Dan: Right.

Ben: Yeah.

Ken: Yeah, I mean the physics that I do is more experimental but recently the detector I work for at the South Pole found some really high energy stuff that nobody could explain. So that fed into the theory world which then went crazy for three or four months trying to explain this kind of thing. So, I think it is an apt description. You see something and then you try to "Oh my God, how did this happen?" and everybody goes off and stares at their whiteboards and makes their equations and then comes back and says "This is how we think it happened". So, yeah.

Dan: Did you get fired for that? Was it/ you just had to plug it back in, right?

Ken: No, no. That wasn't us. Wait, wait. I wanna be very clear here. The faster than light neutrinos was not us. Ours was an actual discovery that we found these things. So, we didn't have to just plug in the cable again. [laughs]

Katherine: I think there's also a lot of work that goes into/ so, ours in the field of quantum computing was how we realistically we get this to work. What kind of way/ how do we correct the errors, how can we make them small. So there's actually quite a lot of work going on to potential practical applications which I think is also reflected in the funding available particularly in the UK and I imagine the US as well. I don't know. Others find out how to develop new technologies that can be of interest to governments or private industry and private industry does fund research. There's interest for them in developing new materials and things which [incomprehensible] leads

Ken: As far as I know, we just sell everyone Twinkies and then we take 10% of that, put it in the missiles. I don't think there's actually any funding of science going on over here anymore.

Ben, Katherine: [laugh]

Ken: And some tiny fraction of this 10% might go to scientists 'cause they might be able to make better missiles.

Dan: But they gotta really prove it.

Ken: [laughs]

72:33

Ben: This is part of the resolution to the EPR paradox. In this sense information isn't travelling between one lunchbox and the other. You open one lunchbox and it's either gonna be red or green. You open the other one and it's gonna be either red or green. There's nothing you can do to keep those numbers from being random but they are affiliated with one another. And so you're not transmitting any information and there's no way to transmit any information because the variables are truly random. So, you know, you say to Einstein, "Well, yeah. One is affecting the other but no information is being transmitted. They're both still random numbers. They're just associated with each other". We can use that to encode information and send it back and forth but in encoding the information, I have to send that slower than light.

Dan: Alright. So there's nothing travelling faster than the speed of light because reality is just reality. Those things are entangled or not entangled, right?

Ben: Yeah, because random is random.

Dan: Yeah, you don't have to send a message to your particle brother saying "you should be random". You do have to send a message - in theory - saying "you should be this". But that, isn't that/ If you're able to do that, theoretically, if we could take entangled particles and set up a telephone using them somehow on Earth and then put them on Saturn, the other half of them. Isn't there some way that we can set up a way to communicate faster than light? I mean, we'd have to lower than light separate these things, keep them from/ you know, preserve their entanglement. Rocket ship goes to Saturn, sets up this phone booth, rocket ship stays on Earth, sets up this phone booth, we very carefully preserve the entanglement of these particles. Theoretically, if there was a way to create actual telephone out of that system, then that means that the message over the phone that we send would be travelling faster than light.

Ken: But we would have to have the ability to set whether the apple was red or green in the lunchbox, so that they would have the opposite, right? And we can't do that. We can only open it and see what's there.

Dan: Ah, that's so sad.

Ken: I know. It really ruins faster than light communication, which is bummer.

Dan: [laughs]

Ben: I mean, we can't even tell when somebody on Earth has opened their lunchbox. So let's suppose that you're like "Okay, Ambassador, I'm on Earth. As soon as we go to war, I'm gonna open these lunchboxes and then when your superposition collapses on Saturn, then you attack", right? There's no way on Saturn to open the lunchboxes and tell whether or not/ you know, your only information you have is that you've done an observation. You can't tell if it was collapsed before you did your observation. You open it, you observe it. It's either red or green and you're like "was it red a moment before I opened this"? Because the wavefunction got collapsed because they've observed it on Earth or was it just green 'cause it's randomly green?

Dan: Oh, come on guys. There's gotta be a way around this. I mean/

Ken: It just sounds like we're saying that physicists continually ruin science fiction.

Dan, Katherine: [laugh]

Ken: What's going on here?

Dan: Yeah, I mean it's like the cellphone ruined horror movies for ten years, we finally figured out how to solve that. But people escaped from Alcatraz using sack threads and mice. I mean, we can/ there's gotta be a way, using superpositioned apples on Saturn and Earth to make a phone that transmits your voice faster than the speed of light. I mean, 'cause you could/ I know you guys have thought about this a long time but I'm just walking in and saying that I know there's a way to do this.

Ben: It certainly sounds like there is except that if a system of number is really random, then by definition there can't be any information in it. So you open your lunchboxes and you know whether it's green or red - it's a 1 or a 0, say. That would give you a train of truly random numbers. And there's no way to communicate any information through a chain of random numbers.

76:23

Dan: You know, you say, okay, on October 15th at 3:07 AM I'm gonna open this lunchbox then you're gonna do it at the exact same time as me. And/ Uh, I don't know where you go from there.

Ben: Let's suppose we said, okay, we're gonna open our lunchboxes at the same time. There's no way for you to tell that I didn't open my lunchbox 5 minutes too early, collapsing your wavefunctions in your lunchboxes. There's no way for you to tell that happened based on looking at the numbers that you have. The only thing you can do is travel slower than the speed of light, come back home, compare lunchboxes and go "Oh yeah, they match, fine".

Ken: That doesn't make much of a movie.

Ben: No.

Katherine: That's also not much useful information because you already knew you were gonna get the opposite color of apple. So, you haven't gained any information in that context. You know since you've both opened your lunchbox, you know what color his apple was.

Dan: Right. Well, obviously the end result we want/

Katherine: You knew that from what your color apple was. There's no data anywhere.

Dan: Right. I mean, the end result we all know we want is you to be able to make a camera that points at my face and converts it into red and green apple values at which point the television on the other side, like, you know, automatically turns red and green apple values, you know, inverts them and turns them into an image of my face for somebody instantly, faster than the speed of light. But we can't do it. Seems like with every method of communication, like with the transatlantic cable, I'm sure you're like, you know, it must have been ridiculous at a certain point when you're rowing in a boat, like you're hooking up all the telephone lines. There's probably somebody who spent their entire life stringing up the cable just so that you could talk to people faster than a boat could travel. But, um, that's so frustrating.

Ken: And little did we know that now we just use that cable to watch cat videos.

Dan: [laughs]

Katherine: I think the key thing is. I know more, so I was insistent on it. If you could transmit information faster than light, relativity would be wrong which would be considered a disaster, so as soon as you get something that says you are transmitting faster than light, you think "what I have done wrong, why is my calculation wrong?" and normally you do find your error as with the faster than light neutrinos experiment.

Dan: So you guys just don't let that first phone call to happen. 'Cause it's two scientists who going "-Hey, James, is it you? -Yeah, it's me. Uh, oh shit."

Ken: [laughs]

Ben: So, Einstein was concerned about this, specifically. He was like, "well is stuff gonna travel faster than light or not?" And the way we've answered the question so far is very legally, right? We're like "Well, technically the other wavefunction collapses. But you can't transmit any information by that". It may very well be that that's true and that it's like a law of thermodynamics or something. People spend their lives trying to build a perpetual motion machine. The law of thermodynamics says that it's not gonna happen. But they still try to, right? People might still try to move information faster than speed of light using this method. And we're not sure, you know, I don't wanna be the person who says "no, it's impossible" just 'cause what if I'm wrong but the speed of light being the speed limit might be a physical law at all levels.

Dan: It's time to yank it, time to pull the plug. I know it seems like a weird place to do it but I'm saying we can go "Yeah, speed of light is the speed limit, forget it". That's just back to square one.

Dan: So if you dig deep enough, you're gonna find a world that doesn't play by your rules. I mean, if you were in a computer simulation and you dug deep enough, if you were in an extravagant enough simulation, isn't that what you'd find? Like, if you dug deep enough? If your simulation was so sophisticated that it included atoms and atomic particles, wouldn't the scientists within that simulation eventually come to a point where they discovered random, not a random seed but just randomness? Because they never can find the seed because the seed was hidden from them? An (...) that existed outside their world? Because they were in a simulation?

Katherine: I think the question is it really depend on what the person doing the simulation was programming in and how they've programmed it. If they programmed our world as a deterministic world, then we wouldn't get randomness.

Dan: Oh Katherine, don't act like you don't know.

Katherine: If they programmed it as a world with imperfect, computer-generated randomness, we'd get world with those properties and if they generated program on a quantum computer a quantum randomness, presumably our world would have those properties. So I don't think the fact that we get this random results can be used to say "we are in a simulation" or "we're not in a simulation". It doesn't tell us any more or less because/

Ken: Wouldn't that be the exciting part? It doesn't rule it out.

Dan: Right. [laughs]

Katherine: Yeah. [laughs]

Ken: We haven't said that there is a science fiction movie here that we haven't/ physicists haven't ruined yet.

Katherine: Yeah. [laughs]

Dan: Yeah, and moving forward as emergent creatures of a quantum universe, we can now know that we are both in a simulation and in not a simulation.

Ben, Ken, Katherine: [laugh]

Ken: Well done.

Dan: We are in a super position to have a great day.

Ben, Ken: [laugh]

Ben: We should put that on a card. And then give it to physics graduate students when they graduate.

Katherine, Dan: [laugh]