Episode 49: Parallel Philosophies with Christopher Reynaga

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The Titanium Physicists Podcast

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Ben: Hi everybody quick note, first you can give us donations on our web site. Drop by our website. You can give us donations using Paypal. You can give us donations using Patreon. Life is pretty cool. Secondly, I'm going to start a question and answer show called the *Question Barn* hopefully weekly with me and another Titanium Physicist, whoever can answer the question. Send me your questions at Tiphyter@titaniumphysics.com. And hopefully in September if we have enough questions we can start making these shows and they'll be really fun too. Okay, here's the show.

Ben: Oh hello old friend. It's good to see you. Let's talk about this word "fascination". It describes an unquenchable urge which compels our hearts to quest and be captivated. As long as there are elegant explanations to complicated phenomena science will never lose its romance. Over the years I've traveled the world indulging in my fascination of 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 have 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 Physicists* podcast and I'm Ben Tippett. And now allez physique!

[2:23]

In the early decades of the 20th century it became clear that Isaac Newton's mathematical apparatus for describing how the world worked was breaking down. At that point in time there were particles, things you could count, they had mass, they moved in straight lines. And then there were waves, and waves they go up and down and a spread out. And if you want to describe them you need to do it in terms of distributions. They aren't really in one place. Waves are described in terms of having wavelength like how long they are, and a frequency, how fast they're going up and down and a speed that they spread out. But like I said, there were troubles, light for instance. We had a theory about how light worked. The theory said that visible light was just a type of electromagnetic wave. But there was a mystery at the turn of the century call the photoelectric effect. And the deal is that if you shined certain types of light on a metal electrons will start popping off the metal. Now we can provide electrons the energy they need to free themselves in one of two ways, like we could either shine a little bit of purply-colored high-frequency light at them or shine a lot of low frequency red-colored light. And as far as light goes energy is energy. But the electrons would only pop off the metal if it was the high frequency light. They couldn't escape the metal if they only had lots and lots of low frequency redish-colored light. And Albert Einstein was the guy who figured out the answer to the mystery. He argued that when light carries energy it does so the way a stream of particles would and the higher the frequency the light, the more energy each particle has. So the deal is that when the electrons interact with the light, a packet of high energy is enough to let them escape but several packets of low energy aren't because they're only taking it in a packet at a time. Now in forming this argument Einstein invented the photon. And he argued that electromagnetic waves have a particle quality and we refer to this as the wave-particle duality because it's both a wave and a particle at the same time. If waves sometimes act like particles, the results of other experiments in particle physics at the time could only be explained using the argument that particles sometimes act like waves. And so in the 1920s the game was afoot to try to come up with a decent way to explain how a wavy-particle evolved. And Erwin Schrödinger was the man who won this prize by introducing his Schrödinger equation. It was a mathematical framework for describing how particles that behave like waves evolved. And so from then on we've had proper quantum mechanics equations to work with and they do a very, very good job at explaining the experimental results that we see. But the problem is we understand how to use the equations but unlike every physical theory that came before this one there really isn't a formal philosophical interpretation that accompanies the theory. The problem with quantum mechanics is that we really don't know what to imagine is going on when we're working with the mathematics. And while this isn't an urgent mathematical problem it's still a weird philosophical issue. And different philosophical schools have evolved to explain what we should be imagining and you might have heard of some of them. The most common and commonly accepted among physicists is the weird Copenhagen interpretation which says nothing is anywhere until somebody looks at it. Anyway today on the Titanium Physicists podcast we're talking about schools of interpretations of quantum mechanics and even the weird many-worlds interpretations. And speaking of things we don't know what to make of Christopher Reynaga is the author of my favorite short story "I Only Am Escaped Alone to Tell Thee" which is a story about how Captain Ahab fought Cthulhu. It's amazing. It's my favorite. And it's been featured on the *DrabbleCast* as an audio recording and I'll post a link to that on the web site if you want to hear it. It's great. Anyway, Christopher Reynaga has won the Bazanella Literary Award and the Writers of the Future Award. He's a fantastic author and I'm so excited to have him on today. Hello Christopher.

Chris: Hello. Thank you so much. I'm really happy to be here.

Ben: Awesome. So for you today I've got two fantastic titanium physicists. Arise Dr. Ken Clark.

Ken: Awoosh.

Ben: Dr. Ken did his PhD at Queen's University in Kingston Ontario. And he's currently an assistant professor at the University of Toronto where he's an expert on neutrino detectors and dark matter. And arise Dr. Tia Miceli.

Tia: Boing, boing, boing.

Ben: Dr. Tia did her PhD at UC Davis and she's currently a postdoc for Mexico State University posted at Fermilab where she's an expert on neutrino particle physics.

[6:58]

Ben: Alright everybody let's talk about the weird quantum world. Alright so Christopher, quantum mechanics is weird right. I guess the weirdest thing about quantum mechanics is this idea called wave-particle duality. I mentioned it in the introduction in the context of light which is a wave acting like a particle but there are experiments that demonstrate without a doubt that particles behave like waves, which is weird. So before we get too deep into the real crazy quantum stuff, we should probably talk about waves. So the big thing about waves is this: it's called the principle of superposition. I mean I'm sure you've seen it, you take two rocks and you throw them into a lake and you get waves right? Particles bump into each other and they interact. But waves don't. They just kind of pass through each other. And so what you'll see is in the pond there will be these two sets of circles both being emitted by where you threw the rocks in, moving outwards. So over time these circles get bigger and bigger. You see from above that they're circles but what's going on is if you took a cross section of the wave you'd see that there are places where the water is higher and places where the water is lower. And it goes up and down up and down. And the principle of superposition says when these two waves pass through each other the height of the water is just the two waves added together. So where two really high peaks of waves meet you get the water being extra tall and where two troughs meet you get a place that's extra low. And if one of them is high and one of them is low they might cancel out and you get kind of a normal height spot. And one of the experiments that you can do with waves is called the double-slit experiment where in essence you take a big box, like a bathtub, and halfway across the bathtub, midway down the length of the bathtub you put in a separator, like a big cardboard or plastic sheet and then what you do is you cut two vertical slits that the water can pass through. So you just make a slit over here on the right and a slit over here on the left. And then if you make a wave on one side, you throw a rock into one side of the bathtub and then ignore somebody pounding on the door asking what you're doing in there. Plunk! And the waves will get emitted and then when the waves hit the wall they'll just bounce off the wall except at the two places where there are slits. And at those two places the wave can move through. But what happens when the wave moves through those holes is: the water going up and down, what it will do is those two holes will be the sources of their own round-shaped waves centered at the hole. So you'll end up with two round-shaped wavefronts being emitted, one from each hole, and those waves will move on. And then at the back of the bathtub you can talk about how high the wavefront is. And how high the water is depends on kind of a superposition of the waves at that point. So at one point one wave is high and the other is low, the wave heights will cancel out and the water will be normal height but there will be other places where the water is super low and other places where the water is super-high.

Tia: So if you were to trace the surface of the water at the end of the bathtub you would see this wavy pattern of high and low high and low. And then you can take a picture at each point in time and those high and low points will keep on changing.

[10:02]

Ben: The really really nifty thing here is there's going to be a correlation between the frequencies of the waves as they're emitted from the two holes because they're both generated by the same wave. So the original wavefront hits the two holes. So the two circular waves on the other side of the bathtub that are being emitted, they're kind of in sync. And what this means is that the pattern on the back side of the wall, and this depends on the wavelength of the wave, but you'll end up seeing a pattern. There'll be some places where the wave goes really high and really, really low, up and down and up and down. And there'll be other places along the wall where the wave won't move at all, where the water height will stay at a constant height. And essentially this is just the overall effect – we call this interference. It comes about as a combination of the superposition principle and the fact that the two waves being emitted are kind of in sync. And the deal is that anything that has waves in it will do this. It's much more apparent with light. So in light, the amplitude, how high or low the wave is at any time, kind of reflects how bright the light is. And if the wave isn't up and down at all then there's no light. And so what happens if you take a laser and do this double-slit experiment, you have to set it up slightly different, but it's in essence the same thing – a big wavefront moves out from a point and then the wavefront hits two slits. And then each of those generates their own circular waves expanding out, starting those points. You'll see what's called interference fringes on the back wall. So there's going to be places where the electromagnetic wave goes up and down up and down crazy on the back wall and some places on it where it doesn't go up and down at all. So you'll see a pattern. It'll look like zebra stripes actually. There'll be places where the light is really bright and places where the light is really dark. And it'll go light, dark, light, dark, light, dark and you'll just see a stripy pattern.

Chris: I want you to know that I'm replicating this experiment in my bathtub right now and I just reached for the lightbulb and I realized that was probably a bad idea.

Ken: We don't want to have a physics-induced death here.

Ben: That's right. We're saving that for episode 50. So these interference fringes, where when you set up this double-slit experiment: two slits, the wavefront hitting both slits kind of in sync, you see these interference fringes. This is a basic characteristic of things that are wavy. You can do with lasers. You can do with light. You can do it with sounds. But the crazy thing is that we mentioned before particles have a wavelike behavior. So when people heard about this they're like "Hey, if particles wave we should be able to get them to do this too." So they set up a similar setup where essentially they had a wall and they put two slits in the wall and then behind the two slits a little bit away they put a great big phosphorus board, something that would light up when an electron hit it. And then they started shooting electrons at the wall with the slits in it. Classically what would happen if you imagine that electrons were just particles is that some of them might make it through the slits and they would just hit the back wall. And so you'd see two big bright spots, one behind one slit and one behind the other on the back wall. But what actually happens when you set this up just right is you see these fringes. There are some places where lots of electrons hit. And some places where none of the electrons hit.

Tia: You get the same zebra pattern.

Ben: You get the same zebra pattern only instead of light hitting the back wall it's electrons.

Chris: Hmm, that is weird.

Ben: The way it happens is pretty crazy because you can say "OK, maybe these electrons they all have frequencies, maybe they're just interfering with each other like a wave. Maybe all these electrons are cooperating together." So what you do is say, "Okay, I'm going to shoot one electron at a time through it." And what will happen is one electron will hit the back wall at a time but the place that the electron hits on the back wall will follow the fringes. So the places where the fringes are really bright you'll see the electron coming through hitting those places more often. And the places where the fringes are really dark you'll never see the electron hitting those places. Even though you're only doing it with one electron at a time.

Tia: But how does that electron know Ben?

Ben: Yeah I know right. So with a water-wave or a light-wave it kind of makes sense because it's a wave. It's interfering. The wave passes through both slits and interferes with itself. In this case, even if it's just one electron that electron has wavelike properties. Part of the electron seems to pass through both of the slits and interferes with itself before deciding where on the back wall to hit.

Chris: That's freaky.

Ben: Oh yeah. It's super freaky because this is a behavior you can't see at all. It doesn't make any sense if you imagine the particle is just a particle and not a wave at all. It's a phenomenon that can only be described in terms of waves. But like I said we're talking about one particle at a time. So what happens is, this is called wave particle duality I mentioned before, the deal is that wave-particle duality we use that phrase to describe both how waves act like particles, the way electromagnetic waves act like photons, and we use it to talk about how particles, when they move around, they act like a waves, like in this case. So it's the same phrase but in this case we're saying a particle, something that we imagine is only in one place at a time, it's got this wavelike behavior and it does these crazy things. So we're going to be talking today about the different interpretations of the quantum mechanics. So I want you to get a good grasp, before we get too into it, of what we know for sure in this, because things are going to get pretty cray-cray. So I think it's important here for you to understand what we know and what we know works.

Chris: Excellent.

Tia: The focus of this show will be what's really happening to that electron. Is it going through both slits? I mean how can we reconcile a particle going through two places at the same time?

Ken: …in order for it to interfere with itself.

Tia: Yeah. So we have the math to figure this all out. But the interpretation of that math is up for debate.

Ken: If we're talking about different interpretations we're really talking about … I liked Ben's phrase about what happens behind the scenes.

[16:10]

Ben: So I thought that it'd be helpful if we talked about how the mathematics worked. So physicists imagine that the nature of our particle isn't a particle. We imagine that it's a wave function. So it's a wave, like a wave on the water. What's it waving in? It's just a wave. And as it moves through space. It does the same thing that a wave does - it can pass through two holes at once and if it does it kind of gets emitted in those circular patterns. And then it can interfere with itself. So it's called the Schrödinger equation and it's the equation we use to talk about the evolution of this wave. The Schrödinger equation is what describes how this thing evolves. What a physicist will do is she will start out and she'll say "How does this system start? What does the wave function look like originally and how does it evolve?" And she'll describe how it evolves. And in the end she'll end up with essentially this fringe pattern on the back wall. But that's not the end of the story because then she takes that wave and she translates it into a probability distribution. And a probability distribution is essentially … so the height of the wave correlates to how probable that the particle is in that place. So those fringes which she calculated on the back wall, those translate into a probability distribution that says that it's more probable that the particle will be found in the bright spots. And it describes really accurately the probability that you'll find the particle in this place or this place or this place. So when one electron does its thing and evolves through the double-slit experiment what'll happen is its wave function spreads out, interferes with itself, makes these fringes, and then something makes the decision and the electron says "Oh, there's a 25% chance I'm over there and a 10% percent chance I'm over here." And then she decides. She says, "I'm going to go into that one." And so the description of what happens when you shoot one electron through the thing at a time is these electrons are making these decisions so you end up with a probability distribution that follows it. So if there's a 30% chance that the electron will end up in this fringe over here then if you shoot 100 electrons through the machine then 30 of them will end up over in this stripe and 25 will end up in this stripe. Do you dig it?

Chris: Yeah.

[18:30]

Tia: Wait, I have a question for you. How does the particle make a choice?

Ben: Yeah I know right. Well that's at its heart…

Tia: Does it have free will?

Ben: Obviously not. It doesn't. So that's a great question Tia. It's almost like you know the answer. The particle doesn't make a choice. It's a completely deterministic … It's not a deterministic system in the sense that we're used to describing. You know like billiard balls are deterministic. You can tell if you're subtle enough how if one ball is moving in this direction with this speed and there's a ball over here, you can figure out which directions they're going to knock each other apart and what the final pool table will look like.

Tia: That's the physicists' favorite game - pool. They all think they can do it but you know there's a little bit of technique involved in it.

Ben: So the system isn't deterministic in that way. There is an element of randomness to it. But this probability distribution is deterministic. We know how the probability distribution is going to shape itself by using the wave function and the Schrödinger equation. And so where the particle ends up exactly is up to chance but we know things like if I did the experiment over and over and over what distribution they would end up in. And I also know things like where the particle won't be. I know the particle won't be in one of the black stripes where it's not probable. And so it's a new type of physics that people found very unsettling that is both deterministic in a way and lacks a deterministic element because there's this random element in it.

[19:59]

Ken: It's not deterministic on a particle-by-particle basis but it's deterministic in an ensemble.

Ben: Yeah. Right. So I've got like an analogy for how people like to imagine this working.

Tia: Sea monkeys?

Ben: No…Goldfish. Delightful goldfish.

Tia: And not swimming bunnies?

Chris: They should be swimming bunnies. Let's use swimming bunnies.

Ben: Okay. Imagine that you had a bunny with a scuba tank so it can stay underwater as long as it wants. And imagine that you have a pond. There are places where the pond is deeper and places where the pond is shallower. And the bunny is swimming around on the inside of it. Now the bunny can be anywhere. But because he could be anywhere and because you know that some parts are deeper than others the probability that you're going to reach your hand in and grab a bunny is slightly higher in the deeper parts of the pool than it is in the shallower parts of the pool. So imagine that the pool is super super wavy. So now the height of the water is changing. There'll be some places where the height of the water is really high and some places where it's really low. And if you reach into places where it's wavy and the water column is really high, you reach into one of those places you're more likely to grab your bunny than in the places where the pool water is really low.

Tia: Because there's more water in which he can swim in that area.

Ben: Right. So one way to imagine this quantum mechanical system is essentially the laws of physics govern how high the pool height water is. And that might change over time. But you know that whenever you're reaching wherever the bunny is in the pool, you're more likely to find them under one of the tall bits of water than under one of the shallow bits of water. So it's like you put your bunny-pool-water through your double-slit experiment and on the back wall you end up with a wavy system where it’s waved in humps and you’re more likely to find your bunny in one of the humps than in one of the narrow bits of water in between them.

Chris: Yeah that makes sense.

Ken: Really? I kind of got lost a little bit. You’re trying to equate the bunny to the particle? Actually locating the particle?

Ben: Yeah. That's right.

Chris: Well, I'm imagining that there's a greater stack of potential bunnies in the wave humps right?

Ken: That’s a good way to think of it.

Ben: So if you do the experiment over and over and over, the bunny might be under a different wave hump. But on average the bunny will be under the larger humps more than the smaller areas and you’ll end up with a distribution of where you’ll find the bunny if you repeat the experiment over and over. So the problem with that explanation is that it’s wrong!

Ken: Why would you do that!?

Ben: I know right. So it makes sense and it’s easy to imagine but fundamentally it’s kind of screwed uuup. What’s real here is that there is always a bunny and it’s always under the wave somewhere. We just don’t know where it is under those waves so we have to deal with the system using statistics. We know how the waves work and so we can describe where the bunny is statistically. But the bunny is always somewhere in the pool. He's never everywhere. That's essentially what this intuition tells us. And it's wrong. There's a variety of quantum mechanical situations where people essentially test to see if maybe the bunny is actually under one of the waves and not under the others. They find out that the bunny isn’t moving around under the waves. The waves are the things. The bunny is actually made up of waves. So in the Copenhagen interpretation what it's saying is the bunny is everywhere under the pool at all times until you reach in and grab him. And the act of reaching in and grabbing the bunny forces him to be under your hand and doesn't let him be anywhere else that isn't under your hand.

Tia: Or he could also be not under your hand. You could have missed the bunny.

Ben: Yes, but in some way in reaching in…

Tia: You’ve collapsed the bunny-probability.

Ben: Yeah that’s right.

Ken: Yeah but in this analogy…I don’t understand. You take all the water away? I don’t know. I mean that's kind of what you're saying right?

Ben: Yeah I guess you drain the water and the bunny is in one place.

Ken: This analogy is stretched to be kind. Can we just put the bunny in a box?

Ben: We have to take the bunny and put it in a box and not talk about the bunny anymore.

Tia: Okay, the bunny is now gone.

[24:15]

Ken: Okay, I still think we need some kind of story and the easiest way to go is with the box experiment. You've probably heard of Schrödinger’s Cat right?

Ben: Oh no, you're not going to kill the bunny. Put the bunny in the backyard; let it go have some lawn time. You're going to find yourself a horrible cat. Put the cat in a box.

Chris: I like cats.

Ken: But you've probably heard of Schrödinger's Cat right? That thought experiment; *only* thought experiment hopefully.

Chris: Yeah. Yeah I've heard of that.

Ken: So basically you have a cat in a box, something random happens, and the cat is either killed or continues to live. So after 10 seconds something either happens or doesn't and the cat either lives or dies. That essentially gives us a nice simple situation, rather than a bunny in a pool, where we only have two states. We only have either the cat is alive for the cat is dead and this is where we finally finally get to the Copenhagen interpretation of quantum mechanics versus the many-worlds interpretation of quantum mechanics. The difference is in what happens when you find out whether the cat is alive or dead. So you run the experiment and put Ben's horrible cat in a box. You leave it for 10 seconds or whatever and then before you open the box, of course you don't know what state the cat is in. That's what everyone talks about, the cat is both alive and dead because you don't know what is happening in the meantime. So when you open the box everything changes. So the one that Ben was just trying to describe, the Copenhagen interpretation, basically what that says is that you open the box and let's be nice and say the cat is alive. So the cat is alive and then what happens in the probabilities is that there is no more probability that the cat is dead. So all that has happened is that we know certainly that the cat is alive and there is no chance that the cat is dead.

Chris: Let me understand this. So you've got the cat in the box and there's a 50/50 chance that it's either alive or dead.

Ken: Yep.

Chris: And then you open the box and the cat is alive and this means that…

Tia: It no longer has a probability of being dead now because you observed it being alive.

Chris: But while the box was closed, both are possible?

Ken: While the box is closed its 50/50. So they're both equally true. But we say there's a super position where the cat is both alive and dead because we just don't know.

Ben: Let me just refer back to the double-slit experiment. So if you take your cat and fire it at the wall.

Ken: What!? You’re a horrible person.

Tia: Oh my god. Dude the SPCA is going to come after you.

Ben: So if you take a *particle* and fire it at the wall what happens is: because the particle is the wave… When we moved away from the bunny and the pool example, the argument is that it's the wave that's fundamental. The wave function is fundamental. It's not that the particle lives somewhere in the wave function. The wave function is the actual representation of the particle. So the wave function will move through both slits in the two-slit experiment at once. And then those two versions of it will interact with itself and that will cause the fringes on the wall. So what we’re saying here is that the cat is both things at once and if you did some experiment with them where you kept the box closed but you shook the box in a very specific experimental way, these two versions of it could interact and interfere with one another in a variety of ways. I'm sure you've heard of quantum computers. Quantum computers kind of work with a similar principle. You have a particle or a system that's behaving quantum mechanically and so it can exist in both states of being both 1 and 0 at the same time. And you can do various computations by forcing the 1 part of it to interact with the 0 part of it as if they’re both in the room at the same time, interacting with each other. So it's not the case when the cat is in the box that it’s either alive or it’s dead and that you just figure out which one is truth when you open it. In this Copenhagen interpretations, the cat is both alive and dead and the dead cat is capable of interacting with the alive cat until you open the box. And once you open the box you collapse, you destroy, the possibility that it's alive or you destroy the possibility that it's dead by taking a measurement.

Tia: Alive and dead.

Ken: Yeah so this Copenhagen interpretation puts some kind of special emphasis on the person thst does the measurement. So once you’ve done a measurement you can actually destroy one probability. So you say, “Ok, so the cat lived. I have now destroyed the possibility that the cat is dead. And it exists nowhere anymore.”

Chris: And in order for this to work you need a consciousness to observe it?

Ken: Yes. Excellent. That’s exactly the point. In order for this to work you need something conscious to actually look, conduct the experiment and determine which of these probabilities is actually the one that has happened. And that's kind of the big thing about the Copenhagen interpretation. It puts this conscious observer in a very special role, with the ability to destroy probabilities at will.

Chris: That's weird.

Ken: Perhaps more weird is the other one I know.

[29:09]

Tia: Yeah. So I don’t know about you but I've never sat well with a cat or anything being alive and dead at the same time. So this is one way of interpreting this quantum phenomena but there’s other ways where you don’t have to touch on this weirdness of a cat being alive and dead at the same time. So you could also imagine the many-worlds interpretation. So the cat is alive or it is dead before you open the box and then when you open the box you see that the cat is alive and then in another world you see that the cat is dead. You just split the world into two parallel worlds by taking your observation of the cat. So in each world you see something that makes sense. You see a cat that is alive or you see a cat that is dead. Both of them make sense to you. You no longer have this weird alive and dead cat existing. So that’s one nice thing about the many-worlds interpretation.

Chris: If you look at both worlds at the same time somehow, that’s the superposition. They’re still both happening?

Tia: Yeah and the special thing about the many-worlds interpretation is that those two worlds can’t interact with each other. You can never see what happened in both worlds at the same time.

Chris: And is that derived from the math?

Ken: I would say yes. Isn’t it true that there’s no way to collapse the wave function? We’ve talked about collapsing these probabilities but there’s no actual mathematical way to do that right? It’s just kind of this ad hoc thing that’s thrown in to say “Ok well an observer came and then we collapsed one.”

Tia: Yeah so the many-worlds theory is a way to get around that kluge that they stuck into quantum theory. Because if you have the many-worlds theory you no longer need this kluge saying that you've collapsed a wave function. You just have a world where the cat is dead and a world where the cat Is alive. I wouldn't say that it directly came out of the math. The math just tells you how likely something is to happen. This is just an interpretation of the math. Just like in the Copenhagen interpretation the cat is both alive and dead.

Ben: Well hold on. So in both of them the cat is both alive and dead until you open the box. And in the Copenhagen one when you open the box you're essentially saying, "Ha! Wave function I observe you. Turn into one or the other. You can't be both anymore." And it collapses the wave function. It changes the wave function. In the other one you open the box and the rules of quantum mechanics say, "Ok, as soon as he opens the box we're making two universes. One where one possibility happens and the other where the other possibility happens." And so quantum mechanics tells you that the probability that you'll end up in universe A or the probability that you'll end up in universe B. The cat is both alive and dead before you open the box. And then after you open the box it's either alive or dead. So in the Copenhagen interpretation you're killing off the part of the wave function that said the cat is alive when you open the box and find out that you're a cat murderer. You've killed that part of the wave function. In the many-worlds interpretation they just sort of split off into different realities. In terms of the mathematics, what we're doing in both cases is…we know how the wave function behaves. If we do an observation and the wave function goes from being two possibilities to one possibility. And once there's only one possibility the system keeps evolving like there's one possibility. You take the cat out, you pet it and you show it to your wife and you say, "See there was no problem. I wasn't doing anything cruel." And she says, "Yes, you're very nice. Let's return the neighbor's cat."

Tia: But in the many-worlds interpretation you're both the bad guy and the good guy.

Chris: So when you say the wave form doesn't collapse in the many-worlds interpretation, it's continuing to act like a wave because it hasn't collapsed down to acting like a particle?

Ben: In one case the wave function is collapsing and I'm killing off the other possibilities and there's only one reality – the reality where I've opened the box and the cat is alive. In the many-worlds both things happen. There's one reality where I open the box and the cat is dead and one reality where I open the box and the cat is alive. The mathematics describe a self-consistent picture. Both of these cases is us trying to impose an interpretation on what exactly happens here. Because we know the math works but we don't know what to visualize when we see the math working.

Chris: These are both mainstream interpretations of like the nature of reality?

Tia: Yeah.

Ken: Exactly. Yeah. Like Ben said, effectively there is no difference. It’s not like we could predict something with either case but it’s an interpretation of what’s going on behind the scenes or something.

[34:06]

Tia: Would it be useful to explain what happens in the two interpretations for the double-slit experiment?

Ben: Sure. Can you do it?

Tia: So in the Copenhagen interpretation of the double-slit experiment if you shoot one electron at a time at this double-slit screen the electron wave interferes with itself because of the double-slit screen. And when it’s detected on the phosphorous screen at the end you get a point that’s lit up.

Ken: It’s basically the electron is gone and it’s been in this quantum superposition state as it traveled but then when it gets to the other end it’s collapsed down to only one probability at the other end.

Tia: Yeah, on the screen.

Ben: As soon as it hits the screen the screen demands that it hits the screen somewhere.

Tia: At one place.

Ben: So as soon as the screen says, “Ok, you’ve got to choose one place to be.” The electron rolls the dice and says, “I’m going over here.” And hits the screen there. And the next one rolls the dice and says, “I’m going over there.”

Tia: So that’s collapsing the wave function. That’s the Copenhagen interpretation. So in the many-worlds interpretation the electron flies through the screen, interacts with itself, and then when it hits the detection screen at the end many possible worlds branch out, where the particle hits the first stripe, the second stripe, or the third stripe. So instead of collapsing the wave function you just have multiple worlds.

Ben: I think maybe one of the motivating features here comes back to the Schrödinger's Cat. So Schrödinger's Cat is a thought experiment. Schrödinger invented it to demonstrate to everybody that this picture is totally bananas because in normal life we don't see a superposition of things. There's only one water bottle. There isn't a superposition of different water bottles.

Ken: But wait, in this we also don't ever *see* a superposition of things. That's the whole point right? What we *see* is only one or the other. We *infer* that there is a superposition before we know.

Ben: Yeah, so the bridge between the microscopic and the macroscopic is the issue here. At what point in time does the cat stop being a superposition? The cat is a macroscopic object but when it starts interacting with the outside world why doesn't that bridge over to everything becoming a superposition right? In the many-worlds explanation you say, "Oh, well all of these universes have just decoupled from each other." So every possible thing has happened. And the probability that you end up down one universe rather than another is determined by the laws of quantum mechanics, this evolution of probabilities. But there's no decoupling between microscopic and macroscopic.

Tia: I don't follow that whole thing about decoupling.

Ben: I mean essentially the Schrödinger's Cat points out this big problem with the Copenhagen picture which is you're saying, "Ok so the cat isn't an observer." It's inside this box so it becomes a superposition and the alive part of it can interact with the dead part of it and they can have a really weird time in the box. But then when I open it, because I am a human with the powers of observation, it decides that it is going to be one or the other. Because macroscopic reality as we observe it is either one thing or the other. It's never both. Whereas in the many-worlds interpretation it's both until you open the thing and then it goes from being both one cat and the other cat are in the box to there being two universes.

Ken: Why are you more comfortable with the creation of a universe than the collapse of a wave function?

Ben: I mean philosophically they both have their problems right? Both the Copenhagen interpretation and the many-worlds interpretation are both kind of bananas.

[37:55]

Chris: I've got a question. Wouldn't the branching of worlds, like creating a new instance of a world, wouldn't that take energy?

Tia: Dun, dun, duuun.

Ben: I know right.

Ken: That is a fantastic question.

Ben: That's one of the big problems…it's like where does all this matter come from? If every moment a quantum decision is being made, there's another universe, where's all that matter coming from?

Tia: But there are a couple of arguments about that right? That in each singular universe energy is conserved but outside of the many-worlds energy doesn't have to be conserved. I don't buy it.

Chris: And so the laws of thermodynamics are suspended?

Ben: Well it's not like the worlds can interact with each other right?

Ken: Yeah the laws of thermodynamics are preserved in each world so that we can never create or destroy energy like all the laws say. But it's true that somehow when you open the box with the cat you've created two worlds where there was one and it's not really clear what that means. Although each world conserves energy and conserves all the laws that we would expect, on some kind of grander scale if you were sitting above all this, which of course you can't do, but if you could you would see that something suddenly got created.

Chris: You know the one thing that I've never heard before that I really like is this idea that whenever anything happens, like in the double-slit experiment, every time something happens all of the possibilities happen. They all always happen if they are possible. The probabilities are different so some universes are more likely than others. So somewhere out there there's a universe where we've like achieved world peace.

Tia: I hope so.

Chris: Or bunnies are ruling the world.

Tia: But none of this is testable right?

Ken: That is right. They perfectly designed the system so you can't prove it one way or the other.

Ben: We should mention that there are thought experiments for each of these cases demonstrating that both interpretations are sort of weird and maybe not all that good.

Tia: It seems like many-worlds is more weird than Copenhagen.

Ben: Maybe. Many-worlds is pretty weird. I mean Copenhagen seems inconsistent in this thing where the cat can't collapse its own wave function but we can collapse the cat's wave function.

Ken: Yeah the role of the observer in Copenhagen is really strange. It just doesn't make much physical sense it seems.

[40:12]

Ben: Let's talk about the EPR paradox briefly. Have you ever heard about the Einstein-Podolsky-Rosen thought experiment? So when the Copenhagen school first came out it was like Niels Bohr and his students in Copenhagen and they had ideas and their ideas were essentially, "The wave function does this thing. Let's not worry too much about it." They said the wave function itself is the real thing. And they talked about it collapsing and it evolving. But fundamentally this wave function is the real thing. There's no bunny swimming under the wave function somewhere that you just need to find. The bunny is everywhere under this wave at once. Einstein had problems with that and he said let's suppose you have a system that's quantum entangled. And a quantum entangled system is kind of like – imagine that you have two lunch boxes and two apples. There's a red apple and a blue apple… or a green apple… a red apple and a green apple.

Chris: I like the universe with the blue apple though I have to say.

Ben: A red apple and a blue apple. So your mother packs your lunch before you go off to school and your brother goes to Venezuela. And she puts either the red apple or the blue apple in your lunch box and she puts the other apple in your brother's lunch box. You go to school and your brother is down at Venezuela. You open your lunch box and hey you've got the blue apple so you know your brother has to have the red apple. That's not so strange. There's some deductive logic going on but it's all nice and self-consistent. The thing about the Copenhagen interpretation again is that things can get really weird when you talk about entanglement because like we said the wave function is what's real. It's what's fundamental. So this fundamental thing that actually exists is changed by you observing it. So if you have two quantum apples there's a 50% chance you'll get the red apple and a 50% chance you'll get the blue and you go off. But they're quantum apples. So you open your lunch box and you observe the system. Smash. You've changed your wave function. Your wave function goes from both being both red and blue to being just red. You observing your lunch box, you changing this thing that exists, this wave function, it changes the wave function of your brother's lunch box. So you've collapsed the wave function of your brother's lunch box even though he's in Venezuela. Even though he's really really far away you've modified his system. So that's bananas.

Tia: That's Einstein's problem with it.

Ben: Yeah Einstein's big thing, like the thing Einstein is most famous for in physics is he was the guy who said nothing can travel faster than the speed of light. Light's the fastest thing. But in this case you can have two kids with lunch boxes, one of them is in Alpha Centauri, one of them is on Earth, light-years apart, you open your lunch box and you've changed the system on Alpha Centauri instantaneously. "Spooky action at a distance", that's what it was called. He thought it was spooky because it was an effect really far away, instantaneously, faster than light. So people have been thinking about this since. It's not like this thought experiment killed the Copenhagen interpretation but it certainly made people think about it. And one of the things they thought is they said, "Ok, what if we made it so that the rule that nothing can travel faster than the speed of light was rewritten and we said no information could travel faster than the speed of light. Whether that's a letter with something written on it or a telegraph code or any information could not travel faster than the speed of light." In that case, you might have collapsed your brother's wave function but there's no way to communicate any information by collapsing his wave function. You can't be like, "Ok brother, if you get a blue apple you'll know that I had a nice day." You don't have any choice when you're observing the system which one of the outcomes it's going to be because it's random. So he doesn't have a choice on his information. So there's no information that passes between the two. So that's how they kind of got past it. Because if they want to compare information they'll have to get back together and them meeting up will have to happen slower than the speed of light. So information won't be travelling faster than the speed of light because no information can be fundamentally transmitted by collapsing this wave function.

Chris: Ok. So you can change the nature of reality instantly, faster than the speed of light, somewhere else in the universe but you can't get any useful message out of that.

Ben: At least that's how the Copenhagen people sleep at night.

[34:33]

Ben: Alright Ken, you want to talk about quantum immortality?

Ken: Yeah so this whole quantum immortality thing is essentially the cat in the box except you put yourself in a box in which let's say every 10 seconds something happens and you're either killed or you're not. And so you're in this box and after 10 seconds there's a 50% chance that you're dead but there's a 50% chance that you're alive, which I guess is pretty good. And after the next 10 seconds there's a 50% chance again. So you have a 25% chance that you have lived through the first 20 seconds and this continues on and on. But the point is if you're halfing your likelihood every time you actually never die right?

Ben: Yeah because you won't ever see the future where you die because you'll be dead. So the only future you can possibly see is the one you live through, these thousands of gun shots or whatever.

Ken: Yeah so the point is if you're dead the many-worlds would consider that the only world you see is the one in which you continue to be alive. So by this logic you can never die. I mean I guess you die of starvation or something eventually depending on how much you brought in the box with you. It's this kind of refutation that says it's kind of ridiculous that after 10,000 of these 10 second intervals you have to still be alive because the world in which you are in means you are still alive. It's kind of the same refutation. It's just bonkers to think of something like that.

Tia: But I mean you have a natural lifespan regardless of…

Ken: That's true. You can't achieve permanent immortality.

Ben: But on the other hand isn't everything that kills you quantum mechanics. Quantum mechanics determines the evolution of everything so isn't it the case that you'll never die because everything that's going to kill you has some quantum nature.

Ken: So I should fear quantum mechanics…?

Ben: No, you should be thankful for quantum mechanics because you'll be the first person to live to be 100 billion. You can never be killed because of quantum mechanics.

Chris: That's crazy. You discovered the scientific basis for script immunity right?

Ken: Yes, exactly!

Ben: That was fantastic. Thank you Ken. Thank you Tia. Your efforts have borne fruit and that fruit is sweet. Here is some fruit. Ken you get a red apple. And Tia you get a blue apple. I'd like to thank my guest Christopher Reynaga. Thanks Christopher. Thanks for coming on the show.

Chris: Thank you very very much.

[47:00]

Ben: It was super fun. Ok, so hey Tiphyters listen. There are four things you need to know. Firstly, leave us an itunes review. Whenever I feel sad or lazy or tired or exhausted with life I check the itunes store and it makes you feel better. Your nice words are giving me power. Now secondly, there's a podcast out called Podiversity for the Android phone. It's a subscription for content space podcast app but they give us money when you listen to our podcast on their thing. So hey, why not? Third, you can go to our store off the Tiphyter website and buy a sweet shirt. They were made by Chelsea Anderson, a brilliant designer from Calgary and they're gorgeous and they last forever. Really, they last forever. You'll wear them forever. It's amazing. Now, fourthly if you'd like to contact us you can send us an email. My email address is Barn@titaniumphysics.com. I forward people their fanmail once in a while when we get it. So if you want to tell Ken and Tia something fantastic send me a letter and I'll forward it on. Also, we're on Twitter and Facebook and even on Tumblr, if you can find me on Tumblr. Oh, also remember to consider leaving us a donation on our website. You can donate through Paypal, recurring or one-time donations or if you want to we have a Patreon page set up. So visit the website for more details on those. Ok that's it for the main part of todays show. Remember if you like listening to scientists talk about science in their own words you might also like to listen to the other shows on our Brachelope Media Network. I'm going to rattle off some shows: *Astrarium* about astronomy, *Science…sort of* about science news and culture, *Technically Speaking* about engineering, *The Collapsed Wavefunction* is about chemistry. And we probably need a biology show. How about an epidemiology show that would be pretty cool about weird diseases that make your feet swell up. Ok, so the intro song 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.

[49:47]

Ben: Its choice is entirely deterministic. It's like, to put it glibly, it's like god is playing dice to figure out where the particle is. God roles his dice and says ok this electron goes here. Rolls his dice and says this electron goes here. I guess rolls her dice. This electron goes here, rolls her dice, this electron goes here. And then places them according to a statistical description rather than any internal decision making.

Ken: Is there a way we can describe this without invoking deities of any kind?

Ben: I was…Einstein said the thing right?

Ken: Yes, Einstein did say that.

Ben: I'm making a call-back to Einstein Ken.

Ken: I got the reference. I just…I don't know. This is supposed to be about physics.

Ben: No it's true.

Chris: I remember that quote, "God does not play dice with the universe."

Ken: Yeah and Einstein even said that he doesn't do that, what you just said he did.

Ben: So let's talk about what the math does. There won't be a test on this but…

Tia: Yes there will be. Multiple choice, 20 questions, Scantron.

Chris: I’m in trouble.

Ken: Do I have to take the test too?

Ben: Do you have a number 2 pencil?

Tia: We don’t have sharpeners so you have to bring your own.

Chris: I always have a number 2 pencil.

Ken: Have I told the story yet about Ben invigilating an exam at Queens when we did our PhDs together? Where I was doing my PhD and he was doing his Masters.

Tia: What?

Ken: We had to watch students write an exam. This is a side-note by the way. We had to watch these students write an exam. And Ben was like joking with the kids and then noticed it was 9 O’clock, time for them to start writing. And he was like “Go!” And all the kids just started laughing at him because you know he was Ben and he was just kidding. And he’s like, “No, no, seriously. Go!” And none of them wrote. And he said, “If you guys don’t go I’m going to punch you all in the face.” And then they started picking up their exams and writing. That really happened.

Ben: That sounds true.

Chris: There’s some universe out there where he actually did go punch them all in the face.

Ken: Yep. That’s exactly what we’re saying. There’s a universe where he individually punched all the students in the face.

Tia: So Ken, you’re telling us that our current universe isn’t the one where he punched them in the face.

Ken: Unfortunately our current universe there was no face-punching.

Ben: We don’t live in the best possible universe then.

Ken: Anyway, side-note.

Ben: That’s a good one. That’s funny. I didn’t know how that story was going to end.