Episode 52: Through the Mirror with Patrick McHale

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The Titanium Physicists Podcast

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Ben: Never be afraid. There's nothing which is known which can't be understood. And 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 birth right: an understanding of the universe. I've travelled 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 allay physic!

[1:47]

Ben: Let's talk about the mirror world. Okay, so let's suppose for a second that the world we see through the mirror is an actual place. The mirror is a portal and the only reason we can't walk into it is that there is some other person on the other side of the mirror trying to do essentially exactly the same thing. So when you press your fingers up to the mirror it's the other person's finger you're smushing your fingers against and that's the reason you can't go through. So the question has got to be asked: What's the difference between this mirror world and our own? Firstly I'm right handed, so when I look into the mirror world and wave around my dominant hand in it my doppelganger will raise and wave around his left hand. So if I'm right handed he's got to be left handed. Is there any other difference? Well, the sun goes through the sky in the opposite direction. Alight hold on, that's kind of crazy, so let's do a though experiment quickly. Imagine you've got a body-like mirror, a great big mirror. You go outside and you turn it to face south. Now you go and stand in front of it, slightly south of the mirror and you face up north. So smile at your doppelganger, wave, who knows what he's thinking in his left-handed duplicity. Okay, so because I'm facing north I'm looking at our North Pole right? But in the mirror what do I see? I see the doppel-Earth's South Pole. Now here's the fun part: because I'm facing north the sun will go through our sky from east to west, which corresponds to going over my right shoulder to my left shoulder. And that's fine but now you look at doppel-Ben. He's facing the doppel-Earth's North Pole as well, but the Sun goes from his left shoulder to his right shoulder. In other words it goes from west to east. So in mirror dopple-Earth, the rights and lefts are switched and everything rotating clockwise on Earth will look like it is rotating counterclockwise in the opposite direction on doppel-Earth. So you might ask a question at this point in time: Is there any physical reason the Earth can't be rotating in this opposite direction, and the answer is no of course not. The reason our Earth rotates the way it does has to do with initial conditions and prior circumstances rather than any hard physical rule. It seems at least in terms of everyday experience that the laws of physics shouldn't depend on whether we are in this world or on this weird mirror doppel-world. Whether or not a system is right-handed or left-handed seems to depend on convention. We drive on the right side of the road in North America but in Japan people drive on the left-hand side. In English we read from left to right across the page, while in other languages people read from right to left. It seems reasonable then that the laws of physics shouldn't prefer right-handedness over left-handedness. For instance, we might expect half the spiral galaxies in the sky to rotate clockwise and the other half to rotate counterclockwise. And we might expect that as atoms decay, as they break off into smaller pieces and shoot off little electrons and stuff, that the particles they spit out are going to be spinning clockwise or counterclockwise randomly. So it came as a surprise to the world when in 1956 one of the greatest experimental physicists of her day conducted an experiment which shattered this notion. Her name was Dr. Chien-Shiung Wu and she was known as Madame Wu or the First Lady of Physics in deferential respect but also she was known as the Dragon Lady because people are horrible racists. Okay, so there's an isotope of cobalt which is unstable; it's just an atom that's unstable. And they cooled this atom down to near absolute zero and they aligned all the atoms using a magnetic field. When the cobalt atom decays it emits an electron, which should either be spinning clockwise or counterclockwise randomly. And if the universe didn't care about right-handedness or left-handedness, we'd see about the same number of counterclockwise as clockwise. But when Madame Wu did her test she found that the electrons emitted spun *only* in one direction. The result is that somewhere, somehow, the universe really cares about handedness. If you woke up tomorrow on a strange planet with your hands cut off you'd still be able to do a physics experiment which could tell you whether you were still in our universe or whether you had been abducted into the evil dopple mirror universe. The laws of physics there *are* slightly different than ours. So today on the Titanium Physics Podcast we're going to talk about these weird symmetries and what we know about them and what we don't. Speaking of waking up in a weird universe where things are similar but not the same as they are at home, I recently watched a cartoon miniseries that blew my mind. It's about two brothers who find themselves wandering through a fairytale forest, trying desperately to find a way home. It's sweet and it's dark and there's lots of singing, and it's called *Over the Garden Wall* and you can buy it off itunes. Now the guy who wrote and produced this cartoon was also a writer and storyboard artist for "Adventure Time" my favorite cartoon. And apparently he's the basis for our favorite character Party Pat. It's amazing! Welcome to the show Patrick McHale.

Pat: Hello.

Ben: Alright Patrick, for you today I've assembled two fantastic Titanium Physicists arise Dr. Tia Miceli.

Tia: Boing, boing, boing.

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

Ryan: Ba-Boom

Ben: Dr. Ryan did his PhD at Queens University with me. And he's currently an assistant professor at the University of South Dakota where he studies neutrino physics.

[07:02]

Ben: Alright everyone let's start talking about symmetries. So the principle question here is: Suppose you woke up somewhere weird and you think it's possible that you've been abducted and carried into the mirror doppel-universe. Is there any way to tell whether or not that has happened? You're not sure whether or not you're in the mirror universe or just on some weird planet in our regular universe. So the deal is that in the mirror universe there's all sorts of subtle effects: things spin in the opposite direction. Can you imagine that based on the introduction?

Pat: Sort of. If it's a different planet, how different? Like the same looking sun and same looking moon and everything?

Ben: Well okay, so when I said different planet I mean that if you were in this weird universe you would leave your house and look up and say "The sun is going in the wrong direction. Ah, we're in the weird universe." Right?

Pat: I see.

Ben: So imagine that they bonked you on the head and taken you to a planet under some star and you have no idea about what anything is. You get out and you're surrounded by green rocks and weird octopus creatures and you look up and the sun is going the wrong way and you go "Is it supposed to go that way or is it supposed to go the other way? I don't know. This is a weird planet full of strange rocks. I'm not at home; I don't know whether the sun goes east to west." So the overall idea here is that, and I have to apologize because at its heart the things we're describing are really mathematical in their nature. The deal is that essentially if you write out various equations describing what is happening at the particle level, the question is: what happens if we switch a sign? We take something positive and make it negative. So in this case we're switching the handedness of things; we're switching the directions of one of the axes.

Tia: Which is the same as looking in the mirror.

Ben: Which is the same as looking in the mirror, switching the right hand from the left hand.

Ryan: All the intuitive laws of physics that apply to you and the mirror guy, well it turns out that part of those laws actually do distinguish which part of the mirror you're on. That's really weird and really unexpected. That's why Madame Wu discovered such an incredible result.

Pat: What’s that?

Ryan: Everything in our world is made out of these little particles and we know that the way we interact with the world, macroscopic objects, stuff is well behaved. But it turns out all this well behaved stuff is made out of little tiny things that are not so well behaved. And when you look at the laws of physics on tiny little scaled of how particles interact with each other, it turns out they do care about left or right and they can tell which side of the mirror they're on. And so the experiment that she did is to look at particles coming out of the radioactive decay like Ben explained. And you can try to see if they're spinning so you can tell if something is counterclockwise or clockwise, of course the definition changes from one universe to the other. But it turns out that in one universe stuff likes to be clockwise and in the other universe stuff likes to be anticlockwise.

Ben: Alright so back in the day, if the laws of physics don't distinguish between things that are spinning clockwise and things that are going counterclockwise; it likes them both equally. There's no particular orientation or handedness to the universe. These cobalt atoms they're radioactive and radioactive things their nuclei are unstable. So these atoms what they'll do is randomly pop and break into smaller things. And the idea is that if the universe really doesn't care about handedness what's going to happen is these atoms are going to pop and in this particular case it's going to shoot off an electron. If the universe doesn't care about handedness then half of the electrons that come out of this process are going to be right-handed and half of them will be left-handed, which kind of makes sense, if it doesn't care it's going to make both. But as it happens, when they set up this experiment they only find right-handed spinning electrons come out. There aren't *any* left-handed spinning electrons. So the universe kind of differentiates between things spinning left and things spinning right.

Pat: Is that because of our placement in the universe? What we're studying?

Tia: So the theory in physics that describes this decay that Madame Wu was looking at, the force responsible for that was the weak force. And the weak force only ever deals with basically left-handed particles. So it doesn't have anything to do with the right-handed ones. It's only the left-handed ones. To see this type of decay you know that it's the weak force going and the weak force is completely blind to right-handed particles.

Ben: Okay so take two globes in front of you, spin one of them clockwise and one of them counterclockwise. They're indistinguishable from one another and theoretically the laws of physics shouldn't be able to distinguish between the one spinning to the right and the one spinning to the left. But it seems like they do. This weak force Tia is talking about only affects the ones that are spinning in one direction and not ones that are spinning in the other direction. And this is kind of interesting for a bunch of reasons. One of them is if something is spinning clockwise if I looked in the mirror universe that thing would be spinning counterclockwise. So in the mirror universe it seems like this force only affects things that are spinning counterclockwise, where in ours it only affects things that are spinning clockwise. In particle physics we wouldn't expect the universe to apply different laws depending whether you're spinning one way or spinning the other way. We would say these laws apply to everything equally. But in actuality the universe will apply different laws depending on which way you're going.

Pat: That's neat.

Ben: Yeah, weird. It’s weird.

Pat: I've been doing a lot of arm movements trying to keep track of the different spinnings. So traveling through space in a straight line is moving forwards, but rotation is not...I don't know what I'm trying to get at with talking, I'm just thinking about things.

[13:30]

Ben: Okay how about this analogy: Imagine that there were some things that you can touch only with your right hand and if you tried to grab them with your left hand your hand just passes through them.

Tia: That's scary.

Ben: I know right. That's kind of what the universe is doing. It's saying that if the universe would care and apply laws differently depending on whether things are interacting right-handedly or things are interacting left-handedly.

Pat: I don't know why I keep thinking about this but let's talk about the big bang for a second.

Ben: Yeah!

Pat: I'm wondering, like from our perspective on planet Earth, seeing things from the way we've evolved and our planet moving through space in a way, I just wonder if things we observe are based on some things we can observe based on our understanding of what we can see and experience.

Tia: Oh I see. But we think that the laws of physics are the same everywhere in the universe. So even if we were to go somewhere else we would expect all the laws to be the same.

Pat: Yes, but if we are observing the universe then what, laws are based on our own observations about our own truth in the universe, not necessarily on the absolute truth?

Ben: Oh that's a great point! So the deal is that there is indeed a tacit assumption. It's fundamental to our studying the universe because a lot of the things we do when doing physics is that we take observations of what's happening really really really far away or really really really far back in time and we use that information to fix and tune our physical theories here at home. Fundamental to that procedure is that the laws of physics haven't changed over time. The physical conditions will change over time but the specific way that two protons will smash together or the specific way an electron will orbit a proton won't change at all. So the circumstances changing but the laws that govern how interactions happen don't change. And then equal to that is the assumption that over great distances the laws of physics don't change. You know, because we need observations of distant supernova to tune how we describe and understand how the universe works on the small scales. In that assumption is also the assumption that far distances from us the laws of physics aren't changing. So there's that but in addition to that there's an interesting question that you might pose, which is: Is there anything in the way that we study things that is arbitrary? And the answer is yes. The laws of physics are full of things that are arbitrary, but figuring out the difference between things that are conventions and things that are fundamental is part of what we're studying and what we're talking about today. So the first convention, the first thing that is arbitrary is right-handed over left-handedness. We call this the parity symmetry. And the argument is that laws aren't particularly right handed or left-handed. And it's an old idea, but this experiment we started the show talking about has disproved. So we know that there's a difference between our world and this mirror universe world. The laws of physics are slightly different.

Pat: Wait, so you're saying there was a law that said the universe didn't care left-handed or right-handed, but then there was something that disproved that, and that was what she did?

Ben: Yeah yeah. What I'm trying to say is we say when you put your hands in front of you, the one that makes an "L" we say that's the left hand and the other one is the right hand. And our description in terms of right-handedness and left-handedness is arbitrary. And we would like to assume that everything in the universe doesn't care about handedness, but it's not quite the case. There are physical processes that would be different between our universe and the mirror universe.

[17:36]

Pat: I think the reason why I was having trouble following the mirror universe thing is because there is no mirror universe.

Ben: Yeah.

Pat: But creating a mirror universe for us changes everything about everything.

Ben: It only kind of does because all it really does is switch the right and left convention. Let's suppose we discovered the writings of a caveman and they mistakenly said the hand that makes an "L" that's the right hand and the other hand is the left hand. If they'd switched it and then came up with a whole bunch of laws of physics, the principle here is that the universe really doesn't care which one we call right and which one we call left.

Pat: Yes.

Ben: But this experiment proves that there is actually a physical process in there somewhere that we can use to say "Okay, this is right-handed." And the physical process is: what you do is you set up this cobalt experiment and you look at which way the electrons are going and you say "Okay, my hand that curls in the direction the electrons are going, that's my left hand and the other one is my right hand." And the person in the mirror universe would get that backwards. But before I go on I want to emphasize that there are other kind of conventions in physics and they're relevant to this discussion. So one of them is charge. Benjamin Franklin is famous for saying “This charge is positive”. I think he was rubbing two things together and he was like “okay, there’s this thing called electric charge; this one is positive and this one is negative.” And so as a result, the electron, which is whenever we're building electronics the thing that moves around are the electrons. The electrons have a negative charge, which is weird. But the choice of which charge is which is a conventional one. It has to do with an arbitrary choice that somebody made, just like the choice of hands, left of right, or the choice of saying which way should a clock go. Should clocks go clockwise or should clocks go counterclockwise. The direction of the arrow of time is another one of these conventions. It's interesting, the point of this whole discussion is that the universe does actually have processes that can be used to distinguish between right-handedness and left-handedness, used to distinguish matter from antimatter, than can be used to distinguish clockwise time from counterclockwise time. But the neat thing is that these symmetries are kind of interchangeable. So the overall theme of today’s episode is that there is a tacit assumption that the laws governing the universe and the test of these are all in terms of particle physics. So these are very very basic laws, one particle smashes into another, or one particle decays into a bunch of other ones. We all thought that the universe would be symmetric, that the equations would be symmetric, that the choice of which one is left, which one is right, or which one’s the particle, which one’s the antiparticle. We thought that the universe wouldn't care about our choice. But it turns out that the universe has a way to distinguish or there are processes in the universe that distinguish between antimatter and matter, between right-handed things and left-handed things, between things that are moving forwards in time and backwards in time.

Pat: But couldn't the lack of symmetry there be something we're just not observing? What I mean is that we're looking for symmetry and if the concept of symmetry is flawed...we think of symmetry as something that is perfect. But if that’s not, what is perfect? We keep trying to look at things and try to figure out what is perfect.

Tia: Yeah we keep on redefining the rules until we can finally find something that is symmetric.

Pat: Yeah and if chasing that symmetry is the wrong path then I guess it's for figuring out...

Ryan: It’s the other way around. Like you said we've got these biased notions in the beginning of what a symmetry should be so we think this mirror symmetry should be true. And then we do experiments and find that's not a real symmetry; that's flawed. And then as we write the model and develop the mathematics and this complicated physics people evolved and found new symmetries. And then found that those new symmetries are also flawed. And now they have this final symmetry that they found in their models, CPT symmetry, and then that one so far looks like it's not flawed. And so it has sort of guided us beyond our intuition of what should be a symmetry, to find the same is completely counterintuitive and say that's maybe the correct unflawed symmetry. Current experiments are trying to figure out if that’s actually true or if that one is flawed as well.

Ben: The search for symmetry is actually one of mathematical convenience because if you understand that a certain physical process is symmetric, it provides you with some shortcuts as to how to describe things and what you know is possible. So the idea here is that we're hoping the universe is symmetric in one particular way because then the math is slightly easier than it could be otherwise.

Tia: Because physicists are lazy.

Ben: This endless process where we discover the laws of you know, particle decay, aren't left-right-symmetric or that some procedure isn't time symmetric, or that some other procedure works differently depending on whether you're dealing with matter or antimatter. It means the physical laws have to be a lot more complicated and difficult to solve and everybody ends up mashing their teeth.

Ryan: But I disagree a little bit with saying it’s a mathematical convenience. I don't disagree that we're lazy. I think we do try to look for some type of fundamental beauty, I don’t know if beauty is the right word, but some fundamental principle that's much more powerful than just the mathematics of it.

Ben: Yeah. There's the eternal quest for a theory that fits on the back of a t-shirt they say right? And if something is not symmetric and you have to consider say left-hand cases differently than right-hand cases, then you double the number of equations that you have to fit on your t-shirt.

Tia: But that's exactly what happened with the weak force.

Ben: Yep.

Ryan: Well I think effectively you're right, mathematically it's probably simplified. But I think there's a true beauty in understanding the symmetry. It feels like once you get to this really fundamental symmetry where all the equations are simple somehow I feel like you've reached some very deep understanding. I don't know maybe that's a human bias, that hoping it's simple and beautiful. Maybe it's ugly and complicated.

[23:58]

Pat: Well not to be nerdy but thinking about from a film perspective or a storytelling perspective, when you're trying to write a story and you're trying to structure it in a way that can lead the audience through it in a perfect way, and you're looking for that kind of perfect journey of the characters and for the audience to follow that as perfectly as possible sometimes you're structuring it more and more until you get to a point where you’re like “this is boring”, because it's structured so well. And the human element of watching something and wanting it to be slightly flawed so that it feels more real or something because if it's mathematically perfect in all these different ways it becomes like this really whatever clichéd Hollywood film thing that people are like "That's boring, I've seen that before."

Ben: Yeah Ryan, symmetry's boring.

Ryan: Well that's actually a really interesting point thinking about film and art.

Pat: But the whole concept of that perfect story is constantly changing with every generation of people. There's still these core elements like the laws physics, but people have liked all kinds of different storytelling through history. I don't know what I'm getting at but it was just making me think of that. I feel like since I'm on a podcast and I'm a filmmaker I should talk about that…

Ben: No that's interesting. I think you're right, not just in terms of storytelling but in terms of the aesthetic search for things that are true that people would appreciate.

Ryan: It's completely arbitrary right? Just because it's more beautiful doesn't mean that it is more true.

Ben: Well no but I think that there is something nice about truth that's beautiful.

Ryan: Well yeah maybe that's what I'm getting at is that in a film or whatever you're trying to communicate something. Something that you kind of feel you understand and you're trying to communicate it to the audience and I think even with science stuff there's something you're trying to communicate to others. "There's this thing in the universe that works a certain way, like do you know what I'm talking about?" And you have to use words and you have to use numbers in order to communicate that and that's limiting maybe.

Tia: It's completely limiting! So I think this is a fundamental difference between experimentalists and theorists. So experimental physicists we like to get our hands dirty and observe everything that happens and whatever we observe is the reality. But a lot of what we've been talking about today in the physics is very sort of theoretical and what a theorist wants it to look like, to look perfect. And that reality is that perfect set of mathematical equations. But the experimentalist is like "Forget that. Reality is what I can measure."

Ryan: That's a good point. There's a limit in the way we need to conceptualize or need to break it down into numbers and words. Maybe for aliens with like super-brains you have a completely different way of conceptualizing it. The math will be completely different and we have to project this really complicated universe into our language of mathematics and English and we try to make symmetries that maybe don't make sense in the super-brain world. It will just never work in our limited capacities restricted to mathematics and language. We'll never actually be able to get the simple theory.

Ben: I kind of disagree with that. I think the purpose for the searches of these symmetries is that if they actually exist...they're no good if they don't exist...our talking about is a little academic because we know that it isn't true. The more versatile, the more true the theory, the more pleasing it is. But also there's a kind of universality to it. When we first sent out the Voyager spacecraft with all that jazz about where the Earth is and what humans were. You're familiar with that I presume?

Pat: Mhmm

Ben: We describe the location of the Earth in terms of big astronomical things that we knew wouldn't change and we knew were really distinctive. So instead of saying "Oh yeah we're near Jupiter" which another alien race might say "Oh what's a Jupiter? Where is it? There are lots of Jupiters. What do you want?" We said we are this far away from this pulsar and this far away from this bright heavy thing. So similarly I think the idea here is that if we can find the symmetries there are choices; there are arbitrary choices we make when we make the theory. We say that this particle is charged positive and this one electrically charged negative. We say that this one is rotating right-handed and this one is rotating left-handed. There is a matter of choice in there but if we can find the underlying symmetries what we can do is...those symmetries won't change despite the arbitary choices involved. So what we're going to be saying eventually is that the universe is symmetric: if you switch right-left, so the parity symmetry, if you switch antimatter for matter, and then if you switch the direction of time, the laws of physics will look exactly the same. If that symmetry indeed holds true experimentally over the coming decades, then if we were to ever talk to Ryan's giant brain god of an alien, then they might say "our laws are completely different than yours" and you could say "you're right let's talk about the symmetry." We know we can start at that symmetry and they would say "oh yeah we know about that symmetry." This is going to be our Rosette Stone in describing your science in terms of ours.

Ryan: I like that way of putting it. You're looking for the symmetry that kind of releases you from your constrained framework.

Ben: Because the convention will change. Some alien might say “no, these electrons have positive charge.” and we'd be like “no”, and fight back and forth because those are all conventions. But what discovering these symmetries will do is allow us to distinguish between what is convention and what truly is different.

Tia: Ben you're not really studying this so you can talk to aliens right?

Ben: I study everything so that I can talk to aliens.

Pat: The definition of words is something that you kind of brought up where it is arbitrary to describe something and then we use our knowledge throughout our life to kind of understand what that's supposed to mean. And we use those words to try to get on the same page as other people, like "I know what an apple is because I've seen an apple but why do you know what an apple is?" “Oh I've seen an apple too.” We point at the same thing and say that's an apple and we can keep going. But in terms of talking to an alien about symmetry, I don't know if they're going to have the same understanding of everything. The hope is that there would be some piece of common understanding about the universe.

Ben: You know that movie Contact, where the aliens contact us? And the first thing they spell out is pi, the number pi because that ratio won't change depending on where you are, and so you might translate the numbers...

Tia: No, they don't do pi, they do all the prime numbers.

Ben: Do they do the prime numbers? Well that's another thing that's not going to change. You know in the mathematical universe there are going to be some things that won’t change in spite of you being a big crazy genius alien that describes numbers in terms of how many tentacles it takes to do things. And if the aliens have studied physics enough and if these symmetries hold true then...if we start our conversation with the aliens just in terms of the symmetries then they should be able to recognize what we're talking about even if nothing else makes sense because so much of the language and mathematics is convention. The idea here is that the symmetries cut through the convention.

[31:57]

Pat: I guess, I know so very little about math, but I just wonder if our understanding of math is not something that's universal.

Tia: Yeah that's an interesting question.

Pat: So if we're talking about prime numbers and we're like, “see don't you see the pattern” and they're like “what are you talking about, that has nothing to do with anything. That’s just something in your own brain that you’re seeing these patterns.” I mean it's true because it's in your brain and it's a human understanding of the universe but I just wonder from different perspectives and different ways of understanding things so...

Tia: Yeah I think the question is “can there be other forms of math which describe the world differently?” And so we can't communicate about the same thing because the language is different. So is there one math Ben?

Ben: Well, I think it kind of depends. What they've discovered overtime is that math is always based on underlying assumptions and so depending on what you’ve assume to be true the mathematical structures might evolve differently. That said, we all live in the same universe, so physical invariances are probably the way to go with these things because even though they might think of things differently, you know wherever they're from stars probably still emit radiation, gravity still points toward the center of planets, basic constituents of matter are going to be the same.

Pat: This is going to sound like a really dumb question but is math based on counting? 1, 2, 3, 4, 5,6, 7.

Ben: Kind of. Some of it is.

Pat: Because that's the question I have. If you have one grape in your hand how are you determining that that is one of something or that that’s a grape?

Ben: Yeah, so essentially the branches of math that come from arithmetic and geometry all start out...you need to assume that there is something called "1" and there's something called "0". And then I think you need the concept of addition. But then if you have those you can start building.

It's funny, addition is an interesting thing mathematically. There are other systems that you describe in terms of mathematics where the system changes in a way that reminds you of addition, but it may or may not have various properties of addition. So one of them is like a rubik's cube. So you can describe the rubik's cube in terms of how the different colored blocks are ordered. But then you can modify a rubik's cube by doing essentially rotations on it. You can rotate 2 faces; so you can rotate one of the faces clockwise 90 degrees, or counterclockwise 180 degrees. The moral of the story is you can start to describe the structure of how you're orienting and reorienting the faces on it, in a way that kind of reflects counting and addition, but isn't itself a matter of counting and addition. Like how do you look at the orientation of a rubik's cube and say "yeah that's 4." But the underlying operations you do to it as you switch the faces around can be described using a mathematics. Often at the higher levels, mathematics becomes a study of logical structures that are predicated on certain systems. So someone will say instead of talking about counting and adding and 1 grape versus 7 grapes, you can start saying: let's imagine that I'm standing on a great big donut, if I take 13 steps in this direction I end up where I started and if I take 15 steps in this other direction and end up where I started, what if I take 4 steps in this direction and then 7 steps in that direction? How many steps is that equivalent to? So you can make all sorts of weird...or you can even talk about chess boards and different ways of rearranging the chess pieces starting at the original start of the game configuration. So you end up defining and then talking about mathematical structures that emerge from simple operations on systems. And so a lot of advanced mathematics comes down to exploring mathematical structures that are not necessarily 2 grapes in your hand versus 5 grapes in your hand but often reduced to similar systems. And so mathematics is kind of interesting in that case but on the other hand you can't really accuse mathematicians as spending most of their lives just studying rubik's cubes.

Tia: So there is a common language, the moral of your story?

Ben: The moral of the story is that some structures come out of it that are similar. I wouldn't say it's universal enough to be universal but it's universal enough in these systems that if you were talk to an alien they would be like "oh yeah, we know all about addition." Even though they might not have started learning about addition by talking about adding grapes, maybe they learned about it by rotating rubik's cubes. They'll still know about it because they really care about rubik's cubes.

Pat: Oh yeah, every alien race in the universe cares about rubik's cubes.

[37:16]

Ben: I think the theme of this particular episode starts out by being “hey I want to tell you about symmetries.” And the question you asked, and it's a really good one is "who cares?" Is there some aesthetic reason someone cares or is there some universality to it?

Pat: I guess more than who cares, “Is symmetry as universal as it seems? Is the concept of symmetry a universal thing or is it a human thing?”

Ben: Yeah what we're seeking out are universal symmetries. And the history of it has been we’ve started out hoping that there’s a symmetry and testing at very basic levels and seeing the symmetry in it. But then as our tests get subtler, as our understanding broadens, we often see that these symmetries that we assumed were true often get shattered one by one. And it's an interesting thing because in spite of this we still insist on saying that all of these symmetries are aspects of some greater symmetry.

Tia: Yeah you combine the symmetry with another thing that you thought was supposed to be symmetric but it’s not. And then when you combine them together, the combination is symmetric.

Pat: Okay.

[38:33]

Ben: Let's go through an example of this because they're actually pretty fun. So each of the symmetries that we're talking about today has been given a letter name. There is "C" that stands for charge; it refers to the electric charge of objects. So an electron has negative electric charge and proton has positive electric charge. There's "T" and that stands for time symmetric. And the idea here is, at least initially, that the laws of physics were time symmetric. What's a good example of something that is time symmetry?

Ryan: Billiard balls. A movie of one billiard ball hitting another. You can't tell if the movie is playing forward or backward.

Ben: Yeah perfect. And then the last one is "P" and that stands for parity. And that’s this mirror universe symmetry. Where we say “Hey the equations describing the universe would be the same in our universe as they are in this mirror universe." Now, they're flawed. We have discovered examples of processes that don't obey these symmetries. But the idea then is...what people started to do is they started to combine them to make new slightly more complicated symmetries which were as follows: There is something called the CP symmetry, which says we know the universe isn't made of antimatter it's made of "regular matter", whatever that means, quote, unquote. I'm making air-quotes, big air-quotes because it seems like it's a convention thing. But there are some processes that care if something is made of matter and they work differently if they are made of antimatter. So what we said in the CP symmetry is "Okay, the universe cares if whether something is made of matter. It cares if something is made of antimatter. The universe works differently in our universe than it does in the mirror universe. But antimatter in the mirror universe works exactly the same as regular matter in our universe. That's crazy. So that's something called CP symmetry. And of course we can talk about it in a second that they discovered that it's wrong.

Tia: Well that's because of how neutrinos come out of interactions. Okay I have a left-handed neutrino on my side of the universe. In the mirror my neutrino looks like it's right-handed. But that's impossible. That doesn't exist. But if I apply C, the charge conjugation operation to it and switch that neutrino into an antineutrino, it is now an antineutrino that is right-handed and those exist.

Ben: Right. Yes. So, what's a neutrino?

Tia: It's the only particle that only interacts weakly, with the weak force.

Ben: The world is full of particles but there are only a finite number of different basic elementary particles. There's like electrons. There's protons and neutrons, but those are made up of elementary particles themselves. Those are made up of things called quarks. So the deal is it's a particle that we have very little experience with. And it came about when people were watching what would happen when a neutron would decay into a proton and an electron. There would be this third particle that wouldn't interact with anything; it would just zip off. And they're called neutrinos which means really small neutrally charged particles. It has no electric charge. And an electric charge is the thing we usually use to detect particles. So in essence it doesn't touch anything once it gets made. It just kind of flies off and barely interacts with anything. And the only strings it feels are through something called the weak interaction. Which as it suggests is a really really really weak force. It only exists in the nuclei of particles. So essentially there are these particles that get made and never talk to anybody else again. So they just kind of float through space. So the sun makes tons of them. Their made as the result of nuclear fission or fusion and then they never get seen again. They just kind of wander around, not really doing much. So people can make detectors for neutrinos. There are chemical detectors and there are actual physical detectors. And what's required are essentially building-sized buildings full of ultrapure water or ice and occasionally one of these neutrinos will come in and bump something. So you need it to be really dark and isolated from a whole bunch of radiation so they put them under glacial ice sheets in Antarctica or in the middle of mines inside of mountains. And that's the only place that's quiet enough where you can see the rare interaction with neutrinos. So they're everywhere but they're really really rare and we have very very little experience with them. It's only the modern era when we've been able to discover and do experiments on neutrinos to see what happens to them. And so neutrinos are really weird because the way they interact with things violates the parity symmetry. If we could see and interact with neutrinos all the time we would know that there is a difference between our universe and the mirror universe. But because they're so weakly interacting, physicists until the modern era, had no idea that they even existed. And so they had no idea that sometimes some things interact differently depending on whether they're right-handed or left-handed. So essentially neutrinos are used to discover that the universe lacks this mirror symmetry.

Tia: But if we add C to it, everything is good again, for a little while, but then...

[44:01]

Ben: So the idea is we're going to combine reversal symmetries. So left-right reversal and switch matter for antimatter and if we do that then the laws of physics will look exactly the same. I want you to imagine that somebody takes a video of a highway with cars going down it. Imagine that a little kid rotoscope-animates these cars but does a really crummy job so all you can see is boxes moving. Let's suppose that the highway is going up down on the screen. So you'll see some boxes on the right moving up and some boxes on the left moving down, representing the right side of the highway where everyone's going north and the left side of the highway where everyone's going south. So if you apply left-right switching to this, so if you watch this video in a mirror, what you'll see is the things going up are on the left side and the things going down are on the left hand side. So it will switch the order of it. And you'll say, “Hey, something's wrong there. I can tell the difference between this and an actual highway because they're on the wrong side." Right?

Pat: Yeah.

Ben: Okay, now imagine somebody had the same videotape, maybe one of those old-fashioned reel-to-reel projectors and switched the direction the movie was playing. So now it's playing backwards. The badly animated cars, the ones on the right side, because the time was going backwards, would go down, and the ones on the left hand side would go up. So the deal is that the tape playing backwards in time is going to look the same as the tape where you're watching it through the mirror. Right?

Pat: Let me think for a second...

Ben: Assume that it's really badly animated so that you can't tell the difference, all you can see are these rectangles moving. And you're like "Uh, dammit Timmy you're fired." The idea here is that you might be able to tell the difference between somebody flipping something in the mirror and the way it's supposed to look. You might be able to tell the difference between time reversing and the way it's supposed to look. They've got it backwards in the projector. But you can't tell the difference between something that is backwards in the projector and through the mirror because that will switch it back. But so someone presents you with a video tape, an actual videotape, not a poorly rotoscoped one. And the videotape is of a highway, and they've made several terrible mistakes. They've set it up so you're watching it in a mirror and they've got it playing backwards in time. You can tell the difference between the original one and the one that is mistaken in 2 ways.

Tia: The cars are going backwards.

Ben: The cars will go backwards. So even though they'll be going on the correct side of the highway you can say look, it's going backwards in time and you're seeing it through a mirror because all the cars are driving backwards on this highway. "Timmy you're fired." The deal is that the universe is kind of like that. In essence what happened was there is another law violating this. We mentioned this before. If you switch antimatter for matter, so take all the electrons and replace them with antimatter, all the protons replace them with their antimatter double. And you switch right and left; you do a parity switch; you look through the mirror universe. The argument was that we can't tell the difference between that universe and this universe if you do these two parallel switches. And of course they did an experiment and they discovered a distinction essentially a difference equivalent to the cars driving backwards. There's a way to tell the difference between a universe that is mirror-imaged and also everything is replaced with antimatter. And so there's this particle physics experiment, I won't bore you with all the details about neutral kaons. But then what they did was say "Well you know, combining two symmetries doesn't give me a universe that looks the same. But if I combine 3 symmetries that's going to be the one that works." They say "Okay, our universe looks the way it does. If I switch the antimatter for matter it would look slightly different. And then if I switch left and right through a mirror that would make it slightly different as well. But then in addition to those

I look at the video of that weird antimatter universe moving backwards in time that would look like the same original universe." Hey lots of fun. That's called CPT: charge, parity, time symmetry. And it's actually the last and the greatest of symmetry operation because you combine all these symmetry switchings, like this one will work for sure.

But right now they're in the middle of kind of testing them. People have proposed various tests for that. So it should be interesting because you know I don't think the universe is actually at the large scale time reversible. This time reversal symmetry they're talking about doing applies only to billiard balls knocking together – very simple systems.

Pat: Well do you mean billiard balls hitting each other or a video of billiard balls hitting each other?

Ben: So the argument was that you couldn't tell the difference between a video of two billiard balls hitting each other backwards and forwards in time. So somebody could reverse the video of the billiard balls hitting each other and you'd be like "Yeah, I don't see any difference."

Pat: In a video?

Ben: In a video. But if you look at a video of a whole pool table, you can tell the difference between the video played forward and the video played backwards right?

Pat: Yeah.

Ben: So there are a bunch of ambiguities as to whether or not CPT symmetry holds.

[49:08]

Pat: Well thinking about the cars, and you realize, "Oh wait, the cars are moving backwards." But the laws of physics wouldn't allow the cars to move backwards if it wasn't a video, if it were actual cars, right?

Ben: Okay so in this metaphor what you would say is a backwards moving car is antimatter. So in this metaphor you'd say “I can't tell the difference between regular cars moving in the correct direction on the highway and antimatter moving the wrong direction on the highway.”

Pat: I guess I get stuck on the simple things but I can't picture...are you like saying like in an alternate universe?

Ben: Okay so in our universe there are types of particles that we classify as regular matter. Those are electrons, quarks, neutrinos. But in addition to that it is possible to create a type of matter that we classify as antimatter and antimatter is just like regular matter in every way except that it has the opposite charge. So you end up with something that looks exactly like an electron but instead of negative charge it has the same amount of positive charge.

Pat: And how does it look exactly like an electron?

Ben: Well okay there are some defining characteristics of any elementary particle and only a finite number of characteristics. So one of them is how much charge it has. Another one is its mass. Another thing is how fast it is spinning. In quantum mechanics everything is kind of moving. So these particles will be spinning with a certain, essentially speed. So the idea is that an antiparticle will have the same spin. It will have the same mass. It will have the same quantity of charge but the charge will be the opposite sign; so it will be a positive charge instead of a negative charge.

Pat: Is this something observable?

Ben: Yeah, sure. It has been observed. And it's been observed since the 50s. Actually there is an interesting thing people do in particle physics. There are things called conservation laws in the universe. You've heard of the conservation of energy right? Conservation of momentum?

Pat: Yeah yeah.

[51:13]

Ben: So there's something called conservation of electron number, where the total number of electrons in a box is always going to be the same. And that doesn't mean you can't make electrons. You've heard of Einstein's $E=mc^2$ formula?

Pat: Mhmm.

Ben: To make an electron you need to pack that much energy into one place and an electron might pop out of the vacuum. But because of the conservation of electron number rule, whenever you make an electron you have to make a positron, an antielectron, an antimatter electron. So anytime you're making regular matter you have to make the same amount of antimatter at the same time. So what will happen is if you take two gamma rays and smash them together out of the vacuum with pop regular matter, an electron, and an antielectron, and they'll have the same mass, and the same spin. They'll be spinning in opposite directions because of something called conservation of angular momentum. They'll have the same quantity but different signs of charge. So one will be positively charged and the other will be negatively charged. And the interesting thing, I'm sure you've heard of this is that when antimatter touches regular matter they annihilate! So if you made an electron and an antielectron if they touch each other they'll turn into something else, probably gamma rays and then neither will exist anymore. And so you can get pairs of electrons and antielectrons popping in and out of existence. And the same things holds for every type of matter antimatter pair. Every type of matter has an antimatter pair. And anytime you bring one into existence you have to bring the other into existence.

Pat: So beyond electrons, what about on the atomic level?

Ben: Yeah, people have actually made antiprotons.

Tia: And antihydrogen.

Ben: Yeah, if you take an antiproton and you put and antielectron around it, you can make an antihydrogen atom, which looks just like a regular hydrogen atom except the charges are reversed.

Pat: And that's just called...that's just what it is?

[53:08]

Ben: Yeah we call it antihydrogen. And if it touches another atom it will annihilate and we'll get a big flash of gamma rays. So there's a bunch of interesting things to talk about with these symmetries we've mentioned before. So we mentioned that anytime you want to make an electron you have to make an antielectron at the same time and the same holds for every other type of basic particle. So when you make an electron, let's say it's spinning clockwise and it's got negative charge. You also have to make an antielectron spinning in the opposite direction. Now if you take your original electron and you switch the charge on that and make it positive. And you do that parity switching where you switch right hand and left hand, instead of rotating clockwise it looks like it's rotating anticlockwise, you'll end up with an antielectron. So doing these two symmetry transformations gives you an antielectron. So CPT symmetry - the idea here is that if I switch charge and switch the mirror universe and then I switch the direction of time, I'll end up with essentially exactly where I started. And the result is if I switch two of those it's equivalent to switching the third. So if I switch the charge and the spin of my electron that's equivalent to taking a regular electron and switching time. This is still a little bit complicated but the moral of the story is that one mathematical interpretation of what antimatter is that it is actually regular matter moving backwards in time. So here's the neat thing: The argument is that there is only one electron in the universe. Because anytime you make electrons you have to make an antielectron or rather imagine two gamma rays collide and produce a pair of an electron and an antielectron and suppose that they re-collide and turn back into gamma rays. Another way you can tell that story is, first there was nothing and then there was an electron and then it turned backwards in time and made a closed loop on itself. And so all the electrons in the universe might just be the same electron moving backwards and forwards in time along these antiparticle paths.

Pat: Cool.

[55:17]

Ben: Another important thing that's a little more serious which has to do with CP violation. We know that there are some nuclear processes that violate this. And it's important that they do because the universe as far as we know isn't full of galaxies made of antimatter. So I mentioned what happened before when antimatter meets matter is they collide and annihilate and they no longer exist and it's just gamma rays. Well why is the Earth not covered in this antimatter. The argument is that if the earth were covered in antimatter it would annihilate with the regular matter and it wouldn't exist anymore. Alright, well everything else in our galaxy has to probably be made of regular matter and not antimatter. Like where is the antimatter!? If every time you make an electron you have to make an antimatter equivalent where is all this antimatter?

Tia: Where is it Ben?

Ben: So one of the arguments is that because these symmetries are violated there are subtle ways that the universe can produce slightly more matter than antimatter. So over the course of the big bang when the universe was just starting out and everything was really hot. It may have made a ton of antimatter at the same time as the matter but that all annihilated. But if it was making slightly more matter than antimatter as time went on all that would be remaining is the regular matter. And that's why the universe is full of regular matter and not pairs of matter and antimatter always colliding and melting each other.

[56:53]

Pat: Thinking about what you said before about an electron going backwards and forwards in time, all over space I guess, right?

Ben: Yeah.

Pat: Doesn't that just get rid of time and space?

Ben: I see what you're saying. So it's like saying if it's all the same electron then nothing happens to it. So doesn't that mean that nothing happens? And I think the answer to your question is that time as we perceive it comes from essentially billiard balls. It's not one billiard ball interaction, it's the accumulation of all the billiard balls on the table and going from a nice neat triangle to all over. That's what we recognize as forward in time and not the individual, one at a time, reversible interactions. And the electron itself doesn't have any internal structure. So the electron itself might be moving around in the universe, but its internal structure isn't chaning. It doesn't have an internal clock that's saying "Oh well we were here half an hour ago." And so it doesn't gather any damage, nothing is going to happen to it anyway because there is no internal structure. Nothing inside it can change as it moves backwards and forwards in time. And so it's only the pool table and not the individual balls that we recognize as time moving forward. I don't know if that made any sense to you.

[58:14]

Pat: I think it will. Can we talk about time for a second? Can you define time for a second?

Tia: Yeah, can you define time Ben?

Ben: I can. Time is a complicated thing because there's more than one way in which physicists describe time.

Pat: Okay, just hearing that relieves my mind.

Ben: (Nobody is sure what they have to do with each other.) Okay so there is something called an arrow of time. We know which way the future is. The future is clockwise on a clock. But there's no quite sense as to why the future is always clockwise on a clock and not counterclockwise on the clock in terms of the equations. Now time is a neat thing because it occurs in several different places in several different ways. In thermodynamics, and this is what people usually describe when they're talking about the difference between the future and the past. In thermodynamics, essentially you've got ice cubes that melt or eggs that go from being a nice round sphere to falling on the floor. You can't uncrack an egg. There are various thermodynamical processes that come about from the macroscopic arrangements of objects that aren't reversible in time.

Pat: Wait, I want you to keep talking about that, but I want to go back to when you were talking about cars moving backwards in a film strip, and if they in reality were an actual car, and I was sort of saying it couldn't move backwards. It's the same sort of thing as an egg can't unbreak, because of the chemical…you know the engine, and all this stuff that’s happening in the car. That stuff couldn't be reversed?

Ben: So if you were watching your video really subtly. Suppose it was a really good high definition video. You know your crappy intern who keeps messing up these videos...

Tia: (laughs) Timmy!

Ben: ...you're watching it and you go "these are cars and they're moving on the wrong side of the highway. They're moving backwards on the highway. I know you've switched the direction the film is going."

Tia: And they're sucking in their exhaust.

Ben: Yeah. So Timmy would reply, "Okay listen, everyone's driving their cars backwards on the highway because it's backwards day." So what you would probably do in this physical world is you would probably look at the exhaust from the cars and say "Listen, that car there is sucking exhaust into the tailpipe. I know that this is a time reversed video. You can't fool me Timmy!" So this is an example of a process, you know the internal combustion engine…you can't unburn fuel. You can't go from having a room full of carbon dioxide and you can't smush those carbon atoms back into being gasoline. So there are various thermodynamic processes that define what we call the arrow of time. And the arrow of time is usually described as being in a state where all the energy is locked up in one thing. There is an ice cube which has a colder temperature than everything around it or all of the fuel is in this nice liquid form. And then the future is the time when all of the fuel is burnt, or the ice cube is melted and everything in the room is the same temperature. So we usually use that, it's called the arrow of time argument, to describe the difference between the past and the future and because of these thermodynamic arguments at the large scale the universe isn't time symmetric. There's a difference between the past because if you look back in the past there was the big bang and the future where there is no big bang. So it looks like our universe at the larger scale does have an arrow of time that isn't at all reversible, time symmetry reversible. And that's interesting but that's not the only time time pops up in physics. Another place it pops up is the theory of relativity, where the deal is that the rate time passes depends on how deep you are in a gravitational well and also how fast you're traveling. So if you go up into orbit time passes at a slightly faster rate than it does here on the ground because we are deeper in the earth's gravitational well, than time way up in orbit. And actually you're familiar with GPS systems right?

Pat: Yes.

Ben: Have you ever wondered how they work?

Pat: Not really. (laughs)

Ben: They're effectively just broadcasting the time. They're atomic clocks and they're broadcasting the time. And your GPS receiver receives information from several different clocks and triangulates your position based on what time those things were broadcasting the time. But the deal is that if time is traveling at a slightly different rate there than it is here if we didn't include corrections for the fact that that is happening, the GPS would stop working in a matter of days. It would just be way off.

[1:03:08]

Pat: Oh wait, this is something from before that I just remembered, about the egg breaking you were talking about, and an antihydrogen particle. Now if you made an anti-egg.

Tia: Ah! Anti-egg!

Ben: Clever! So clever.

Pat: Well, what happens with that egg?

Ben: Yeah would it antibreak? That's a good question and nobody knows the answer to that question. I think the argument is that once when we start talking about the thermodynamic of objects, we're usually talking about them in terms of their relationship to other objects around them. So we usually say the system becomes more messed up over time. And this would apply to both the anti-egg and the regular egg. So the answer is probably that it would break as you went into the future rather than come together. But I don't know if anyone has an answer to that. CPT symmetry says that an antiparticle is equivalent to a regular particle moving back in time. There are other issues with it, like nobody knows how it behaves with gravity. So just as your egg smashes, over time objects are pulled toward the center of the earth. So one of the things nobody is quite sure of: how antimatter reacts with gravity. And part of the reason for that is you know antimatter is pretty unstable because it will bump into something and pshew. You've heard of water clocks or even sand hourglasses, where you flip them over and gravity describes where the future is. In the future all the sand in the hourglass ends up at the bottom chamber. So in time gravity makes things go down. If I reverse that time, does that mean that antimatter feels a push out from gravity. And nobody is sure what the answer is. And the answer, my guess, is no, that gravity affects regular matter. Because antimatter has a certain amount of energy to it. You need a certain amount of energy to make it. And it needs to be regular $E=mc^2$ energy, positive matter mass. And so it has positive mass, so I believe it should be attracted toward more massive things and that gravity might break the CPT symmetry. But nobody knows for sure at this point in time. It's still a matter of experimentation. The experiment is still out on that. People are still trying to design a decent test to see if gravity will violate the symmetry.

Tia: Yeah, particle physicists have a lot of problems with gravity. We don't like it very much.

Ben: Yeah it's a real downer.

[1:05:53]

Pat: What were you saying about antimatter? That it can go back in time?

Ben: Yeah because of the formal CPT symmetry in the mathematics we can interpret antimatter, so you know antimatter is usually just regular matter. It's usually spinning in the opposite direction. You know if you make an antielectron and an electron, they'd usually be spinning in the opposite direction because of conservation laws and they have the opposite charge. So one looks like the opposite of the other one, where the antimatter looks like the regular matter where you've switched the charge and you've switched it so it's rotating in the opposite direction, which is equivalent to a mirror image of the original thing. And so the idea here is that if formally the charge and the rotation direction are switched that's equivalent to an electron, in this case, moving backwards in time. And so they say, and it's a little bit facetious but it’s a notation thing particle physicists do to describe it. They say these antielectrons are describable mathematically describable as regular electrons moving backwards in time. So when people chart things out they chart them out using something called Feynman diagrams. You might have heard about them. People talk about them a lot. It's just a diagram showing what the particles are doing, what they're bouncing off of in time. What particle physicists do when they're charting out what happens to antiparticles is that they draw all the antiparticles traveling backwards in time and all the regular particles moving forwards in time and that's how they distinguish between the two visually on paper. So it's something people believe in but I think it's a little bit facetious. I’m not sure if we actually think the particles are moving backwards in time. It's just like on an individual one-by-one interaction basis, like how two things will bounce off each other, it is kind of like billiard balls where the film strip looks the same forwards as it does backwards.

Pat: How is the particle observed?

Ben: The antimatter?

Pat: Yeah.

Ben: They behave like a regular electron except they'll have an opposite charge. So if I put a big positive charge near it, a regular electron will be attracted to the positive charge and an antielectron will be pushed away from the charge.

[01:07:55]

Pat: But then how is it created?

Ben: Antimatter pairs pop out of really energetic reactions. So anytime you have two energetic particles coming together often you'll end up with matter-antimatter pairs generated as a result.

Pat: But if something that's matter and something that's antimatter is created at the same instant, doesn't that defeat the concept that that is moving backwards in time?

Ben: So what you do is, imagine an electron and antielectron pair were generated, so they emerged from the same point. And then imagine they got sucked back together and annihilated. So there is two descriptions of that on the page. One of them is that immediately an antimatter-matter pair were created and then annihilated each other. And another way to describe it is one electron moving in a circle through time.

Tia: Time and space.

Ben: Time and space yeah. So it's moving in a circle in time and space. So then part of the electron's time axis that moves parallel to our direction of time, we say that's an electron, and the part of the path that's moving backwards relative to our direction is called an antielectron.

Pat: So there's one antielectron? Let's say that there is one sitting somewhere and at some point it comes in contact with an electron?

Ben: So what I'm saying is, the one electron hypothesis, where it's just one electron moving backwards and forwards in time is kind of predicated on the idea that you get the same amount of antimatter as matter. But the idea here is that anytime you make an electron you also have to make an antielectron. Well that antimatter's destiny is to collide with another electron somewhere and disappear. So instead of talking about a bunch of particles annihilating and creating you just talk about one particle zigzagging through space and time. So anytime two of them are generated you would describe that as an antielectron that goes backwards in time until it meets some photons or something and that reorients it so it's moving forwards in time. And anytime you see an electron-antielectron annihilating that can be described as an electron moving forward in time meeting some mean photons and reorienting itself so it can go backwards in time. It's facetious but fun.

[01:10:14]

Pat: So what's the use of caring about antimatter for humans? Is there a goal?

Ben: One thing about antimatter is that it's crazy. It's neat because it's novel. It's neat because of some of the implications it has on the universe.

Tia: And it's also useful.

Ben: How’s antimatter useful?

Tia: PET scanners. We use antielectrons to image the inside of your body. The soft tissue in your body.

Ben: PET scan stands for positron emission tomography. A positron is another name for an antielectron. It's a positive electron.

Ryan: Yeah I think they inject radioactive stuff into your blood and that radioactive stuff emits positrons and that positron will meet an electron and create two gamma rays that are detectable and we can tell exactly where it happened because we have both gamma rays.

Ben: So around your body are a bunch of gamma ray detectors and so they get emitted from the same place in your body. So if one gets emitted from the right lobe of your lung both gamma rays come from that point and they're going to be moving in opposite directions. So based on the timing that your detector receives them and based on which direction they were heading you can figure out where in your body they went and then based on that you can figure out where all this radioactive fluid is. So yeah there are uses hooray! That was great. I was going to say starship fuel. But Tia's answer is much better.

Ryan: I thought you were going there.

Ben: Yeah me too. Well that was pretty fun. Thank you Ryan. Thank you Tia. You've pleased me. Your efforts have borne fruit and that fruit is sweet. Here is some fruit. Ryan you get an orange. Tia you get a pomegranate.

Tia: Nom, nom, nom.

Ben: I'd like to thank my guest Patrick McHale, creator of *Over the Garden Wall*. Patrick I hope you had fun.

Pat: I did.

[1:12:13]

Ben: I had fun explaining it to you. I hope it wasn't too boring to you.

So it's announcement time. First off, I hope you're enjoying these *Question Barn* episodes that we've been putting out. Our fifth one should come out on Isaac Newton's birthday. If you've got a question that you'd like to hear us talk about send us your questies to Tiphyter@titaniumphysics.com. Second thing is, good news, our Patreon Campaign is building and we've reached our first funding goal so I've used the money to transcribe one episode so far and I'll post it on the website. And if you can think of better uses we can put it to as time goes on send me those suggestions. For now they're going to stick around on the website but there is no end of use we have to use them for once we have them. So it's pretty fun. So now on that note I'd like to remind you that we are now accepting donations. We'd be grateful to receive your support frankly. And you can make a one-time donation using Paypal through our website or you can set up automatic donations. Every time I finish an episode, that's an episode of the *Titanium Physicists* not at *Question Barns* because those take no energy to make. So you can set up an automatic donation every time I finish a Titanium Physicist episode through our Patreon website. This particular episode of the *Titanium Physicist* podcast has been sponsored by a collection of generous people. I'd like to thank DMB Screener, a man named Hugo, and Joe Piston, Brent Evans, a lady names Jill, and a gentleman named Greg and a gentleman named Ian. Thanks Josh and Steve and James Closin, and Mr. Devin North, a gentleman named Scott, Ed Lollington, Kelly Weinersmith, Jocelyn Read, a Mr. S. Hatcher, Mr. Rob Aberzado, and Mr. Robert Shtetca. I'd also like to thank Brent Knopf for remastering our intro. I appreciate the help. 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. You might want to listen to ones about chemistry or ones about science or ones about astronomy. We have a whole bunch, take a look at it. If you click on the itunes, the Brachiolope Media Network in our itunes, you can see all the Brachiolope Media shows or you can go to the Brachiolope Media Network website. Okay, until next time my friends. Have lots of fun and remember to keep science in your hearts.

...

[01:15:46]

Pat: I shouldn't bring up time machines. I've heard loud conversations, loud arguments about time machines.

Ben: Oh, what are your strong opinions?

Pat: Thumbs down.

Ben: You don't like them as a plot device?

Pat: I don't like them as a concept...

Ben: Why?

Pat: in reality. Well because I don't know stuff maybe but it just doesn't make sense. It doesn't seem realistic. And whatever time it is, it's not for going back for visiting the dinosaurs

Ben: So the level of people doing time machine stuff. Physics imagines time as a big tapestry. So all the events are laid out. The story is you can use the curvature of the system to go backwards in time. BUT you can't change the past. You can only consistently modify it in a way that it had already been modified by your future self.

Tia: That's what happened in Interstellar!

Pat: Oh. I haven't seen it.

Tia: Oh sorry.

Pat: I understand and believe in the concept of being able to monitor all of time. But not to physically travel to a different time.

Ben: Well you can travel to the future. You just can't go back.

Pat: Yeah, yeah exactly.

Ben: Okay. Well I mean that's probably the way… There's a bunch of more serious theorems of whether or not it would be possible to make a time machine. Thanks Steven Hawking. The answer is probably no.

Pat: I think even the word "machine" is not taking the concept seriously. But then we might be able to create something that can move back in time.

Ben: Like an electron.

Pat: Yeah or I don't we might be able to create some egg to hatch something. But it's not us moving in time in a time machine or us moving backwards in time.

Ben: The physics when you start to talk what happens when there are time machines it becomes really complicated really quickly because of this self-consistency thing I mentioned where you can't change the past. Our laws of physics really like the idea that if you know the details of how the system starts you can describe how it will evolve in time. And it might be a really complicated evolution that involves chaos theory and whatever but we can still say if it's like this right now, half a second later it's going to be like this and half a second later it's going to look like this. When you have loops back in time things get a lot hairier because there are issues with something called back reaction, where information or matter even can travel back in time on loops and pile up on themselves an infinite number of times. So you can have an infinite number of say a photon traveling back in time, crossing its own path an infinite number of times. And if they do that there should be an infinite amount of energy at that place which will cause everything to collapse into a black hole. So, it's essentially one of Steven Hawking's bigger arguments against it. It's probably not feasible to let us travel backwards in time in a proper time machine or even receive information from the future in that way because doing so would allow these weird build-ups and you'd have everything turning into a black hole. So it's self-annihilating I guess. The system prevents itself from existing.

Pat: Okay so there's a rock outside my house. It's been sitting there for who knows how long. It's moved around a little bit and it's been there for a really long time and it will be here for a longer time. If it's possible to create something that can stay, like it doesn't move back in time, but is timeless.

Tia: Something that is outside of time.

Pat: Yeah.

Tia: Like an object? Because I mean ideas can be timeless.

Pat: I don't know. See time machine - thumbs down.

Ben: One of the things that is important when we were talking about cracking eggs in the arrow of time, one of the laws of thermodynamics says that the entropy of an object is always going to increase. In other words objects change over time because they're made of atoms because atoms are always bumping into each other. The object is going to change. So if you loop something backwards in time or if you try to remove it from time or somehow tried to make it so that it didn't change at all forever, you would essentially need to make it not interact with anything ever again. Because if it did interact with things then it would cause disorder to increase and that would be a measure of error of the arrow of time. But you know on that note if you throw something into a black hole something really funny happens inside a black hole. One way to describe what happens in a black hole is that time kind of moves...one way to describe it and this isn't mathematically particular formulated but one way to describe the arrow of time is to going from forwards to sideways. Things inside a black hole formally takes an infinite amount of time for an object to cross the boundary into a black hole. And this will manifest in a variety of ways. It takes someone falling into a black hole to cross the boundary in a few seconds but from the outside universe it will look formally like it's taking an infinite amount of time. So if your grandmother fell into a black hole 300,000 years ago you can still pick up a telescope and if you tune the telescope to pick up the deep deep deep deep deep infrared radio super-long-long wavelength you still should be able to see your grandmother floating on the horizon staying there forever. And in fact, one of the reasons you can never get out of black hole is because once you're inside the boundary, the universe outside the boundary has died of old age. So in some sense you're removing yourself from time by falling into a black hole.

Pat: Time travel. But only forward.

Ben: Yeah only to the death of the universe. Then you fall in and you get crushed to death. The theory of relativity that describes space-time in terms of curvature also says that the rate at which time passes will depend on how much curvature there is. So you can set up systems where the rate of time passing in one place is much much much slower than the rate time is passing in another place. That’s effectively what happens at the entrance of a black hole. Time just slows down for an object about to cross into a black hole.