Episode 59, "Strange Truth And Charming Beauty"
Dramatis personae:
- Ben Tippett
- Ryan North
- Tia Miceli
- Ken Clark

The Titanium Physicists Podcast
www.titaniumphysics.com

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

01:11

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

01:46

Ben: Physicists are a bunch of nerds. I'm not sure if you've noticed but we are. And the most glaring habit of nerds is that when they think no one is watching they make stupid jokes that no one else understands. We've talked about that on the show before. Remember that episode where we talked about pasta matter in neutron stars? And how, depending on how deep you go into a neutron star, there's a different mix of protons and neutrons and how they technically describe that mix in terms of being a spaghetti phase or a lasagna phase? And we mentioned in that episode that this is just the tip of the iceberg. And it really is. And we mentioned earlier there is something called a penguin diagram and in particle physics you can draw the subatomic interactions in terms of imagining little particles bouncing around so you can draw their trajectories and sometimes they look like penguins. And so they call them penguin diagrams. And we mentioned barns, a barn is a unit of area and it's a joke, right? 'Cause, you know, you couldn't hit the broad side of a barn? Yeah, so a uranium atom's nucleus has a pretty big cross section and so they describe that area as a barn. And we mentioned the no-hair theorem that says that for black holes, metaphorically, there's no hair. Anyway, someone should put a stop to all it but nobody's going to because it's too much fun. So, today's episode involves some of the dumbest physics inside jokes you've ever heard. The names that people have given to some of the things we're gonna talk about today are really silly. So - fair warning - it's gonna be nuts. Today we're gonna be talking about the strong nuclear force. It's the force that sticks all the protons and neutrons together in an atom. And speaking of nuts, today's guest is very accomplished author. He's written a very popular web comic but he's also written comic books and his stint writing the Adventure Time comic books won him an Eisner and a Harvey award. His Kickstarter - choose your own adventure Hamlet book - broke Kickstarter records and he's refused since then to rest on his laurels. He's currently writing Marvel Comics hit new book The Unbeatable Squirrel Girl and has recently announced a Kickstarter for a new choose your own adventure book about Romeo and/or Juliet. And also recently he notably got stuck in a hole with his dog. Welcome to the show, Ryan North!

03:58

Ryan: Thanks Ben. Uh, all that was true except for the Kickstarter thing with the Romeo and Juliet book. And/or Juliet is being published by an actual publisher and not through Kickstarter.

Ben: Oh, okay. Do you want me to delete that part?

Ryan: [laughs] It's fine.

Tia: [laughs] We can perpetuate more lies.

Ben: Yeah, sure.

Ryan: To make people more confused when they want to buy my book.

Ben: I'm/ Yeah, it's no wonder I couldn't find it on the Kickstarter webpage.

Ryan: [laughs] It's not out yet. It's coming in June 2016, should be in bookstores everywhere.

Ben: Fantastic. So, Ryan, for you today I've assembled two of my very favorite Titanium Physicists. Arise, Dr. Tia Miceli!

Tia: Raaaaaar!

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's an expert on neutrino particle physics. And arise Dr. Ken Clark!

Ken: Wooosh!

Ben: Dr. Ken did his PhD at Queens University in Kingston, Ontario and he's currently assistant professor at the University of Toronto where he's an expert on neutrino detectors and dark matter. Alright everybody, let's talk about things that stick together.

05:02

Ken: We're gonna talk about the fundamental forces, right?

Ryan: Right. And there's a bunch of them.

Ken: There is. There is in fact four of them. Four total. And we already have some of the weird naming that Ben talked about. So if you start from the weakest force in terms of the kind of strength over distance, that's gravity, right?

Ryan: Right. Gravity is just hot garbage.

Ben: Yeah.

Ken: Pretty much everybody, nobody cares about it, it holds us on to the earth, does a bunch of other stuff. Other than that - who cares? Right? Nobody likes that.

Tia: [laughs] Ben writes science papers about it.

Ken: Yeah, yeah, yeah. That's fine.

Ryan: But we're not here to talk about gravity.

Ken: Right. Gravity is hot garbage, as you said. Okay, so working our way upwards in terms of strength, you go up 33 orders of magnitude, you get to the weak force. So, it's already really the naming convention that already put gravity in its place. Because it's 33 orders of magnitude weaker than something that we call weak.

Ryan: Right.

Ken: And that/ the weak force really just kind of governs, like, neutrino interactions and beta decays and stuff like that. It's mostly involved in that sort of thing. But it’s fairly/

Ryan: So this is like, room temperature garbage but not/

Ken: Yeah, yeah, that's right. We're getting better. And then you go up like what? Three or four more orders of magnitude and you get to the electromagnetic force which is, you know, the repulsion between like charges and attraction of opposite charges and that kind of thing, which you know, I think probably everybody has a relatively good handle on.

06:26

Ryan: Yeah. Does that include, like, when I put magnets together?

Ken: It does. I mean, I don't know if you're gonna ask how they work, you know, to do that/

Ryan: No. We've all discovered/

Tia: [laughs]

Ryan: Everybody knows how magnets work, it's/

Ken: Clearly, we/ the Internet has outlined that nobody knows how magnets work. Magnets work with electromagnetic force, that's correct. Yeah.

Ryan: So that's/ this is the first of the forces that I can actually observe with my hands and a couple of magnets. (...) gravity I can observe by falling down the stairs.

Ken: Yeah, well, that's one way to observe it. I might suggest dropping something but to each their own.

Ryan: Ourselves.

Ben: Yeah, downstairs.

Ken: That's true, yeah. You really put me in my place there. Yes, good. Okay, so then if we go to the top force, so like another two orders of magnitude stronger than electromagnetic force - that's the strong force. So the most powerful force is the strong force. And this is the one that we're gonna talk about. So that's kind of the really brief tour through what we know about fundamental forces.

07:18

Ryan: I'm with ya.

Ben: There's kind of a mystery here when it comes to classical physics. So, you got these protons, right? And electrons. And the reason electrons are stuck to protons is essentially they're in orbit around it because they're pulled together using the electromagnetic force. Opposites attract, one's positive, one's negative, they're pulled together.

Ryan: Got it.

Ben: The electromagnetic force gets stronger the closer the charges are together, right?

Ryan: Is that inverse squared?

Ben: Yeah, it's inverse square.

Ryan: Got it, yeah.

Ben: So, in terms of atoms this kind of makes sense, you know. So, if an atom has more electrons orbiting around it, it's kind of puffed out a little bit, it's a bigger thing because all those electrons don't like being that close to each other. So you know, it puffs out a little bit.

Ryan: Yeah, sure. Like magnets.

Ben: Exactly.

Ken: Exactly like magnets.

Ben: So, there's a mystery here which is protons, right? You got two protons in a helium nucleus, or 3 in whatever gets 3 – what is it, Lithium?

Ken: I guess Lithium comes next.

Ryan: I guess.

Ben: [laughs]

Tia: Good job, guys.

Ben: You have multiple positive/

Ryan: [laughs]

Ken: I'm not a chemist.

Ben: I know, right? The nucleus of an atom is really tiny.

Ryan: Yeah.

Ben: And so somehow, even though the distance between each of these positive charges is infinitesimal, there's a force that can overwhelm that really strong electrostatic repulsion. And so, yeah.

Ryan: That's the strong force.

Ben: That's what they call the strong force. 'Cause it needs to be crazy strong.

Ryan: Alright, well, good podcast. We've figured it out.

Ken: Yep, done, talk to you later.

Ryan, Tia: [laugh]

Ryan: So the strong force is so strong it can overwhelm all these tiny magnets, if you will, inside the nucleus that wanna be further away from each other.

Ken: That's actually a good way to think of it, right? You've got these little things that are trying furiously to get away from each other and the strong force is keeping them in really close proximity, sure.

Tia: Like glue.

Ken: [laughs] Like glue. But the fact that they're kept together is not even the main aspect of the strong force. It's only a by-product of what the strong force is actually doing, which is kind of the other, really neat part. Because the strong force is really acting on the quarks, which are the make-up of the proton and neutron.

Ryan: When you say "make-up", you mean intrinsic elements and not surface decoration?

Ken: Yes, good correction. The proton and neutron aren't fundamental particles, like for example the electron. The proton and neutron are made up of smaller particles, which we think are fundamental. I'm not willing to go out on a limb and say that they are fundamental but as of right now it looks like they're fundamental. And those are called quarks.

Ryan: When did we discover the idea of quarks?

Ken: The late 60s?

Tia: 70s.

Ben: Yeah, 60s/70s.

Ryan: Okay. That must have been crazy. 'Cause everyone, I'm sure, at that point pretty much thought that protons and neutrons were pretty fundamental, right? Like, what's smaller than a proton? I don't know.

10:00

Ken: Yeah, exactly. I mean, people are thinking, you know, "okay, we've figured out essentially the atom, we've got electrons, we've got protons and neutrons. We're done." You know, science is over, pack up the bags and go home.

Ryan: Yeah.

Ken: And then yeah, somebody had said "wait a second, how come we can have basically protons changing into neutrons?" If those are fundamental, how exactly does that work? And so that led to people thinking "okay, well, turn the lights back on, we have to figure this out".

Ben: [laughs]

Ken: And in doing that they thought "well, maybe they're made up of smaller particles". And I think the crazy part is, I mean it was proposed in, like, the mid-60s and discovered in the late 60s. It wasn't very long between when the theory started and when they actually showed that it existed.

Ryan: That must have been so satisfying.

Ken: I know, 'cause there's lots of things, right? You propose them and it's like a lifetime later that they actually get found. But no, this is like 5 years or something.

Ben: 'Cause like the Higgs boson took, like, decades between it was/

Ken: Yeah, that's what I was thinking of.

Ryan: That took forever.

Ben: Ken was saying something really fascinating which is that the strong force, what it primarily does, is it sticks the various quarks inside of a proton or a neutron together. And then the reason the protons stick together inside of a nucleus is just 'cause the sticky force, the strong gluon interaction inside the protons is a little bit leaky. And so if there are two protons next to each other, the strong force interactions inside of one proton might kind of stick to the strong force interactions in another proton and kind of hold them together.

Ryan: So when you say "leaky", is that/

Tia: It's a technical term.

Ryan, Tia: [laugh]

Ryan: Like what you're saying is the strong force exceeds the volume of the thing it's acting upon.

Tia: Yeah. That's what he means.

Ken: The radius of the strong force is larger than it needs to be to just stick the quarks to make a proton or a neutron.

Ryan: Which is great, 'cause if it didn't we'd just have a bunch of protons sticking around without any nucleuses.

Ben: Yeah/

Ken: Yeah, although I guess we wouldn't be here to be upset about it, so

Ryan: Yeah. I would not say "upset", I'm just curious.

Ken, Tia: [laugh]

11:59

Ben: Maybe we should talk about this in more detail. How we know that there are quarks. Essentially, the short answer is, eventually somebody came along with a really strong particle accelerator and detected them. But it's a little bit stranger than that because nobody has ever seen a naked quark. For instance, we detect things. Usually in particle physics a particle gets created and then we see it. We're like "Alright, that exits, we saw it". With quarks, we've never seen a loose quark outside of its proton/ protony shell. They don't wander around alone. And part of the reason they don't wander around alone is because the strong force is just so sticky but we have other means of seeing that definitely quarks are the best explanation, aside from having shot electrons into a nucleus. It all goes back to kind of the 60s, when we were building stronger and stronger particle accelerators. So, the deal is, you've heard of $E=mc^2$, you're familiar with that?

Ryan: Yeah, it's hot garbage.

Ben: Yeah, good hot garbage.

Ryan: [laughs]

13:04

Ben: It's important in a variety of ways but one of the really interesting things that comes out of it is particle creation. The idea that you can have essentially no particles, let's say that there's no electrons around. If you shoot two really, really high energy photons together and they smash into each other, the energy density in a little region might be high enough to create an electron and an antielectron pair.

Ryan: Do they go separate ways? Don't they annihilate each other?

Ben: Yeah, well they might reannihilate. And if they do, they'll probably emit the energy into some other form.

Ryan: Listen, I'm a simple cartoonist, simple country cartoonist. But it sounds like you're saying, you get high enough photons, which are light/

Ben: Yes.

Ryan: That hit each other, you get electrons which, when they move, can cause electricity.

Ben: Yes. That's what I'm saying.

Ryan: You can generate electricity from light?

Ben: Uh... yes. You can.

Ryan: When I say "you", I mean you specifically?

Ken: [laughs]

Ben: You can create electrons and their antiparticle.

Ryan: Have we done this?

Ben: Yeah.

Tia: Yeah.

14:04

Ben: We do do it sometimes, though. I mean, cosmic rays, which are really, really heavy protons and stuff up in space and they hit our atmosphere and they hit our atmosphere moving fast enough that it will generate a shower of electrons and antielectrons.

Ryan: Really?

Ken: Yeah, you generate a shower of particles.

Ben: If the energy density in a little region is high enough, you can generate spontaneously a particle and an antiparticle pair, is an interesting thing. And it underlies/

Ryan: It's crazy

Ben: /a lot of what we're gonna be talking about today. So, an electron antielectron is an interesting thing to start with for one thing because it obeys a conservation law. It actually obeys two conservation laws but one of them is electric charge, right? So one of the various laws we know of is the total electric charge of a system is conserved.

Ryan: Mhm.

Ben: If you rub a balloon on your head and the balloon ends up with a slight positive charge, your head will end up with a slight negative charge/

Ryan: Sure

Ben: /equal and opposite in quantity.

Ryan: Right.

Tia: How do you know it's not that way and not other way around?

Ben: I don't. But I like to think positive. No, wait. Think negative. Which one did I say ended up on my head?

15:14

Tia: I don't/

Ryan: It was negative, I think.

Ben: Uhh...

Ken: We'll fix it in post.

Ben: Yeah, let's/

Tia, Ben, Ken: [laugh]

Ben: So yeah, moral of the story is you end up/ There are these conservation laws that dictate what can be created and why. So when the two photons come in, prior to that, two photons - photons don't have an electric charge - if the energy is high enough, if it's gonna make electrons, then it has to also make an antielectron, which has the equal and opposite amount of positive charge.

Ryan: Right.

Ben: So, this dictates a lot of fun things and essentially, early particle physics was a lot of smashing stuff together and seeing what came out.

Tia: Hey, we still do that.

Ken: I was gonna say, that's current particle physics.

Ryan: [laughs]

Tia: What are you trying to say?

Ben: I'm trying to say that it's a wonderful field full of honorable people.

Ken: [laughs]

Tia: Okay. I like that.

16:02

Ben: So, one of the goals with particle detectors is to smash things together so hard that you increase the energy density wherever that collision happens.

Tia: Wait, I don't think you said that right.

Ryan: Particle accelerators (...)

Ken: There we go.

Ben: I'm sorry. I'm sorry everybody.

Ryan: I'm a simple country cartoonist but even I can see distinction between a particle accelerator and a particle detector.

Ben: Particle accelerators accelerate particles, they smash together and the hope is the energy density where they smash together is so high, that it will spontaneously generate other particles.

Ryan: Let's set up just fundamentals of what we're talking about I wanna get it solid.

Ben: Mhm.

Ryan: Is this threshold where particles get generated at like a point where if you're just below they don't happen, if you're just above they do or are we not sure quite what that threshold is?

Ben: Yeah, if you're above it, it can happen. And sometimes does.

Ryan: What?! It doesn't happen all the time?

Ben: Well, no, right? I mean that's why they had to smash so many hadrons together before they could see the Higgs boson.

Ryan: But that's crazy. Why is the Universe not deterministic?

Ben: Well, it's probabilistic because of quantum mechanics.

Ryan: This has destroyed my worldview.

Ben: Right?

Tia: [laughs]

Ben: So there's some probability, if the situation is right, that something will happen.

Ryan: So you're saying we live in a Universe of maybes.

Ben: Yes.

Ryan: Where things could happen.

Ben: Exactly.

Tia: [laughs]

Ryan: And if we do everything right, we still might not get particle showing up, even if we do everything right?

Ben: Yeah.

Ryan: That's horrible.

Ben: Even if you do everything right, you can still fail.

Ryan: That's horrible!

Ken: That's fantastic! It allows you to fail and feel good about yourself. You're like "Oh, even if I'd done everything right, it might still have failed, so it's okay".

17:37

Tia: Well, I think/

Ryan: Not my fault, the Universe sucks.

Ken: That's right, exactly!

Tia: As you go higher and higher in energy at these accelerators, you know, you start to pass by all of these thresholds. So you know, you can make electrons then you can make up and anti-up quarks and you keep on getting to heavier and heavier particles. And soon, I mean, the Higgs boson was so heavy and it was so hard to find not just because it was produced rarely but because we had to have such high energy there was a high probability of producing all of these particles that were below that energy, too.

Ryan: Okay, yeah so, we/ You know, electrons I guess are the easy ones and no one is excited about producing electrons or antielectrons. But when you're at the level where you're trying to produce Higgs boson then electrons are just like "uh, whatever", no great shakes.

Ben: It's kind of like if there was a random change machine where you put in a bill and then it gave you a random amount of change equal to the amount you put in. So like, we're looking for a very special 500 dollar coin and so we have to put in at least 500 dollars worth of bills and then most of the time it just gives us pennies. But once in a blue moon you'll, instead of getting a whole bunch of pennies, you'll get just one big coin.

Ryan: This is crazy. I'm willing to accept it but I feel like/ I mean you guys are used to this idea. I thought we lived in a world, in you know, a Newtonian world. Of cause and effect. And things made sense all the time. And not this random chance that maybe you'll get a particle, maybe not.

19:09

Ben: They ask God if he played dice. And he said 1. I gave no gender and 2. Yes, definitely, all the time, I love playing dice, do you wanna make a bet on something?

Ken: [laughs]

Ryan: You wanna bet? So, Tia mentioned up quarks and this reminds me that I think quarks have spins, right? I remember hearing that in my travels.

Tia: Quarks have spins.

Ben: So, quarks do have spins. But up doesn't refer to the direction of spin, it refers to a type of charge.

Tia: A strong charge.

Ben: Yeah, hold on, hold on. Let me take a step back. [makes a stomping sound] Okay.

Tia: Did you just take a physical step back?

Ryan: I think you really took a physical step back.

Ken: I started wandering the same thing, yeah

Ben: I twitched in my chair

Ben: So, in the 60s, when they were building these particle accelerators, the higher energy the collisions they can create, the more different types of elementary particles might be generated. So, they started seeing a zoo/ They classified the subatomic particles in three different ways. They called them hadrons, mesons and lepton.

Ryan: Okay.

Ben: So, hadron is something that's really heavy, like a proton or a neutron.

Ryan: Okay.

Ben: A lepton is something that's really light, like an electron or an electron's heavier cousin, called a muon. Neutrinos are leptons, too. So, anything in between is called a meson, which means "middle-on".

Ken, Tia: [laugh]

Ryan: Go on, professor.

Ben: So they started trying to classify the different types of particles that they would generate in these crazy collisions and what they found was there's a certain breed of particle that didn't quite decay in the normal way. So usually these particles are really unstable, which means that if you can create it, it's fine. It's usually pretty and heavy and weird and then it pops, it turns into other, lighter, more common forms of things, like electrons.

21:00

Ryan: Right.

Ben: So, what they saw was things weren't decaying in the way they expected. And when they wanted to start interpreting why these breeds of particles weren't decaying in a way they expected, they had to introduce another type of charge. You know, how I said there's like a charge conservation here? Where every time you wanna make an electron, you always have to make an antielectron so that the total charge doesn't change?

Ryan: Yeah.

Ben: So, they were saying "okay, so there's a charge like that". It's not an electric charge but it's some quantity that our basic elementary subatomic particle has and anytime the subatomic particle changes into something else, it needs to/ this other type of charge, it needs to be conserved. So they called that charge strange, because it was strange.

Tia: Well, the thing that was strange was the long lifetime those particles had.

Ben: Yeah. They had really long lifetimes, 'cause they weren't all that many things they could change into because it had an attribute, a number, the strangeness quantity to it that limited the number of things it could change into and so it stuck around for much longer than it should have. And so they're like "wow, this is strange, let's call this charge strange". They had to use different word, they used the word flavor, electric charge where there's some positives and negatives and the total amount of strangeness in your system of atoms that are decaying or creating has to be constant.

Ryan: Okay.

22:23

Ben: So the moral of the story is, this introduced this idea that there was some attribute of these particles that wasn't in the more common electron, proton, neutron particles.

Ryan: Right, 'cause those don't have flavors that we know about.

Ben: Yeah. Well, they all have some kind of common flavor to them, so you're like/

Ryan: Right.

Ben: They didn't have the strangeness.

Ryan: So they're all, if you will, vanilla particles.

Ben: [laughs] Right.

Ken: Very well done.

Ben: So, you essentially see a lot of different particles and so they started classifying them in terms of how much electric charge they have and how much mass they had and what they saw was kind of a pattern that looks kind of like the periodic table of the elements. And so one of the things that periodic table of the elements tells you is that there's kind of an underlying structure that are common to all these chemically different elements. And you can say "well, the difference between a hydrogen and helium is that helium has one more electron, one more proton", right? Its mass is twice as big and you can start talking about different atoms in the periodic table in terms of being composed of protons and electrons and that kind of explains the different general properties while it's laid out that way.

Ryan: Right.

Ben: So they were doing this with the subatomic particles and you end up with a similar pattern that kind of indicates that there's some underlying structure. That the mesons and the hadrons are all composed of smaller little bits of LEGO, that these mesons aren't fundamental particles the way an electron is.

Ryan: Is there a periodic table of subatomic particles?

23:56

Tia: Yes.

Ben: It's called like "The Eightfold Way", right?

Tia: Yeah, we still use it. Oh no/ So the Eightfold Way was just if you permute the charges up, down and strange, so you can have up up up, down down down, up up down, you know, and you/

Ryan: Up up strange.

Tia: Yeah, and you write down all of those. You can organize them into this sort of triangle and then that's for the baryons and that was the chart that was sort of like the periodic table of/

Ryan: And all those, do all those exist? Like, if I want up down strange as a particle/

Tia: Yeah, yeah, so actually one of the ways that we knew this was definitely true was from mapping out all of the permutations they predicted that they should see a strange strange strange, which was the Ω^- [Omega minus].

Ryan: Oh, Ω^-

Tia: Yeah. So/

Ryan: That's the best name for anything ever.

Tia: So when we actually found that, you know it's pretty controversial before. Like, Eightfold Way, substructure, what are you talking about? But then, you know, I mean, okay. You predicted this particle, I believe you now.

Ryan: Yep. And that made the prediction that came true so we believe that this theory isn't hot garbage.

Ben: Yeah. Right. Not like gravity.

Ken: Not like gravity or relativity.

Ben: Yeah, right.

25:21

Ben: So, the moral of the story is, that the study of the zoo of elementary particles told us two things. One of them is it looked like you could explain all of the different types of subatomic particles you would generate in these colliders, you could explain them in terms of an underlying structure, some combination of different LEGO pieces where one LEGO piece is called up, one of them is called down and of them is called strange. And it was like, okay, so it looks like that different permutations or combinations of these little bits give you all of the different subatomic particles we're detecting. And it was interesting and so what you could do is you associate the up quark, the down quark and the strange quark all have very specific charges and spins, right?

Tia: Yeah, up, charm and top have +2/3 electrical charge and other guys: down, strange and bottom have - 1/3 electrical charge. And they're all spin 1/2.

Ben: Right. So a proton is, what is it? Two ups and a down?

Ken: Up up down, yeah.

Ben: 'Cause then when you add up all those it's 2/3 + 2/3 - 1/3, total charge 1. And a neutron is/

Ryan: Ooh.

Ben: One up, two down. So it's +2/3

Ryan: 2/3 minus

Ben: Minus 1/3 minus 1/3, equals 0. And it also explained all of the different charges of mesons, which might have different electric charges because one meson might be two ups together, one another meson might be an up and a down, right?

Ryan: Sure, yeah, yeah

26:58

Tia: So mesons, let's clarify a little bit. They're made up of a quark and an antiquark pair. So it's actually a bonding between the quark and the antiquark.

Ryan: Quark and antiquarks don't mutually annihilate?

Tia: So, that's another interesting question. Not all the time.

Ryan: But some of the time?

Tia: Well, for a really long time that was one of the defining mysteries in particle physics. Was "okay, so I have this particle called a pion, a π^0 [zero pi], and it's made up of an up quark and an anti-up quark. And so why doesn't it annihilate itself?" And it will annihilate itself after some time but that's due to, like, quantum fluctuations after a long time

Ryan: Right.

Tia: But it's mostly stable. The answer is the same reason why electrons don't just fall into the nucleus. You have some internal interactions going on between these two quarks.

Ben: So they're metaphorically in orbit around each other but not colliding.

Tia: Yeah.

Ken: Right but π^0s [pi naughts] do decay - into two photons, don't they?

Tia: Yeah.

Ken: I mean they do eventually annihilate but what Tia's saying, I guess, there's a reason why it doesn't happen immediately.

Tia: Yeah. Why they're allowed to be formed?

Ken: Why do we allow these things to exist at all?

Tia: Yeah.

28:23

Ben: So, moral of the story is: there are different quarks. So far we've got 3 different quarks and their antiquarks, right? And all of the particles that we're familiar with, like protons and neutrons but also all these weird particles that were generated in the early 60s' particle accelerators can be explained in terms of some combination of the quarks: up, down and strange.

Ryan: Yeah.

Ben: So, two things to go on from there. Eventually they built a particle accelerator, I think in the 70s, it was accelerating electrons but they were going fast enough that they could penetrate the inside of a proton or a neutron. And so inside, what they saw was that there was clusters of electric charge:

1/3 and 2/3, just like we'd expect in this quark model. So we have experimentally detected evidence that the inside of a proton does have a three little bits of charge, the inside of a neutron does have three little bits of charge.

Ryan: So we're feeling pretty good.

Ben: So we're feeling pretty good about this quark model. Than the story is, the strange thing, how come we don't see strange subatomic particles in regular life? Like, how come there aren't any strange atoms chemically? And part of the reason for that is that we talked about how there's kind of an energy threshold beyond which a certain type of particle and antiparticle would start randomly getting generated? So, the deal is that the strange quark is heavier than the up and down quark. And so you couldn't start seeing it until your accelerators got energetic enough to exceed that energy threshold and would start randomly generating them

Ryan: Sure.

29:49

Ben: So since then, as the accelerators got more and more powerful, they could exceed these higher and higher energy limits and so they started seeing different types of quarks. And so there's up, down - they're a pair, right? One of them has +2/3 charge, the other has -1/3 charge.

Ryan: Yeah.

Ben: So the strange has +2/3, it has a companion that has -1/3, there's a charm flavor to go along with the strange flavor. So then the last two are even more energetic and required even more energetic particle accelerators to generate. Their labels are t and b. And it's funny because it depends on whether, I've heard as to what those initials mean, they're called "top" and "bottom", so top is the +2/3 charge and bottom is the -1/3, right? We discovered the bottom one and then the top one finally got discovered in the 90s. But in Europe they're called truth and beauty.

30:51

Ryan: Oh, it's so good!

Ben: I know, right?

Ken: Way better!

Ryan: So is this sealed? Can we expect to find more pairs of properties? Or do we have a reason to think that this is it?

Tia: Well, we have no reason to think that this is it. I mean/

Ken: We, okay, hold on, I was trying to think of this before. Isn't this something about electroweak unification that requires the same number of quark families as lepton families? I'm pretty sure there's something that at least suggests we have to have the same number of families in both.

Tia: If you're referring to a theory, I don't trust it. I only trust experiments. So the reason why there could be something that we haven't seen yet, is just that we're limited by what our particle accelerators can do. If we can have another couple billion dollars, we can build a more energetic particle accelerator and maybe we'll find some more families. Actually at the LHC, I mean, they do searches for more heavy quarks, called t' or b'. They haven't found/

Ryan: 'Cause if they could maybe show up, there's always a chance, right?

Tia: Yeah.

Ryan: If these were discovered, we wouldn't still call them t' and b', we'd call them new names, right?

Tia: Yeah, what should we name them?

Ryan: Can we name them now and then when they're discovered, we'd be like "called it, they're like dog and cat".

Ben: No, the d letter, the d initial's already taken, right? 'Cause you need two letters.

Ryan: Okay. Hot or not, H and N.

Ben: [laughs]

Ryan: That'd be contribution to particle physics.

Ben: I think keeping with the charm and strange pair, yeah.

Ryan: We got strange and charm, truth and beauty and hot or not.

Ben: Yeah.

32:27

Ben: So, Ken was saying that we're pretty sure that there's only three families of leptons so electron, muon and tau particles. And they're all fundamental particles in the theory, so there's three of them. And then they have those similarly flavored neutrinos, so there are electron neutrinos and muon neutrinos and tau neutrinos and so Ken's argument is essentially: somebody argued that because at really, really, really high energies the strong force and the electroweak force are all supposed be two aspects of the same force, there needs to be the same number of types, of families, of flavors of quarks as there are electrons.

Ryan: Sure. And that sort of a "let's hope the Universe makes sense to us" sort of argument.

Ben: Yeah, that's right. And it might. I mean, when people make these guesses, sometimes they're super right and then they win Nobel Prizes, so... So essentially, we got this nice theoretically proposed and then experimentally verified substructure defining all these different types of subatomic particles in terms of these quarks that are sticking together. But how and why they stick together is totally bananas. Let's start talking about that.

33:40

Tia: They stick together by something called gluons.

Ben: Gluons!

Tia: And so these are the mediators for the strong force. So you know, you were saying, like, you can smash two photons together and produce electron and positron? So, the same thing with the gluons, you can smash two of them together and produce for example an up quark and an anti-up quark. So they help facilitate quarks interacting with each other. Another cool thing about them is that they don't care anything at all about leptons. They only interact with quarks, so we have six quarks and we have our gluons.

Ben: Alright, let me try backing this up. So in theoretical quantum field theory, when two objects interact, they interact by essentially playing catch with an invisible particle, okay? So when two electrically charged particles - a proton and an electron interact with each other, they do so by throwing a photon back and forth. And then that quantizes the interaction.

Ryan: Wait. Is that, this is literal? This is literally what happens? It's not a metaphor?

34:56

Ben: Well, it's kind of a metaphor. It comes from a numerical approximation to the actual theory, which is quite complicated. This is like Richard Feynman. So Richard Feynman is like "Hey, instead of trying to solve these crazy equations, let's just talk about it in terms of approximations of more and more complicated interactions where the interactions/

Ryan: Right.

Ben: /are all mediated. And so this is what a Feynman diagram draws. It essentially says, alright, you've got this electron, it's over here, it tugs on a proton over here. How does it tug? It shoots a little photon between them and so you draw a little line, you say that's the photon and then they do their thing.

Ryan: Okay. That's cool

Ben: So in this case we have these two quarks and they stick together by throwing back and forth - they're exchanging one of these gluon particles. The crazy bit here is that in electromagnetism there's two different types of charge, right?

Ryan: I'm with ya.

Ben: In these strong force interactions there's three different types of charge. This is the reason you have three different quarks inside of a proton or inside of a neutron. Because those three, one has each type of charge and they're sticking together to become an overall charge neutral object. So they were like "okay, so what are we gonna name all these charges?" And somebody – 1970s, right? – somebody is like "alright man, color theory. This is the best thing. We're gonna name one of them each of the different colors, that all add up to white". So/

Ryan: Ohhh

Ben: /one of the charges is called red, the other a blue charge, the other a green charge. And they stick together to make an object that has an overall white charge. The desire here is if you have a group of objects where the total amount of charge adds together to make white, then that won't really exert too much strong force on any other thing. So if you have a/

Ryan: Right.

Ben: /one atom of hydrogen and another atom of hydrogen, their protons won't pull each other together because each of those protons is white.

Ryan: Right.

Ben: In terms of this charge.

36:50

Ben: So it's absolutely bananas. You get all sorts of really crazy things. Like, we were talking earlier about mesons where there are two quarks. So, one of them is red, say, so for the particle to be white, the other one has to be anti-red.

Ryan: What is anti-red?

Ben: Yeah, what's/ it's cyan, right? So it's a color opposite red on the color wheel.

Ryan: Oh.

Ben: And so red plus cyan is equal to white.

Ryan: What? This is garbage. Colors don't work that way. This is a stupid metaphor.

Ken: It's a terrible metaphor.

Ryan: I may be a simple country cartoonist but this is a bad metaphor 'cause it gains you nothing and it only makes things more confusing because red and cyan do not give you white in any color system except for this particle physics' color system.

Tia: You know, it's not true. In light, if you mix, if you were a stage hand and you controlled the lighting system, when you only had a red light and a cyan light, you can make a white spotlight by mixing them. So, that's legitimate.

Ryan: Am I wrong? Is this what it feels like to be wrong?

Ken: Really? [laughs]

Tia: Yeah, so it's the difference between, like, additive color theory and subtractive color theory. I forgot which one is which one but one is for lights and one is for, like, painting and coloring.

38:12

Ryan: Yeah. Painting is all the colors give you black and in light all the colors give you white.

Tia: Even though it's an analogy, it's kinda cool only because it makes the math a lot simpler.

Ken: I didn't mean to interrupt, I just looked it up and I see what they're saying. They're saying that cyan is the combination of blue and green. So when you have red and cyan, you're essentially having red + blue + green. So it does equal white.

Ryan: Ooooh....kay. I guess I should take back stuff what I said about particle physics being stupid.

Ben, Tia, Ken: [laugh]

Ken: For this reason. I mean, you don't have to take it back entirely. Just the justification's gonna have to be different.

Ryan: Yeah. Well, so the metaphor holds and that is at least not a actively fighting against you metaphor.

Ken: So yes, yeah. Tia, you are correct.

Tia: Yeah, I know I'm right.

Ken, Ryan: [laugh]

Ben: So the strong force is really crazy. Because most forces get weaker the further away you get, right?

Ryan: Yep.

39:07

Ben: The strong force gets stronger the further two things are apart.

Ryan: What, indefinitely?

Ben: Well, here's the thing. We've never seen a naked quark. And the reason is because of the strong force. So, thought experiment. Let's imagine it in terms of a spring, right? So, a spring - the more you stretch it, the more it pulls together, right? So you imagine these two particles, one of them is anti-red - cyan - and the other is red and they've got a gluon sticking them together. And then you take out your tweezers and you're like "hey, let's see what this thing is made of" and you pull them apart and you start stretching them apart. The more you stretch it, the more energy the spring has, the more potential energy we need to put into the system.

Ryan: Yep.

Ben: And the deal is - the strong force is really strong. So the further we pull them apart, the more energy it has until the energy threshold for creating a pair of quarks is exceeded and then once that happens, spontaneously you get a quark-antiquark pair popping into it. And essentially you'll end up with two systems of two particles instead of one system of two particles.

Ryan: Hm.

40:08

Ben: So, anytime you try to see a naked quark, anytime you'd try to drag one away, it requires so much energy that it will spontaneously generate a new pair of quarks to fill in the gap and you'll end up with two sets of white charged objects.

Ryan: So, it sounds like it's impossible to see a naked quark. Given our current understanding.

Tia: Yeah, no. I don't think we will see them ever. I mean, oh no, this podcast is going to the archives and you know, some physicists, like, a thousand years in the future will be like "ha ha ha, she didn't know but we made this amazing detector that can see naked quarks".

Ryan: Well that's why I said given our current understanding.

Tia: Yeah.

Ryan: To prepare ourselves for those 1000 years in the future physicists who just wanna, like, prove that podcast wrong.

Ben: Yeah.

Tia: Yeah. There might be one of those out there but I wouldn't bet money on that anytime soon.

Ryan: Okay.

Tia: You'd be better off playing the lottery.

Ben: Well that was great. Thank you Tia, thank you Ken. You've pleased me, your efforts have borne fruit and that fruit is sweet. Here's some fruit. Tia, you get apple slices from my school's cafeteria.

Tia: Yummmmm.

Ben: They're red. That's right. And Ken, we had these ones left over, these are apple slices from my school's cafeteria that are anti-red.

Ken: Does that mean they're anti-yum?

Ryan: Well, yeah.

Ken: Mmm.

Ben: Okay, I'd like to thank my guest, Ryan North! Thank you Ryan!

Ryan: Thank you for having me. This is great.

Ben: Listeners, you guys can find his web comic at http://qwantz.com/index.php, you can buy Squirrel Girl comics from your local comic book store. Or that new Romeo and/or Juliet coming out next year. Fantastic!

41:49

Ben: Hi everyone. This episode was pretty fun, huh? Okay, time for the announcement. Lots of good news. Now first, I was thinking around this time of the year people go around poking for new podcasts to listen to while they sit in the airport or on a bus or on that long car trips to visit their great-aunts and it's time to remind the world that we exist. So I've got a plan - the paper that Dave and I wrote about how to make a TARDIS? It's been published in a book "More Doctor Who and Philosophy". It's sequel to a book called "Doctor Who and philosophy". It's not "More Doctor Who and More Philosophy". Anyway, moral of the story is - the publisher sent me a couple free copies. From December 1st to December 15th there are two ways to win a book. Now, if you find us on Facebook and interact with our Facebook page in any way, your name will be entered in a draw for the book. Reblog our stuff, tell your uncle about us, like our episodes - whatever. I'll pick one of you at random and send you a signed copy of the book. Now, second way is: give us an iTunes review then send me an e-mail at tiphyter@titaniumphysics.com to notify me when you've written your review. And I'll enter your name in a draw and the winner gets a signed copy of the book. Now, even if you wrote your review two years ago and you can't update your review – I mean, you can, but it doesn't count as a new review; who knows how iTunes works? – just drop me a note and I'll let you in on the draw. But you know, anyway. Moral of the story is, lots of you haven't written iTunes reviews and that's fine but if you do, we shoot up the charts and more people discover us, just in time for the long car trip to their great aunts. Now, in other news, transcriptions are firing on all cylinders. We've got about a dozen done and many more out there being written as we speak. Email me if you're interested in trying your hand in transcribing an episode and we'll talk about the details. On that note, we're still humbly soliciting your donations. Your donations go to paying for server fees and our ambitious project to get all the episodes transcribed. This particular episode of the Titanium Physicists has been sponsored by a collection of generous people. I'd like to thank the generosity of Melissa Burk, Yaseen Owarzazee, Spider Rougue, Insanity Orbits, Robin Johnson, madam Sandra Johnson, Mr. Jacob Wick, Mr. John Keese, a Mr. Victor C., Ryan Close, Peter Clipsham, Mr. Robert Halpen, Elizabetha Theresa, and Paul Carr. A Mr. Ryan Noule, Mr. Adam K, Thomas Sharay and Mr. Jacob S. A gentleman named Brett Evans, a lady named Jill, thanks Steve, Mr. James Clawson, Mr. Devin North, a gentleman named Scott, Ed Lowlington, Kelly Wienersmith, Jocelyn Read, a Mr. S. Hatcher, Mr. Rob Aberzado and Mr. Robert Stietka. So, if you want to donate, you can donate through one-time donations on our website or through Patreon. So, that's it for TiPhy this time. Remember that if you like to listen to scientists talk about science in their own words, there are lots of other lovely shows on the Brachiolope Media Network. The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Good day, my friends, and until next time, remember to keep science in your hearts.

45:04

[Outro song; *Angela* by John Vanderslice]

45:59

Ryan: Do we know what gravity is, besides "a force"?

Ken: In terms of like do we know what/ how it's mediated?

Ben: It's a curvature of spacetime!

Ryan: But, like, gravitons don't exist.

Ben: Gravitons are a linear approximation for the force of gravity. And so they exist when people try to quantize gravity but nobody knows how to quantize gravity. So/

Ken: Yeah, this is really Ben's area. [laughs]

Ben: So, we think that somebody eventually has to figure out how to quantize gravity. But nobody knows how to apply quantum mechanics to gravity because the theory of General Relativity, the theory of curved spacetime, is like/ it doesn't work. It's like when you plug

Ryan: It doesn't work. That's a full quote. "General relativity. It just/ it doesn't work".

Ken, Tia: [laugh]

Ken: I like that.

Ben: It's like when you plug in 1998 webcam into your computer. It just like does not understand what I'm talking to and you're like "ugh, I shouldn't have saved $15 like that". Uh, yeah. It doesn't work/ they/ the theories are too different. And you get weird infinities popping up everywhere.

Ryan: Okay, so gravity, sorry.

Ben: If you did manage to quantize gravity, you would describe the interaction in terms of gravitons. So they show up, people talk about them as if they're going to come/ show up on store shelves next year but who knows?

Tia: You never know.

Ryan: So when Star Trek talks about graviton emitters, that's actually really good science fiction? 'Cause it predicts something we're expecting to invent? Not discover, invent.

Ben: Yeah. It's a word from science and they added a fictional element to it.

Ryan: So it's science fiction. I like it. Star Trek is right and Einstein's relativity doesn't work.

Ben: That's right.

Ryan: Alright.

Ben: That's what they're saying.

Ryan: That makes me feel good about my life choices. 'Cause I know way more about Star Trek than I know General Relativity.

Tia: Oh, a graviton emitter. So that would be like anything/

Ryan: Tractor beam.

Tia: /that gives off gravity waves, so like a binary system?

Ben: No, but I think they mean anything that produces gravity, because

Ryan: Well, they use it as a tractor beam.

Ben: Yeah.

Ryan: Then they put it in reverse. They reverse gravity to push things away.

Ken: Oooh, that's a (...)

Ryan: An anti-gravitron. Graviton. Gravitron is a thing you ride at the fair.

Ben: It's a pretty fun thing, yeah.

Ken: I just had this debate with my class of second years and none of them knew what it was. I was really upset.

Ryan: Gravitron (...)

Ken: Yeah, I actually had to put up a picture on the, you know, on the screen in class and say "this is what it is". Nobody got it.

Ryan: If I was in your class, I would've been a star student.

Ken: Yes, yes you would. No doubt about that.

48:47

Ryan: So, I wanna ask the three of you. Do you think the fact that the research into quarks and discovery of quarks and their naming and stuff happened in the late 60s and 70s, is partially responsible for them having such ridiculous names?

Ken: I would say 100%

Tia: No, I think the fact that it's physicists trying to name things give them ridiculous names.

Ryan: I mean, physicists named other particles, like electron was probably named by a physicist and that sounds pretty normal. It's an -on that is electro.

Ben: Yeah.

Tia, Ryan: [laugh]

Ken: As soon as I hear, like, charm and strange, I think like, bunch of dudes with big moustaches and paisley shirts sittin' around?

Ryan: Yeah.

Ken: Oh, yeah. (...) charm and strange.

Ryan: Yeah. It's probably the most dated physics term I've ever heard.

Ken: Well, quark in itself is already kind of a strange one, too, right?

Ryan: Yeah, that sets the tone for what follows after that. If they called it a boring particle, just called it a boring particle, then there wouldn't have been all these other cool names attached to it. We'd have like grey and off-grey.

Ken: And taupe. And beige.

Ryan: Yeah, beige and anti-beige.

Ken, Tia: [laugh]

Tia: I'm glad you guys weren't particle physicists back then.

Ken, Ryan: [laugh]

Ben: I think Tia's right. It's probably that we're just horrible nerds.

50:16

Ben: I guess if you had one in the Universe, where there was only a single quark, then it would have nothing to pull on and it wouldn't have, it could be naked alone. But as soon as/

Ryan: But that's not our Universe.

Tia: How do you create a Universe with a single quark in it?

Ben: Just use relativity. You start speculating, no, you're right.

Ken: That's what Ben does all day, is create universes.

Ben: That's right.

Tia: [laughs]

Ryan: Universes of the imagination.

Ben: I should start wearing a turtleneck.

Ryan: We're not so different, you and I.

Ben, Ken: [laugh]