MomentumConservation

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Jorge: [00:00:00] Hey, Daniel, do you think podcasts obey the laws of physics? Oh,

Daniel: why? Sure. Hope so. I don't want to get some sort of fine. Well, what makes you worried

Jorge: about it? Well, I first, when people use podcasts

Daniel: to fall asleep, well, I don't know. That sounds pretty harmless. How's that? Violating the laws of.

Jorge: Well, isn't there something about how bodies and motion

Daniel: stay in motion.

Mm. I see where you're going with this. That could be a problem. If the podcast puts bodies at rest, that used to be in motion. Yeah.

Jorge: Yeah. That might be a problem. Like if they're driving or something, maybe they should get in bed and get comfortable before they, you know, put on a podcast. Then they can just, uh, continue

Daniel: being at rest then they might be asleep before we get to the main topic of the

Jorge: podcast.

Maybe we just put a bunch of people to sleep, wake up,

Daniel: wake up. What,

Jorge: what I put you to sleep?

Daniel: you're the physicist. I take naps wherever I can [00:01:00] find them.

Jorge: Hi, I'm Jorge, a cartoon and the creator of PhD

Daniel: comics. Hi, I'm Daniel. I'm a particle physicist and a professor at UC Irvine. And I try to stay in motion.

Jorge: is that hard as a physicist? Don't you sit on your couch or your desk all the time and just think up, uh, solutions to the questions about the.

Daniel: Yeah, but I find that as I get older, a body at rest tends to stay at rest.

So it gets harder and harder to get out of that

Jorge: couch. Mm. I think a body at rest also tends to get bigger. Unfortunately,

Daniel: with our age. That's true. And we're gravitationally attract more physicists onto the

Jorge: couch. that's right. We expand space time around our waste. It's a weird law of the universe, the no diet theorem.

Daniel: the [00:02:00] law of general snack.

Jorge: But anyways, welcome to our podcast, Daniel and Jorge, explain the universe, a production of

Daniel: iHeart radio in which we put your mind into motion to understand the fundamental nature of the universe around us, or at least to ask the deep questions about how it works and try to observe the patterns, the trends, the symmetries, the conservation laws, the fundamental rules that seem to be organizing our universe on this podcast.

We. All of those big questions and we don't shy away from trying to find

Jorge: answers. Yeah. Because the universe is full of things to ask questions about lots of questions that we still haven't figured out despite hundreds and maybe thousands of years of science in observing the universe. And we try to talk about it and to increase the gravity, I guess, in your brain.

Right. Like information causes gravity to increase. Right.

Daniel: that's true. Yeah. Eventually our goal is to turn your brain into a black hole. oh,

Jorge: no. no, we want stuff to get out too.

Daniel: that's true. Ooh, that would be [00:03:00] undermining the fundamental purpose of our podcast.

Jorge: That's right. It wouldn't go viral if everyone turned into a black hole

Daniel: but we do want your brain to absorb information or to feel like you are part of this centuries, or maybe even millennial long progress towards understanding the universe.

When people look back on the path of theoretical physics in a hundred years from a thousand years, we'll wonder how far along that path we are. Have we just gotten started? Are we around the corner from revealing the deepest secrets of the. Only time

Jorge: will tell. Yeah, because it's amazing that the universe is even understandable, right?

Like we look at it, it seems kind of chaotic, but the closer we look, we start to notice patterns and trends that seem to sort of govern how it works and what's gonna happen.

Daniel: It is amazing that the universe can be described by sets of physical laws that don't seem to change in. Right. We take that for granted.

I can do an experiment and measure something about the universe, like the gravitational constant. And then I can do that same experiment [00:04:00] in 50 years and get the same number. Why is that? Right? Why do repeated experiments get the same answer? That's not something we know. It's just something we've seen.

It's just something we. Basically assume as one of the foundational principles of science, we don't know why it's true, but we certainly do rely on it. Yeah.

Jorge: You don't even have to get that fancy to see how the universe has these laws. Right. You can just toss an apple in the air over and over, and it will always sort of come back to your head,

Daniel: but you can also do it while being fancy.

You can wear tuxedo and toss an apple into the air. nothing stopping you from getting fancy. Are you anti fancy now?

Jorge: That's right. I guess you could be tossing a, a can of caviar instead of an apple too.

Daniel: I mean, person. I'm always wearing a tuxedo while doing these podcasts. I thought we had a dress code on this podcast.

What are

Jorge: you wearing? Um, I'm wearing a pajama with a tuxedo printed on it.

Daniel: oh man. Standards are sliding everywhere. Folks. It's

Jorge: hard. That's right. We don't have a dress code law here in the podcast.

Daniel: That's right. And you're also allowed to wear whatever you like when you're listening to this podcast. So if you've been dutifully, getting your [00:05:00] tuxedo dry cleaned before you listen to this podcast, you can now just wear pajama pants.

Mm, I'm

Jorge: pretty sure nobody was wearing a tuxedo while listening to us, unless maybe they're like a waiter, maybe at a fancy restaurant, you go that, you know, tunes out the customers. By listening to our podcast, I hope that

Daniel: we have a pretty broad variety of what folks are wearing, you know, all the way from athletic gear to tuxedos with tails and top hats.

I'd just like to imagine we're sampling all of the human experience, the same way we are trying to explore the entire range of physical phenomena out there in the

Jorge: universe. But it is interesting that the universe has lost, right? Like you can imagine maybe a universe without loss is that even sort of like possible to a physicist, it's

Daniel: possible to imagine that that universe exists, but it's hard to understand how you would understand it.

You know the idea that there are laws and that we can reveal them through experiment, and then we can try to simplify them and use them to predict the future is pretty basic to our notion of understanding. It's sort of like goes to the heart of storytelling [00:06:00] even well before, like what we call modern science, indigenous cultures, just learning about their environment as they experience it are telling stories, you know, like you take this tree bark, you make a tea out of it, you drink it, you feel better.

And it's a story and it's sort of fundamental to the way I think humans.

Jorge: Yeah, that that is science as well. Right?

Daniel: Absolutely. It's accumulation of knowledge through experience. Yeah.

Jorge: Well, it's a good thing that the universe does seem to have laws because it allows us to kind of predict what's going on and to build things, to make our lives better.

And to have a little bit of context about where we sit in the universe and why we're here.

Daniel: That's right. And the patterns and trends that we notice in the universe, they give us a lot of clues as to the fundamental nature of the universe though. We assume the universe has laws. We don't make a lot of assumptions for what those laws are.

So we'd like to look around and notice, like, what are the patterns that happen in the universe? What are those laws that it seems to follow in? What are those laws mean? And why do we have those laws and not other laws?

Jorge: Yeah. And probably one of the most important laws or at least the most, uh, useful laws [00:07:00] that we found.

Understanding the universe and predicting what's gonna happen is the idea that momentum is conserved. That's a law, right? That's. Written in the statute of the

Daniel: universe. that is still a law. A lot of things that you learned about in grade school that you thought were conserved in the universe are not mass energy, energy, plus mass, all of this stuff.

You thought that stuff was conserved in the universe. It turns out it's not, but conservation of momentum still holds as far as we know.

Jorge: Oh, interesting. Some laws have been repealed. like they made it all the way up to the. Supreme court of the universe and they , they got shut

Daniel: down. Yeah. Well like Newtonian physics, some of these laws turned out to be almost true, true in many, many cases, but not fundamentally true, not actually written in stone at the foundation of the universe.

Just sort of like mostly working in the scenarios. We had tested them in so far, which is a cool Testament to like how science progresses. You find a pattern. It seems to be true everywhere. And then a hundred years later, people find exceptions, [00:08:00] exceptions that reveal a deeper.

Jorge: So when you say that momentum is conservative still law, it's it just means that it hasn't been repealed kind of right.

Like as far as we know, that's the one that's still

Daniel: true. Yeah. That's why we say it's still a law, like as of the date of this podcast, but you know, in a thousand years where people are listening to this episode, they'll laugh into their hands at our naivete right before they fall asleep. right before they fall asleep, but there is something really deep and fundamental that we're doing when we find these conservation laws, you know, we are looking around to trying to figure out.

What is important in the universe? What's a meaningful thing. Like when we think, oh, maybe energy is conserved in the universe, we just look around, we notice that we say like, okay, you have a bunch of energy in this configuration. You let the universe do its thing and you notice, oh, there's the same amount of total energy that suggests that maybe energy is like important.

It's fundamental. It's interesting. More important than like, you know, the number of ice cream cones in the universe. Changes a lot with time there's billions of years [00:09:00] when there was no ice cream and then a brief flash of ice cream. And who knows whether there'll be ice cream in the future, but nobody expects the number of ice cream cones to be conserved because nobody thinks that that's an important thing in the universe.

So if something is conserved, that suggests that's probably important somehow to the

Jorge: universe. Well, Daniel, I think ice cream is important. I dunno about you, but it's an important part of my diet for sure.

Daniel: well, if only the things that are important to you are also important to the universe.

Jorge: I think ice cream is pretty important to a lot of people.

it still around? It's it's survive several, uh, lost trying to ban him,

Daniel: but if ice cream was conserved, then you could ask questions like. Well, where did this ice cream come from? Or where does the ice cream go when you eat it? Right. It turns into something else which is not ice cream. So that suggests that what's conserved is not ice cream, but like some larger category of thing.

Anyway, it's the same thing with energy and with momentum, we discover whether these things are conserved by the universe. And then we get to ask, what does that mean about [00:10:00] the nature of the.

Jorge: Right, because I guess asking these questions is how we understand the universe, right? Like it's one thing to notice trends in it, but it's another to sort of understand why the universe has these trends and like why, uh, do certain things they conserve and others don't.

Daniel: Yeah. What does it mean about the universe? Can we find some fundamental principle that tells us about all these conservation laws, where they come from? The wonderful thing about science is that every answer leads to more questions. You know, question number one could be what's conserved in the universe.

Question number two is then all right. Well why these things and not other. Always leads to more questions, which reveal a deeper truth of the universe. That's the joy of science that the questions never do

Jorge: end well. Let's reveal some deeper truths today. So today on the podcast, we'll be asking the question.

Why is momentum conserved? Okay. So Daniel, you're saying that energy is not conserved in the universe. We have a podcast. Discussing that, but momentum is conserved. Does that mean momentum is more important than energy?

Daniel: Hmm, that's a good question. [00:11:00] Yeah. I would say that momentum conservation tells us something fundamental about the nature of the universe and the nature of space, which we'll get into the fact that energy is not conserved actually also tells us something about the universe and the nature of time.

So I think both of those facts that momentum is conserved and that energy is not do tell us something deep about the nature of the. But yeah, I think momentum fundamentally is more important. If you had like a competition between quantities and physics, I would vote for momentum over energy

Jorge: who would win in a fight momentum or energy

Daniel: well, momentum is a vector also, right?

So it has multiple components. It would definitely defeat energy, which is just a scale. It's just a number. So momentum is a bigger army.

Jorge: I see. Yeah. Also momentum has more momentum. going for it. You know, that's important in a fight. Yeah. It's momentous. Right. But only in the moment,

Daniel: Daniel maybe they should have called it Porto instead of momentum.

Jorge: Yeah. Yeah. I'm not sure renaming. It would help there. but this is a fascinating question. Like why is momentum [00:12:00] conserved? Cause as you were saying earlier, this is something you learn, you know, early on like high school, middle school, maybe even before like the idea that if something is in motion, It stays motion.

And if something's addressed, it it'll stay and rests unless something, uh, changes mm-hmm .

Daniel: And I think that when people learn about these conservation laws, the one that's most intuitive is the one that's actually least true, you know, conservation of mass. It sort of feels like it should make sense. Like you have a chemical reaction, you start out with a bunch of like little Lego, brick, chemical, atoms, and molecules, and all you're doing is rearranging them.

So of course you should end up with the same amount of stuff at the end. Right. That's the one that seems to like, make the most sense to people. And I think that's a revealing example because it makes sense because you think of like stuff as being basic and fundamental to you, the universe is it can't be like created or destroyed.

You hear that a lot in science fiction. Of course, now we know that it's not, and you can destroy mass and turn it into energy and you can turn energy into mass and all that kind of stuff. But you know, the idea that a conservation law tells you about what's important in the [00:13:00] universe is sort of underlying all of this.

And I remember learning about conservation momentum and, and wondering like, well, what does that mean is conserved is like, what does that mean about the nature of the.

Jorge: Well, in, in the case of mass, I mean, you just kinda have to figure that all mass is really energy. Right. And so then you're just, uh, it's like it's embedded in the question of is energy conserved in the universe.

It generally is just to be clear, but, uh, we've recently found that sometimes energy is not conserved. Yeah.

Daniel: It's a nice idea to generalize the conservation of mass into the conservation of energy and say mass is just one form of energy. So when it disappears in the energy, that's okay. Because it's not true.

That mass is the fundamental stuff in the universe. Energy is right. But then as you say, we discovered actually the universe doesn't really care. If energy is conserved, it can. Go away and we can just sort of increase it. So dig into that podcast, if you're curious about that, but what that tells us is that energy is not like the fundamental element of the universe.

It's more like ice cream cones. It's just like [00:14:00] something we came up with that makes sense to us, or is important to us. It's not deeply true. It's not a deep feature of the universe.

Jorge: It's not the, uh, chocolate ice cream of the universe maybe, or, or are we saying momentum is the vanilla ice cream of the universe?

Daniel: first of all, ice cream is not important to the universe only to you and to humans. But I guess we would be saying that, you know, momentum is the dark chocolate of the universe and energy is the white chocolate. .

Jorge: Well, uh, chocolate aside. This is an interesting question. Why is momentum conserved? Because we, we all the feel like it's true and it, it, it does seem to be true so far, but the question is why does it get conserved in the.

So as usual, we were wondering how many people out there think they have an answer to this interesting and deep question about how everything

Daniel: works and thank you to our volunteers who are willing to answer deep, difficult questions of physics without any chance to prepare so that we can get a sense for what people out there are thinking.

If you'd like to participate, please, you are very welcome, right? To us to [00:15:00] questions@danielandjorge.com.

Jorge: So Daniel asked this question on the internet. Why is momentum conserved? And here is what people had to say.

Daniel: I'm not really sure that momentum is preserved cause momentum's, uh, massive velocity, a product of mass and velocity and velocity's relative.

So if some, so if velocity's relative, I don't know how it could be preserved because if, if somebody else measures it, it's gonna be a different velocity. I always just took that kind of as a given and never really questioned why, why is just cuz they tell us it's always conserved but it's related to.

You know, a closed system of matter in energy, none of that matter, or in energy is created or lost. It's just converted one way or the other. And since momentum is in a way, a function of your mass and your energy, then it's just always there. It can't, it can't be bled off into another dimension or something as far as I know.

Well, I guess [00:16:00] the reason that my mention is conserved is because of. Mutant said so, and Einstein said, so maybe

Jorge: both of

Daniel: them, I think all that we've been able to observe so far indicates that momentum is conserved in terms of interactions that we've measured, those kinds of things in terms of a.

Conceptual reason behind why momentum should be something that is conserved. I don't know if there's any good explanation for that. I'm thinking about a collision right now between let's say two objects and why it' conserv. So an energy to another object. transfer to the other one. So, um, it's concern because nothing, [00:17:00] the energy it's constant, nothing gets wasted.

Everything gets. Transferred or transformed momentum may be described as mass times velocity. It may further be described as the second law of thermodynamics or is it Newton's second law of motion? I forget. College was a long time ago. However, The question of why is it preserved? I think is something nobody knows

Jorge: yet.

Daniel: I think it just all has to do with the way energy is

Jorge: transferred. So if I were to be pushing something for me to be pushing that thing,

Daniel: so it moves, I need to be adding energy to the system. I need to be pushing it and adding a force and therefore transferring energy from me into it. But just due to the

Jorge: way,

Daniel: uh, Newton's laws.

It too, has to be pushing back on me. It's like it has friction, there are other forces being applied, et cetera,

Jorge: et [00:18:00] cetera. And it also is a massive

Daniel: object. It takes

Jorge: energy to move. So knowing that

Daniel: momentum is mass times velocity, I know if something has mass and you're trying to make it accelerate and then have some sort of velocity afterwards, then you have to be adding some sort of energy to get.

and it has to bounce back to you cuz if it didn't then I think you could push something

Jorge: and not have any energy being used. And if you don't have any energy being. Then you pretty much violate everything

Daniel: because that means you could do whatever you want without ever expending any energy. And that's not really the way things work.

Jorge: All right. What do you think of the answers?

Daniel: I like the, because Newton said so, and Einstein agreed. They're like the council of physics and they decide what's true.

Jorge: Oh, maybe my kids should try that the next time their parents tell 'em no. But Newton said, so, and Einstein

Daniel: agreed that you should go to bed.

Jorge: two out of two seminal physicists. Agreed. [00:19:00]

Daniel: as if physicists have any voice in anything relevant at all. Yeah.

Jorge: Do you think physics in general is sort of done by, by polling kind of right. Like there is a little bit of sense that in science it's about what the majority thinks is true.

Daniel: That's true. The consensus view is important.

Although, you know, one person against the world doesn't have to be wrong. And in some cases like one Seminole physicist can persuade a lot of folks. You know, if you say, well, Einstein thought this or Murray Gilman said that, or Fineman put it this way. That can be pretty persuasive. But I guess

Jorge: in general, none of the answers question, that idea that momentum is conserved, right?

Nobody said like, who said momentum is

Daniel: conserved. Yeah. Though. Some people thought that we don't know the answer that we have no idea why momentum is conserved sort of like, why is the speed of light? What it is? We don't know. We just measure it. Some people put it in that category.

Jorge: I think they've been listening to our podcast and reading our books.

too much, you know, sometimes the answer is we have no

Daniel: idea. You think they've become persuaded that physics actually doesn't [00:20:00] really know very much about the universe. uhoh mission accomplished.

Jorge: uh, oh, we spoiled the ice cream.

Daniel: it just means there's more ice cream of discovery left to eat for everybody.

Well,

Jorge: let's just recap it for people. So momentum, uh, conservation means that, um, momentum is conservative. Like momentum is defined as what? Mass times your velocity.

Daniel: Yeah. So momentum for slow moving objects is just mass times velocity. And when we say momentum is conserved, we mean that if you have the momentum of a bunch of stuff, Then you let it do its thing.

Follow the laws of physics, bang into each other, bounce off of stuff, or just float through space. And then later on you add up the momentum again, you should get the same number. And interestingly momentum is actually three different quantities. There's momentum and X momentum and Y momentum and Z. Cause we live in three dimensional space and those are all independently conserved.

So momentum conservation is kind of three laws in one. Ooh. It's a deal. Yeah, exactly. For those of you who [00:21:00] do like classical mechanics for freshman physics, you know, that makes it very powerful. Cause you get three equations to constrain your answer rather than just one from conservation of energy.

Jorge: Right.

But, uh, you were saying that it's only for slow moving things like it's different for other things.

Daniel: It turns out in relativity, the definition of momentum is different from just mass times velocity there's this boost factor. We call it the gamma factor or the lore factor. Which is one for slow moving objects and approaches infinity as things get towards the speed of light.

So the real equation for momentum is mass times, velocity times, this gamma factor. We never notice because the gamma factor is close to one. So you can ignore it for stuff that's less than, you know, like half the speed of light or a third of the speed of light, but it becomes important as you get near the speed of light.

Jorge: Oh, I see. You have to, you have to adjust it because nothing can go faster than the speed of. Because it, it has to have a limit. Like you can't have momentum, that's greater than the speed

Daniel: of light. You have to adjust it in order to get conservation momentum. Like the quantity that is [00:22:00] conserved is not mass times velocity it's mass times, velocity times gamma.

And you notice this as you get to very high velocity in order order to have conservation before and after some interaction, for example, you have to use gamma mass velocity, not just mass and velocity. And this is actually the source of a lot of misunderstanding about relativistic physics. People used to define.

Gamma times mass has this weird relativistic mass and say things like your mass gets really large as you go towards high speeds, because they wanted to redefine momentum to be relativistic mass times velocity. Anyway, we're gonna do a whole podcast about that question about whether your mass actually does get larger as you approach the speed of light.

Short answer is no it doesn't.

Jorge: Right. Right. Well, I think at least for slow moving objects, it does kinda match. People's intuition is about momentum, right? Like mass time velocity, we have something large, even if it's moving slow, it has a lot of momentum and it's hard to stop, but E even something is small and has a lot of velocity.

It's [00:23:00] also hard to stop, right? Like a bullet is, is pretty hard to stop. If it's coming towards you, it's sort of like, it's a sense of how hard it is to stop in way. Yeah. And

Daniel: Newton's law force equals mass times. Acceleration says exactly that. Another way to write Newton's law instead of mass times, acceleration is the change in momentum.

So Newton's law is force is the change in momentum. If you wanna change something's momentum by a lot, it takes a big force. You wanna change something's momentum by a little bit, takes a smaller force and said another way. Something with a lot of momentum takes more force to stop something without a lot of momentum, doesn't take much force to stop.

Right.

Jorge: And the idea that it's conserved means that it, it, like it goes somewhere, right? Or like if I try to stop a, a train , I may be able to stop it, but that momentum has to go somewhere.

Daniel: That's right. If you throw a tennis ball, for example, in front of a train, it will push that tennis ball really, really fast and slow down the train a little bit.

So the total momentum is the same. The momentum can flow, as you say, from one object to another, but the total momentum has to stay the [00:24:00] same before and after every physics process.

Jorge: Right. And the weird thing is like, like, it's not like somebody's like, uh, overseeing this transaction, right? Like it just happens.

Right. When things interact, somehow momentum is concerned, but it's not like, uh, momentum actually flowed from one thing to do. They just pushed on each other. And somehow momentum was

Daniel: conserved. Wow. What a touch on like deep questions of philosophy? Does the universe like calculate what's happening and follow some laws?

Like it's some big computer following a program or does it just happen? And we are observing it and trying to tell our own mathematical stories about it. We don't really know, uh, what we notice is that it does happen and it does tell us something about the nature of the universe, but yeah, we don't really know sort of like how it happens.

Jorge: All right. Well, we know it's conserved momentum. And so let's ask the question why it's conserved and let's get into that and we'll get into the person who actually made this big breakthrough. But first let's take a quick break.[00:25:00]

All right. We're talking about ice cream. It seems Daniel a lot. Are you, are you hungry? Do you need some dessert right now?

Daniel: That's for two reasons. One is because. We record this podcast around lunchtime. And the other reason is that today is the birthday of the person who solved this riddle and made one of the most important contributions in physics.

Mm

Jorge: that's right? Yeah. The person who discovered the, basically the answer to the question that we're asking today, why is momentum conserved? So we talked about why that momentum is conserved, what momentum is, and it just seems to be conserved in the universe. And so, Daniel, I guess what's the answer? Why is momentum conserved?

It has something to do with symmetries.

Daniel: That's right. So Emmy mathematician who just dabbled in physics about a hundred years ago, she turns 140 today. The day we are [00:26:00] recording this podcast, she discovered that there's a really deep connection between these conservation laws. And symmetries of the universe.

So patterns that we see in the universe are connected to these symmetries. So what do we mean by symmetries? This is a case where we're using the totally normal definition of a symmetry. We don't haven't like imbued it with any special confusing, meaning. It just means that like you change something and there's no impact.

Like you could take a ball and rotate it and doesn't change the ball at all. It still behaves the same way. It still looks the same. It's an example of as symmetry, or you can take a road, which is a straight line and shift it by a hundred meters. And if it's a straight line, it doesn't change it at all.

Or it's the same road, these kinds of symmetries turn out to be really important in the nature of the universe and are connected to these conservation

Jorge: laws. Right. Right. But let, let's maybe take a step back, right. Because I, I think the history of this is that we knew that momentum was conserved. And at the same time, we were discovering something about [00:27:00] the universe that it, it is sort of symmetric in these weird and interesting ways.

And so maybe before we make that connection, maybe step us through like what exactly is a symmetry in the universe. So

Daniel: there are lots of cool symmetries in the universe. One of them is that space seems to be the same everywhere. The nature of this universe, we find ourselves in doesn't change based on where you are.

If you do an experiment to measure something fundamental about the universe, it doesn't matter where in the universe you measure it. Or said another way, if you shifted the whole universe over by 10 meters, no one would be able to notice, right. The universe is the same, no matter sort of where it is.

Jorge: Right, right. Yeah. That's a pretty cool idea. But I think maybe I wonder what confuses people a lot sometimes is the, that the name symmetry is a little bit different than what you just describ describe. Right? Like to, I think the most people, the, the word symmetry kind of means like it's the mirror opposite.

Or like, if I have a pattern and, and a piece of paper, and then I have the mirror. [00:28:00] Image of the pattern right next to it. Then we would say the whole drawing is sort of symmetric, cuz it's the same left or right,

Daniel: right. Mm-hmm and that's an example of what we consider a discreet symmetry. Right? You can like flip the whole image and it looks the same.

A continuous symmetry is like take a piece of paper and draw a circle. Right. That circle is the same, no matter how much you rotate it. And there's an infinite number of ways you could rotate it and not change the circle. Right. Or if you had an infinite sheet of paper and you drew a picture, it wouldn't really matter where you drew that picture.

You could draw it here or draw it there. It would be the same because the paper is infinite.

Jorge: Right. But I guess maybe I wonder like a more, a better word. Would've been like. You know, consistency or consistency of, of things, right. Because I think the reason you guys use symmetry, the word symmetry is that it has to do with the equations of, of motion of the universe, right?

Like if you apply like an, a mirror transformation or some kind of transformation to the equations, then it should stay the

Daniel: same. Yeah. So to totally generalize the word symmetry, what [00:29:00] mathematicians mean by it is that you make some kind of transformation to the universe. And then that doesn't change whatever it is you're interested in.

So in the case of physics, we make some sort of transformation to the universe. Like we shift it to the left a hundred feet, or we rotate it around some angle. And then the thing we're interested in are, are the laws of physics the same, as you said, like the equations of motion, would you predict that Jorge's apple flies through the air and lands in his hand the same way?

If you put your access over here, or if you said, you know, zero is over there or if you did the problem upside. When you get the same answer, if so, then there's a symmetry to

Jorge: the problem. Or even like, if I move the earth a few light years to the right, it should still be the same, right? Yeah. If you

Daniel: move the whole universe, right.

A few light years to the right. Nobody could do an experiment to determine that that's the case that that's happened because no place in space is different. Right. The rules should be the same everywhere.

Jorge: Right. So when you hear the word symmetry in physics, really, maybe in your head, you should be thinking like a ancy in the universe or like.

In [00:30:00] variability or something that doesn't change when you move it or rotate it or flip it. Right.

Daniel: Right. I, I like that. There's no word in physics that you're not up for redefining and improving. , you know, science is a constant project. And so we're always striving to improve, but there is a bit of confusion there because if you call it like an invariability, it comes close to another word we use, which is in variance, which actually means something quite different, right.

In variance means no matter who's measuring it, you always get the same answer. An example of an in variant is like the speed of light. Everybody measures a speed of light to be the same quantity, no matter where you are or how fast you're traveling. Momentum is conserved, we say, but it's not inva because for example, you are standing still, you measure your velocity, be zero.

I'm moving past you. I measure your velocity to be non-zero. So I measure you to have momentum. You measure yourself to have no momentum. Momentum is not the same for all observers though. It's always conserved. I will see your momentum is conserved. [00:31:00] You will see your momentum is conserved, but it's not in variance.

So in variant means something different in physics. Yeah.

Jorge: I, I mean, I'm not saying you should not use the word symmetry. I'm just saying that it might be helpful for people to kinda understand what's going on. If, if, when they hear the word symmetry, they should sort of be thinking more about like that things are the same.

No matter if you move them over here or you do. You throw the apple over here, over there or upside down, or if you, you know, rotate the whole universe 90 degrees, it should still fall down back to my head.

Daniel: Exactly. And those are a few examples of symmetries, right? Like if you shift the whole universe over your experiment should work the same way, you know?

And that's true. If space is not different in different places in the universe, if it were different, right. If space was like different over there and over here, if you had different laws of physics over there, and over here, you'll be able to tell sort. Where the universe is relative to those like different parts of space.

That would be fascinating. Um, but it seems to us so far, like space is the same everywhere and that's a pretty deep symmetry, right? It tells you something about the [00:32:00] nature of the universe itself, that the experiments are the same everywhere you go. And the same seems to be true for rotating. There's no up or down in the universe, you could rotate the whole universe and you wouldn't be able to notice that it had been rotated.

Whoa. In the sense that you mean that, you know, the laws of physics don't change and your experiments get the same results.

Jorge: Right. But I wonder if that's sort of dependent on space time, right? Like. Depend does that depend on flat space time or, you know, would that be still be the same around, uh, close to a black hole or something where space time is sort of bent or distorted?

Daniel: Yeah, it's a good question. You know, so you might ask, like, I do an experiment here and I notice my apple falls. What if I move a Jorge near a black hole? Wouldn't this apple fall

Jorge: differently? Yeah. Wouldn't you like that? Right?

Daniel: no. Then who would eat all the ice cream? You know, I need somebody else to eat it, so I don't gain too much weight and become.

Black hole myself. It would all fall

Jorge: into the black

Daniel: hole. All right. So we can throw you into a black hole, as long as we send a continuous stream of ice cream scoops as well.

Jorge: [00:33:00] let's keep it as a thought

Daniel: experiment. No, that's a good question. And you know, essentially the issue there is that the black hole is sort of part of your experiment.

And so underlying space itself isn't changed, but the sort of laboratory of the experiment you're doing, um, includes a black hole in one scenario. And doesn't in the other scenario. That's why you get different outcomes, cuz you're sort of doing a different experiment. I

Jorge: see. So the theory still works, uh, no matter what hap what's happening with space time.

Yeah. Although

Daniel: if it's not true, that space is the same everywhere. Then the theory doesn't hold, you know, for example, what if space was not like continuous and infinite? What if it had a boundaries you've mentioned on several podcasts, there was like an edge to it. Then, you know, the laws of physics would be different at the edge because space would be different at the edge.

Different things would have to happen. So maybe the laws of physics would be different at the edge. We don't actually know. Right. Is there a boundary to space and does it go on forever? Another possible way that it could not be true is like, if space is not [00:34:00] continuous. If it's like Pixelz or like a crystal, then it might not have a continuous symmetry.

It might be like, location is a symmetry up to a certain value. You know, if you take like certain steps in space, you get the same answer. But if you take like a half step, maybe you get a different answer, cuz you're sort of like caught between two parts of the

Jorge: crystal. Yeah. If it's quantum, then it, it maybe wouldn't be, uh, symmetric, but I guess to sort of generalize it though, as far as we know, it's it is symmetric the laws of physics throughout all of space, time.

As

Daniel: far as we know, as far as we know, it's symmetric to translations shifts and symmetric to rotations, and with a couple of exceptions, it is symmetric to shifts in. Like, if you do an experiment today and you experiment in a hundred years, then you should get the same answer because the laws of physics, we think don't change in time.

Those are three really basic symmetries that we've discovered in physics,

Jorge: right. Translation, rotation, and time. And that even applies to like, um, moving backwards in

Daniel: time. Right? [00:35:00] It does. Yeah. In the sense that if you're comparing two experiments down at two different points in time, one of them could be further back, but I guess always one of them is further back.

Right? It's it's not about time travel necessarily. Well,

Jorge: so that's the idea of symmetry in the universe. We noticed that the equations of the universe have these symmetries in them, but I guess we didn't know that they were connected to the idea of conservation of momentum. Right? Mm-hmm that's right. All right.

So those are kind of like the, the three main symmetries that the, the we've noticed about the equations of the universe. And those are kind of like the, um, more intuitive one, but there are sort of deeper also. Symmetries kind of in, at the quantum level, right?

Daniel: Yeah. We've talked on the podcast a few times about other kinds of symmetries we've noticed in the universe, and these are not things that are easy to grasp in your mind because they're not things you see, but these are like properties of quantum fields and it turns out that you can like rotate different quantum fields, sort of into each other.

You. Swap in different colors of quirks, [00:36:00] turn red to green and green to blue and blue to red, nothing changes in the universe. Right? So we've noticed these kinds of symmetries on the sort of like quantum level that are very similar to these symmetries mathematically, like they involve rotations. But not in a physical rotation, you're not like spinning anything.

You're just sort of like changing labels on quantum stuff. But these are just as important and reveal. Also, something really deeply true about the universe. And we wouldn't have discovered the Hix bow on if we hadn't noticed these

Jorge: symmetries. And again, these are like symmetries or kind of in varying things you can do to the equations that you're like, Hey, wow.

That's, that's something strange about the equation. They they're symmetric. They work no matter what you do. Yeah,

Daniel: it just seemed to matter in these cases, which gauge you choose for those of you who know, like electrodynamics, you know, that there's sort of like an overall gauge you can choose in electrodynamics and doesn't change the answers at all.

Just like an arbitrary choice. Just sort of like where you choose your potential energy to be zero in classical [00:37:00] mechanics problems. It doesn't change the answer. It's just a choice. So there's a symmetry there to the problem. You can change these things and nothing changes in how you predict the laws of physics.

And that's in the same sense. You can like change these. And how we describe these quantum fields and doesn't make any difference for our predictions for, or how particles should interact with

each

Jorge: other. Right. Right. And I think we had a whole podcast about this, about this idea that, you know, the word G here, it's sort of related to the idea of measuring something or like having a reference, you know, length or something.

Yeah. It

Daniel: actually comes from trains because back in the day, people were building railroads all across the United States and they were building them with different gauges and people thought. Okay. It's just sort of an arbitrary choice of train gauge. So then when physicists were like making arbitrary choices in their theories, they were trying to find a word that captured that like, sort of sense of arbitrariness, as you say, like to set a scale.

So they chose the word gauge because physicists love trains. I don't know why, like in thought experiments, right?

Jorge: Yeah. Well, it it's Europe. It's full of trains. Yeah, I

Daniel: suppose it was before the [00:38:00] era of the car that these things took over. So yeah. Yes, that's

Jorge: right. You would just call them Ubers today. or Lyfts.

All right. Well, so that's kinda where we were in the history of physics. Like we knew that momentum was conserved, right? We, we could see it with simple experiments. It seemed to work with Newtonian physics, but at the same time, we had these more complex equations of the universe and we noticed kind of these special.

Symmetries mathematical symmetries about them, but I guess people hadn't put the two together, right. To make the connection.

Daniel: That's right. We had noticed these properties of the universe, that things seemed to be conserved. And we also noticed mathematically that there were symmetries to our equations.

Until

Jorge: we got a very, uh, special physicist on the scene. And so let's talk about her and how she put the two together and answer the question basically. Why is momentum conserved? But first let's take another quick break.[00:39:00]

All right. We're asking the question. Why is momentum conserved? And we know it has something to do with symmetries, but, um, we, nobody had put the two and two together until, uh, physic name. No. That's right.

Daniel: Actually she's a mathematician Meher and, uh, she was an expert in abstract algebra and really kind of a genius.

And she sort of like got pulled into a question in physics just very briefly wrote like, you know, one paper on it and then moved back to a real interest in math. But this one paper is basically now the foundations of all of theoretical. Her like, you know, side hustle turned out to be, you know, the most important thing anybody's ever done.

Jorge: Oh man. Does it feel like, you know, you guys like the entire field of physics was stuck and then they just like, you know, one mathematician had to take like a five minute break from, from their important work and come and save all of

Daniel: you. Yeah. And it's even more tragic than that because due to the fact that she was a woman, she wasn't even really allowed to participate in academia and in research, [00:40:00] even in mathematics, not necessarily just in physics.

And then when the history of all this stuff was written, she was largely sidelined. So people, a lot of people have never heard of Emmy nuther, even though she's like more influential than Einstein. Whoa.

Jorge: All right. Well maybe take us back. So she was around in the 19 hundreds, right? She was born before the 1900.

Daniel: She was born in 1882. And, you know, the end of that century had like important mathematical work by like reman. And Minkowski laying really the foundations for relativity that Einstein would later pull together in the early 19 hundreds and teach us a whole new way to think about space and time. So she was around during a sort of very exciting time when mathematics was really informing physics and she came from a wealthy family.

That had academic background. She had like professors in her family, but because she was a woman, she was not even allowed to enroll in university. Like just not a thing that women could do back then. Right. This is like before Mary Kiri became [00:41:00] the first woman in France to get a PhD, you know, it's just like, not something that women were allowed to do.

It's mind boggling now, but it was sort of the way things were back then. Yeah.

Jorge: It's pretty tragic. And she was born in, uh, Germany or,

Daniel: yeah, she's German. She was born in Bavaria and she, um, wanted to study in Gagan and they just didn't allow it until 1903. When they finally allowed women to enroll. She'd been sitting in on lectures of course for a while, not officially enrolled, but then she was allowed to enroll.

And then in 1907, she was only the second woman ever to earn a PhD in mathematics. Wow.

Jorge: In the world, right. Basically.

Daniel: Yeah. In the world. And you know, there are famous folks out there. Hillberg Klein, Minkowski Schwartz child. All these folks knew her and they all knew and said that she was smarter than they

Jorge: were.

Wow. And these are like, you know, seminal, uh, you know, mathematicians in physics. Yeah,

Daniel: absolutely. And yet there were a lot of institutional barriers for eight years after she got her PhD, she was doing [00:42:00] teaching and research and she was not being paid. You're just sort of like volunteering. Nobody would hire her because she was a woman, even though she was making important contributions.

It's. You know, it's really ridiculous. Yeah.

Jorge: That's pretty tragic. Pretty crazy. And she actually had to sort of practice physics and teach it for free kind of right. Cuz they wouldn't hire her.

Daniel: Yeah, exactly. Despite her like glowing recommendations from Seminole folks in the field, she's rejected from position after position just because she was a woman Hillberg, who's a famous mathematician.

He wanted her to teach because she was also a great teacher. Uh, but they refused to give her the position. What he did was he signed up to teach the class and then he hired her basically to be his TA and then he just never showed up. So she taught the class.

Jorge: I don't know if that's noble or lazy , can't tell or both.

Somehow

Daniel: both. I'm not sure, but you know, she came from a wealthy background, so she was able to just keep working, even though she didn't have a salary. And after world war, I, she finally was able to get an academic position, but they wouldn't pay. So they're like finally letting her in the [00:43:00] door, but like, yeah, but we're drawing the line at providing you any funding or any money for your work.

Jorge: Talk about like unequal pay that's the ultimate UN

Daniel: inequality. And around the time that Einstein was developing general relativity people were trying to understand, like, what did it mean. You know, Einstein had these equations and it took decades for people to like really understand what it means. And one of the questions about general relativity was like, what does it mean for energy conservation?

People thought energy was conserved back then, but in general relativity, they were like, hold on a second. It's not clear if energy is conserved in general, relativity what's going on. People knew that nuther was an expert in algebra and in mathematics. A lot of which was really important underlying general relativity.

So they asked her to look at this question. Right,

Jorge: because I think at this point in the history of physics, like we were at the point where basically Newtonian physics were being upturned, right? Like we had relied on Newtonian physics all the time. People thought there were the thing that told us that momentum was conserved, but now they had this whole new sort of class of physics, this whole new sort of level [00:44:00] of.

Quantum and, and relativity. And so people were like, wait a minute. What's going on? Is momentum still conserved, according to these new sort of equations, right? That's kind of where we

Daniel: were. That's where we were. People were like, well, we think general relativity makes a lot of sense. There's a lot to like about it, but now we get to ask new questions about it.

Like. Why does it seem that in general relativity energy is not necessarily conserved under what conditions would it be? Conserved? What does that mean? This is like a big question about the nature of these new mathematical and physical discoveries. And so she looked into it and she figured out something really interesting and very deep about the nature of the

Jorge: universe.

Wow. She took a little coffee break and she came and figured everything out

Daniel: for everybody. I know all these folks who were like paid and had full professorships, you know, and this is their job. They like asked the volunteer mathematician who they'd excluded from academic positions to come and solve their problem.

And she did. And then she went back into mathematics. Right.

Jorge: That's wild. And then it's interesting too, because she was surrounded by all these like famous mathematicians. [00:45:00] Right. She worked with them. Hillberg Schwar shell. I mean, these are big names, even, not just in math, but also in physics. Like, you know, Shore shy, uh, radius of a black

Daniel: hole, right?

Absolutely. All these folks knew her and had great respect for her. And it's a little sad that in the telling of these stories later on, she was mostly omitted from it. You know, even though she made this really seminal contribution, which we'll talk about in just a moment, history has largely forgotten about her.

And like, I think if you ask people who made the most important contributions to physics in the last century, You'd get Einstein. You might get shrouding her, but like Norther is up there. Maybe even more important than Einstein. And yet almost nobody knows about

Jorge: her. Wow. Up there with Einstein. All right.

Well, let's get into what exactly she did. Like what was the breakthrough that she had? What was the connection that she made? So

Daniel: it sounds very simple, but the connection she made was that any symmetry you have in your equations will generate a conservation. What that means is that any conservation you see in the universe, any time you see something being conserved, you don't understand [00:46:00] it.

What it means is that it comes from some symmetry. There's always some symmetry, which produces a conservation law. So for example, conservation of momentum comes from the fact that space is the same everywhere. If you shift your experiment from here to over there, you don't get a different answer. That's why momentum is concerned.

Can you

Jorge: maybe go a little bit into more detail? Like why is that? Why is it that having the equations be the same here or there. Result or gives us conservation of

Daniel: momentum. Well, remember that what we're talking about is that physics doesn't change, right? So you shift your whole experiment from here to there.

You get the same equations of motion and the equations of motion. If you know anything about like Hamiltonian or LaGrange and mechanics, these equations only depend on the derivatives of your position, how your position changes with time, not the actual value of the. Right. And so if you take your position and you add a constant to it, and you know, X goes to X plus a, then the derivatives don't change because when you take the derivative [00:47:00] a disappears, I mean, the equations of motions you get when you shift your position, don't change because the equations of motion only depend on the derivative.

And the derivative of your position is your velocity, which is closely connected to your momentum. That's sort of like a sketch for why the symmetry in position gives you conservation of momentum because the equations of motion only depend on the derivative of the position. Not the position themselves.

Mm.

Jorge: I think what you're saying is that the equations of motion of the universe basically don't have position in them. They just have velocities in them. Yeah. Another

Daniel: way to think about it is that they only have relative positions and you shift everything over and nothing changes. So only changes in position are important.

That's what the equations of motion are about and changes. The position is velocity and velocity is basically momentum.

Jorge: Right. But I guess the question then is why does the fact that it's. Same here or there. Why does that mean that, you know, objects in motion, stay in motion and, and objects and address stay addressed.

It might

Daniel: seem weird to connect [00:48:00] these two quantities, momentum, right. And position, but you know, there's another great advance in the early part of this century, that connected momentum and position that told us that there was a close relationship between these two quantities. And that's quantum mechanics, which like the Heisenberg uncertainty principle tells you that momentum and position are closely related to each other.

Cuz one is basically like the Fourier transform of the other one. And so these two quantities are like really coupled together. And so the fact that you can shift your experiment over by 10 meters or by light ear, and it doesn't change. The answer tells you something about the relationship between momentum and position.

Uh, and so that's sort of where it originate. Is that helpful at

Jorge: all? No. Um, let's try this. Maybe let's assume that the equations of the universe were not symmetric, right? Like, let's say that, uh, you know, you didn't have these equations, how would that translate to momentum? Not being conserved. All right.

Daniel: So if the equations of motion of the universe. Depended on [00:49:00] position, right? Not just changes of position. Like if

Jorge: F equals ma here and F equals three ma and Mars, not in Mars, but like near the, in the neighborhood of Mars, like, let's say the equations, the universe. Change from here to there. How would that affect whether or not a ball of ice cream might throw at Mars is, is gonna change

Daniel: velocity.

If you're a particle and you're moving through a universe where the rules are changing, as you move right, then your trajectory might change because the rules are the things that govern your trajectory that tell your trajectory, how it moves. So if over here in our part of the universe, it requires a force to change your momentum, but over there, it doesn't.

Right then your momentum might change without anybody applying a force to it, uh, in that part of the universe. And so your momentum might be changed just by the fact of moving from here to there, to where, where the rules are

Jorge: different. Right. But what if nothing interacts with my ice cream ball from here to there?

Why would it change Velo or how could it change velocity? You know what I mean? Like how [00:50:00] could the momentum change or maybe like, are you saying like maybe the definition of momentum would change? You're

Daniel: assuming implicitly there that you need to interact with somebody to change its momentum, which is assuming conservation of momentum.

But in this example, we're talking about a universe where the rules are different from one place to another. And so you don't have conservation of momentum. And so it would break pretty basic fundamental things. That things could change momentum without anything interacting with it. Right. That would break,

Jorge: well, let's say like here on earth or in our neighborhood, it's F equals ma, but near Mars it's F equals three ma right?

Like if I apply a force, I need three times the amount of force to get something to accelerate. Would that break the, the laws of conservation momentum or not?

Daniel: Yeah, absolutely. It would because remember force is a change of momentum and so it's talking. He's having a different change in momentum over here and over there.

So you'd have to have some like gradual change in the laws between here and there. And then, you know, the same acceleration would require a different force here [00:51:00] and over there. And so that would mean a different change in momentum.

Jorge: Absolutely. What are you saying? Are you saying the ball would slow down or the ball would speed up in that

Daniel: case?

It would slow down because effectively you'd be increasing its mass to like 3m without changing its momentum. So its velocity would drop. Are you saying

Jorge: because there's no force then. Because we sort of changed the mask kind of then the velocity would change.

Daniel: Yeah. Um, it gets pretty hard to do these calculations because your intuition really assumes that these things are

Jorge: conserved.

Right. Well, I guess what I'm trying to do is, is get, as you know, kind of an intuitive sense of what, um, you mean when you say like symmetries equals conservation of, of something. I think

Daniel: maybe an intuitive way to understand it is to think about just the relative sense of these quantities, you know, We know that no place in the universe is different from any other place.

We also know that the only important thing is not your position, but your relative velocity, right? Those two really are saying the same thing. That what matters is not where you are in the universe, but [00:52:00] your velocity relative to that stuff. So momentum is important and not position. That's why momentum is conserved and not like location.

So I think that's the most intuitive way to think about it. You know, that underlying you, there's no fixed grid where somebody's measuring your position is just about how you're moving relative to stuff that's important, not your location. So one way to say that is, well, you can move your experiment somewhere else and get the same answer.

Another way to say that. Actually the important thing is motion, not position and that's conservation and momentum. I think

Jorge: maybe you're telling me that you sort of have to go into the math to really understand that connect. Like it sort of comes, comes from the math, but it's kind of hard to really see it from an intuitive point of view because maybe we are so ingrained in this idea of conservation.

Now we can't think of, of things not being conserved. Yeah. I

Daniel: used to think I had intuitive understanding of it until you asked me a bunch of questions about it and now I'm not so sure ,

Jorge: I've destroyed the conservation of knowledge in, in

Daniel: your brain. But it is very simple, mathematically and very deep and fascinating.

You can take this [00:53:00] example that translations in space, lead to conservation momentum and apply to lots of other things. And it also holds that's why north the is so powerful. It doesn't just explain conservation momentum. It also explains other conservation laws that we see in the universe. For example, you can apply the same thing to rotation, right?

We don't care about the orientation of anything in the universe because there's no up or down. There's no preferred direction, the same way. There's no preferred location. That's why we have conservation of angular momentum, because rotation is not fundamental, but relative rotations are rotational.

Velocity is important. And so we have conservation of angular momentum because the universe can be rotated through an arbitrary angle and nothing change. Right.

Jorge: I, I think what you're saying is that she sort of drew that connection between these mathematical symmetries and these sort of physical ideas of conservation of, of things like things overall, if you're looking at 'em at a system, they don't change.

And she said, Hey, that's because you have these symmetries [00:54:00] in these equations, like. They're sort of one and the same.

Daniel: Exactly. And not just a symmetry in the equation, a symmetry in the universe, right? Conservation momentum tells you that space is the same everywhere. That's a big conclusion, right? If momentum really is conserved everywhere in the universe, it tells you there's no different place in space.

Every place in space is the same. It's not just the equations. It's like. The universe, man,

Jorge: the universe, man. Huh? So what exactly is theorum like, how do you, how do you verbalize that? Theorum

Daniel: theorum is that every continuous symmetry of the lain, which describes the motion and interaction of particles leads to a conservation law.

So continuous symmetry, like translation in space or rotation in space or shifting in. The original question she was trying to ask is, is energy conserved in general relativity, and if not, why not? And so this was her answer. Her answer was if space doesn't change with time, if the laws of the universe don't change in time, then energy is [00:55:00] conserved.

If the laws of the universe do change in time, then energy is not conserved sort of blew everybody's minds when she discovered that,

Jorge: wow, So she sort of made a bridge between the new physics and the old physics, right. Or she provided kind of the answer that said, Hey, they're all sort of one and the same.

Daniel: Yeah. She helped us understand why these conservation laws appear and under what conditions they do. And of course, for decades afterwards, people were like, well, Obviously energy is conserved in the universe. And so therefore the rules of physics must be the same as a function of time. Now, of course we know the universe is expanding and that means that energy is not conserved because space is changing with time.

Right? So, you know, the is still teaching us things about the nature of the universe. The fact that the universe is expanding means that energy is not conserved. And we know why,

Jorge: because it, it sort of breaks her theorum or it's outside of her. Theorum yeah,

Daniel: because there isn't a symmetry with time. Which is why we don't have energy conservation.

If the universe was symmetric in time, if space was the same size and not [00:56:00] expanding, then we would have energy conservation. So we know why we don't have energy conservation, just the same way we know why we do have momentum

Jorge: conservation. All right. Well, I think that sort of answers the, the main question of the episode, which is wise momentum conserved.

And it seems like the answer is that it's, it's sort of. Baked into the equations of the universe. Like it's because the equations of the universe don't change no matter what, where you put it. Yeah. It's

Daniel: because space is the same everywhere in the universe. That's why momentum is conserved.

Jorge: Well, it's everywhere.

It's the same everywhere in the universe, but not everywhere in time. Like it's. It's changing, but it's changing everywhere at the same time, I think is

Daniel: what you're saying. Space is expanding. It is changing, but the rules of the universe are the same at every location in space. Yeah. There's no different parts of space.

There's no like vanilla space and chocolate space and strawberry space. It's all the same space. It's all

Jorge: the same. Um, it swirl

Daniel: right. Exactly. You only get one. And that's one kind of space swirl in this universe. I see.

Jorge: [00:57:00] But if we do maybe find out sometime in the future, that space is different, like at the borders or at the edges, or maybe in the next universe over then maybe momentum wouldn't be conserved.

Yeah,

Daniel: exactly. Maybe momentum will be de thrown the way energy

Jorge: was. Mm, or at least, you know, not Deone, but just like, Hey, it would confirm, uh, no, theum actually in a

Daniel: way, right? Yeah. And if you're interested in other weird quantum applications in north, theum check out our episode about gauge symmetry, which relies heavily on this idea and which promised to have a whole episode diving into north.

The, so here it is, but not serum also explains why we have. Conserved electric charges in the universe. It comes from an internal quantum symmetry and also to other weird conservation laws in particle physics. Come from symmetries. We see in the equations of particle physics and are powered by Noster.

Well,

Jorge: I feel like there are two big lessons here. One is that sometimes even the, like the things that seem intuitive in the universe have a deep sort of mathematical root in the, in how

Daniel: the [00:58:00] universe. You should always ask mathematicians for help with your physics problems.

Jorge: yeah. They're like the 9 1, 1 of the physics world.

Like we've been trying for centuries. Can you guys, you know, take a break and uh, help us out.

Daniel: Yeah, well that part of history is really rich with fascinating mathematics. That was developed for decades, just had a pure interest in mathematics and then oh, turns out to be really helpful and solve important problems in physics.

Jorge: Yeah. And I guess the other interesting thing is here is that, you know, I mean, know there was someone who was sort of outside of academia, right. Kind of it. Unjustly. So in justly, so she's excluded, but, um, she still made this amazing contribution. Like, you know, these breakthroughs can come from anywhere.

Daniel: Yeah, exactly. And we really should have much more diversity in physics and in mathematics and in academia, cuz we need all sorts to solve the tough problems that are facing this. So happy birthday immuno and thank you for all your contributions. Yeah, for sure. Thank you. Let's all. Have a scoop of space, swirled ice cream.

And to celebrate her birthday

Jorge: yeah. [00:59:00] And, uh, expand the space around our waste loads a little bit and blow

Daniel: our minds

with

Jorge: what it all means. All right. Well, I think that, um, answers the question and it tells us some pretty deep things about the universe. We hope you enjoyed that. Thanks for joining us. See you next day.

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