Episode 27: Death and Heat Death
Physicists: Jocelyn Read, Miles Steininger

Transcribed by Denny Henke

Ben: Oh. Hello old friend, it's good to see you. Let's talk about this word fascination. It describes an unquenchable urge which compels our hearts to quest and be captivated. As long as there are elegant explanations to complicated phenomena science will never lose its romance. Over the years I've traveled the world indulging in my fascination with physics and now I find that a new hunger has woken within me a fiery need to share these great ideas with the people around me so I have assembled a team of some of the greatest most lucid most creative minds I have encountered in my travels and I call them my Titanium Physicists. You're listening to the Titanium Physicists Podcast and I'm Ben Tippett, and now allez physique!

[1:49]

Ben: Let's talk about time. The basic deal with time is that some things change and they don't change back. So, ice cubes melt into glasses of water, sand in an hour glass goes from the top ball and settles in the bottom ball and sometimes people die. So time kind of acts like a ratchet for change. But the thing about physics as it applies to particles bouncing off of each other at the microscopic level is that time shouldn't act like a ratchet. It quantum mechanics anything that can happen can also un-happen. Let me explain it like this imagine you take a video camera and you put it over a pool table and focus it in on the eight ball and then you record a film of you smacking the cue ball into the eight ball so that they hit each other and roll out off of the top of the screen, all right. Now you could watch that video backwards or forwards. Backwards you see the two balls come into the top and bumping into each other and that would stop the eight ball. Well if you show this video either backwards or forwards to a physicist and you asked them, there's no way, using the laws of physics, there's no way that they could tell if the film was being played backwards or forwards because these interactions are entirely consistent with the laws of physics played backwards or played forwards. So, the moral of the story is you can't tell the difference between pool play forward and pool being played backwards. Except you can, right? I mean at the start of the game of pool all of the balls are clumped together at the center and then very shortly after the game starts they're all over the place. So time as we've described it it's something that shows up as a macroscopic phenomena. It only shows up when you have a whole collection of objects interacting. Specifically the passage of time can be described in terms of the change of a system from being neat to being disordered. So today we are going to be talking about entropy. If the world of commerce and communication and intellectual property in the 20th Century can be described in terms of billiard balls knocking around the table then the onset of the Internet could probably be described as hitting the pool table with a wrecking ball and throwing it down a waterslide. So who is the man that has the vision to tell us the new rules of this game? Who is the man who reassuringly tells us to bravely face the chaos and to pluck its delicious fruits? Who is the cat who will drop out when there is danger all about? It's Cory Doctorow! Hey Cory!

Cory: I thought you were talking about Joseph Shrimpiter, but okay.

Ben: Cory Doctorow is a blogger on BoingBoing.com where he is one of the world's most prominent minds in arguing in public for liberalized copyright laws and file-sharing and he's also a science fiction author. His book *Little Brother* won the 2009 Prometheus award, the Sunburst award, and the John W Campbell Memorial award. His latest book *Rapture Of The Nerds A Tale Of The Singularity Post Humanity And Awkward Social Situations* just came out at the end of September, just in time for Christmas. Alright Cory welcome to the show.

Cory: Thank you very much, it's my pleasure!

Ben: I'm really excited! So for you today, I've assembled to of my finest thinking Titanium Physicists. Arise Dr. Jocelyn Read! Dr. Jocelyn did her undergraduate at UBC, her PhD at the University Wisconsin Milwaukee and she's currently faculty in the physics department at Cal State Fullerton. Now arise Miles Steininger! Miles did his undergraduate with me at UBC and he worked at D Wave Systems, the people that just sold the world's first quantum computer and he is a patent clerk. So hey Miles how's the development of your theory of universal gravitation going?

Miles: Um yeah, no, I should get back to that one.

Ben: Alright, Let's start talking about entropy. Essentially, entropy is a classic thermodynamic concept that came to prominence in the 1800s. So I thought the easiest way to explain this, might start off talking about how an internal combustion engine works. So, in essence you have a piston and you inject some vaporized gasoline into the chamber and then you set the gasoline on fire and this gives the gas inside this chamber a whole bunch of energy. The temperature goes right up and then what happens is the chamber expands and attached to the piston is a rod and that rod pushes a wheel that goes around that pushes the wheels of your car around, right?

Cory: I don't own a car but I understand that this is what other people's cars do

Jocelyn: And trains.

Ben: Trains, locomotives.

Cory: I take trains. I'm European we take trains.

Ben: Yeah so in essence back in the 1800s when people were starting to build these engines, there was a question of how much energy you could get out of fuel. See you'd take this coal or you would take this gasoline or you'd take whatever and you would light it on fire. Clearly it's putting out a ton of energy, right, so it's putting out a lot of heat and that heat escapes out into the environment and as it does we can do things like force the heat to push a chamber wider and use that to do work. So we can use that to turn our motors. Incidentally the question was: how efficiently can we make this? Can we make one of these systems 100% efficient? And the short answer is no, you can't. There is a fundamental limit to how efficiently you can make one of these engines. One way to imagine it is when you light the gasoline on fire that produces heat, the heat tries to escape out into the outside environment and as it does you know your clever mechanic is stealing a little bit of that heat to do work, a little bit of taxation but it can't steal it all it can only steal a chunk of it and so the sizable chunk of heat that doesn't get used for work is called entropy. In essence it's a big chunk of the energy we are never going to be able to use to do any useful work in the system.

Cory: Which is why engines get hot.

Ben: Which is why engines get hot! That's right. So you know expanding gases in thermal dynamics are little bit hand wavy.

Cory: I think the term you're looking for is airy fairy.

Ben: Oh airy fairy. So I imagine things in terms of, you know, a water wheel. We have a river, It's got a waterfall in it and what I'm going to do is I'm going to hook up a great big wheel that's going to catch the water before it hits the basin at the bottom and so as the water moves past the wheel it's going to turn the wheel and I can hook up the wheel to a generator and get power out that way. So, what would one of these water wheels look like if it was 100% efficient? So, the water is coming in, it's falling from a great height, It's got a whole bunch of velocity when it hits the wheel and then it lands in a bucket inside the wheel in the bucket gets pulled down towards the ground. What would one of these systems look like if the wheel was 100% efficient and could collect all of the kinetic energy of this water falling down on it? And the answer is, well if it was 100% efficient the wheel wouldn't be able to turn. If it was 100% efficient then it would mean that somewhere along the wheel the water would stop moving and if the water's not moving the wheel's not turning. So for the wheel to turn the water has to be moving past it and if the water is moving past it it's got to retain some of its initial kinetic energy.

[8:41]

Cory: So this example has failed to illuminate things for me because it seems to me that you could capture 100% of the energy of the water that has fallen and then there would be some more water that's still falling whose energy you haven't captured that you would then proceed to capture. I'm still having a hard time understanding. I think maybe you're using a definition of 100% efficient isn't it immediately intuitive to me.

Jocelyn: So 100% efficient means that when the water hits the top of the wheel it's going to convert all of its kinetic energy which means all of its speed into the wheel so that when it gets to the bottom of falling through the wheel it will be stopped.

Cory: So the water will be stopped.

Jocelyn: The water will be totally stopped.

Cory: So assume a wheel is sort of a fractal, hairy, infinitude of buckets and of a precise width of the waterfall which means it's been channelized by the US Corps of Engineers and so the first bucket load of water has moved the wheel in but there's a second bucket load of water that's come in while that first bucket load has been going around that continues to push the wheel and continues to push the wheel. I don't really quite understand what it is about 100% efficiency that implies that the thing stops working.

Jocelyn: Well, you're going to need to get rid of the water you're done with.

Cory: Right

Jocelyn: And to get rid of it you'll have to send it off with some speed.

Cory: Ooooooohhhhhh! Okay, I got it. Um, right, oh, right okay now I understand.

Ben: So the ocean absorbs all of the energy, the ocean will heat up, the energy of the water rushing into the ocean get completely absorbed into the ocean but we can't use that energy to power anything is kind of the idea. So in terms of our ability to tax these natural systems and get energy out to, you know to run our cars, there is a limit to efficiency.

Cory: Right

Ben: So, the deal is that, just from thermodynamics, nobody really knew what's the deal with entropy was. They had established its existence using experimentation. No matter how what You build your steam locomotive 30% of the heat will escape out and just cause your engine to heat up, and won't go in to turning the wheels of the train. But the fantastic thing is somehow we were able to explain this thing called entropy, this number, this quantity in terms of something called statistical mechanics. You know statistical just means statistics and mechanics refers to how things move around and bump into each other. It's just the name of the field.

Cory: Right, it's just kind of like a macroeconomic look at the micro-phenomena.

Ben: Yeah. That's exactly what it is.

Jocelyn: It's how you describe something where you have so many components that you don't want to try to sit down and track them all or it's maybe even impossible with your resources to track them all but you can talk about their average properties. So for example I'm sitting in this room and there is some air around me and I don't know where every molecule of oxygen and hydrogen is in this room but I know that there's an average temperature which is basically the average speed of all the molecules. I know there's a pressure which comes from the average collisions of all those molecules with me so there are all these average properties are well-defined by thinking of what a bunch of basically randomly moving molecules average out to.

Cory: It's like if you drop the ropes precisely 8 AM at the end of main street you know that 20% of the crowd is going to Space Mountain but you don't know which 20% or exactly which steps they will take.

Ben: It's like Abergabager's number, it's like 10^{23} or something right, it's this monstrous number of particles that make up all gas, all liquids, all solids because there's a ton of these individual particles, you stop treating them like they're individual particles and start treating them like an ensemble. Just like you know you can't track every raindrop that hits your roof but you can talk about the pressure of the rain on the roof.

Cory: Right

Ben: And so, you know, thermodynamics, you know people building steam engines, it was concerned with things like temperature, pressure, these macroscopic quantities that we could measure and what statistical mechanics did was it gave you a way to describe all of these large observable quantities in terms of averages from these kabillion different particles bouncing around. So the deal is that statistical mechanics also gives us an insight into where entropy comes from and it's fantastic because it's not an obvious quantity the way the average energy of the particle would turn into the temperature. It's kind of an emergent property of the system as a whole.

[13:19]

Jocelyn: So, in thermodynamics a system where the entropy stays constant is one where every step can be reversed. As soon as you do something irreversible, like for example I have a gas in this little container and then I open a window into a bigger container and the gas just expands out. Now it's never going to just sort of expand back into this little container again.

Cory: So I understand irreversible changes what's a good example of a reversible change?

Jocelyn: So, you generally make things reversible by making them slow enough that each individual step along the way is in equilibrium. So, you slow everything down and do it so that at each point you and can either go forwards or backwards without changing the system. Hmmm, I'm not sure I…

Cory: So it is reversible the kind of stuff that happens Gedanken experiments but not so much in the physical world?

Jocelyn: Right, so physically we almost never see an exactly reversible process but you can get closer and closer to reversible things like, for example, something that's reversible would be bouncing a rubber ball and the ball falls down, bounces and comes back up again and in an ideal system where it squishes and then expands without losing any energy it would come back to the original point and you can't tell the difference between playing that forwards or backwards.

Cory: Right

Jocelyn: So, reversible is basically something that can continue forever. Like for example, if I had a perfect ball, a perfect elastic ball that didn't dissipate any heat I could drop it it would come back in my hand then it would fall down again, then come back to my hand it would just do this forever.

Cory: Right

Jocelyn: But really what happens in pretty much any system we actually have is some of the compression of the rubber doesn't get returned to it's exact original state but it heats the rubber ball up a little bit and we lose that energy and that increases the entropy of system as the ball doesn't quite get up to its original position so that's no longer reversible, that's an irreversible process is one where we produce some entropy because at least classically you can never reduce entropy overall.

Cory: Yeah, now is the noise of the ball bouncing also contributing to the entropy?

Ben: That's right.

Miles: And this is actually worth pointing out when we think about Gedanken experiments we often do this frictionless and in a vacuum so we can disregard things like noise.

Jocelyn: Yeah

Ben: So, incidentally the statistical mechanics explanation for entropy kind of accommodates the total idea of irreversible interactions. So one way to characterize it is imagine if you had a glass of milk in your hands. Okay it's kind of cylindrical and you tilt the glass of milk a little bit to the left or the right everything in the glass will slosh a little bit and then settle and then if you tilt it back to its original position everything will be indistinguishable from how it started. The milk won't be appreciably heated up and then everything will kind of be where it started out. So that's an example of reversible interaction. An irreversible one, if you have a glass of milk if you took a dropper full of food coloring and you dropped a couple drops of food coloring in it, the food coloring would start off as a dot in the milk and then as it diffused through the milk there would be no way to return the system to back when all of the die was a drop at the center. Eventually it becomes dissipated throughout the milk and there's no getting it back. In statistical mechanics entropy kind of works like this the argument is… I want you to imagine there is a great big room like a racquetball court and you have divided the racquetball court into eight regions in there upper quadrants and lower quadrants, and then you get your friend the Hulk, to walk in wang the racquetball against the wall and then close the door.

Jocelyn: You have an ideal racquetball here.

Ben: You have an ideal racquetball.

Miles: Assume a uniform, a perfectly spherical racquetball of uniform density.

Ben: That's right and it's not losing any energy to heat and all of its bouncing off the walls is completely reversible. So it's banging around on the inside of this racquetball court the same way of particle would on the inside of a chamber see and you don't know where it is it could be in one of the eight different octants. And so you can deal with that statistically you can say well there's a one in eight chance it could be in any of the octants. So that's fine, trivial I guess. So then you imagine that your friend the Hulk walks in with four different racket balls, each a different color, and then throws them against the walls and closes the door. Suddenly we can start talking about the macroscopic distribution of racket balls in this racquetball court in terms of the statistical probabilities of each of the different racket balls right?

[18:10]

Cory: So each octant would have half a racquetball on average?

Ben: Yes, that's right. But then it becomes less and less probable that say four of the racket balls are in lower south east quadrant and even more so if you go in with 300 racquetballs and wang them around and suddenly you have this big ensemble and it becomes very very improbable that all of the racquetballs are in the left hand lower quadrant and it is much more probable that racquetballs are more evenly distributed.

Jocelyn: And extrapolating this is why you don't worry about suddenly suffocating in your room because the air suddenly randomly bounced all up to one corner.

Cory: Right.

Jocelyn: Because there is a fantastically huge number of air molecules in your room and any particular air molecule just like the racket balls has an equal chance of being in any of the octants of your room but when you sum up, you know something like 10^{30} air molecules or so in your room the chance that all 10^{30} of them are in 1/8 of the volume get's so low that it's never going to happen in the age of the universe.

Cory: Right

Jocelyn: So, you quantify the entropy of a particular state which is the way that all of the air all molecules or the racquetballs are positioned by the number of different ways that you can construct that state out of the individual molecules.

Cory: Right

Ben: So, to return to the horrible ink in the milk experiment

Cory: We use green food coloring around our place, we call it goblin milk.

Ben: Right, so when you're making goblin milk technically you imagine each of these little dye particles bouncing around randomly inside of the volume of milk and technically it's possible that all of the droplets of dye start off in the same region.

Jocelyn: But you set it up that way where they are all in one region.

Ben: Right, but that as time goes on and these droplets of dye get bounced around their distribution throughout the overall glass of milk kind of becomes random to the point where it becomes less and less probable that all of the droplets of milk will return to their original tiny droplet configuration.

Cory: So can I skip ahead a bit here

Ben: Yeah

Cory: Because I kind of know where this is going. But here's the question, so, leaving aside the question of how it is we could be so (unintelligible), we appear to have gone from a state of disorder to a state of order to become human beings that talk about physics, in general I would think that most of the stuff that you did would be entropic as well, that in general you'd sort of be contributing to the general decay of your body every time you moved it. But we seem to do a bunch of things that counter entropic as well like we know things better, we worry about physics which seems to me to be counter entropic, we take disorganized worlds and we organize them and yet sometimes you do things that are more entropic like we take some nicely organized green food coloring and we put it in a glass of milk and contribute to the general entropy of the Universe. What is it that gives rise to one class of counter entropic activities that we seem to be able to undertake and then this other class that is and do they all balance out somehow so this entropy can be reduced - is there like a cosmic balance sheet where every time you learn about physics you have to put green food coloring in a glass of milk?

Jocelyn: Yeah, everything you do is increasing the entropy of the Universe. Even if you're putting a little bit of the Universe into order the physical process that led to you organizing all your pens neatly on your desk you've spent a lot of energy, your body is generating heat, your net contribution to the Universe is entropy even while you were precisely arranging all of your pens is to increase the entropy. So I actually had a whole thing with my college roommate where I had a really messy room and she made this joke that you're so entropic that you're always increasing the entropy of your surroundings and I was like no, because all that effort you put into tidying up is on the whole contributing more to the heat death of the Universe than me just living in my natural state of mess because you picking up all your stuff and putting it back into the original places is actually contributing more mess to the Universe as a whole than me just leaving things scattered everywhere.

Cory: So that seems to imply that by participating in natural selection rather than all of us sort of walking into the ocean with a pocketful of rocks, that we are increasing the entropy of the universe and hastening the heat death and the stelliferous period and all the rest of it.

Ben: Yes, but don't worry about it.

Miles: The timescales you're talking about here are, the entropy you contribute relative to the rest (unintelligible) universe is minuscule, it's a drop in the ocean.

Ben: Let me give you a fun example of this there's a great explanation but first I need to talk to you about air conditioners. So if you take you know a piece of ice put it on the table it's going to melt, right? And the reason it melts is, in essence, all of the little motes of energy in the room say hey how come we're not sitting inside that ice cube? And I was like well statistically there's no reason we shouldn't move into the ice cube, so the energy slowly starts to flow into the ice cube and that raises its temperature and it melts. But where did the ice cube come from, right? We have cooling devices called heat pumps because they pump heat away from things. That cool the ice, you know, refrigerators and air conditioning units so we can make a region, say the inside of your freezer, but in doing so it's always good to take more heat.

[23:20]

Jocelyn: So, on the back of your refrigerator is that whole radiator system of coils that are releasing extra heat to the environment to compensate for the decrease in temperature and the decrease in randomness inside the fridge. And at that's the same reason why if you have an air conditioning unit, it always has something that's venting to the outside that's actually always pushing extra heat, producing more heat, than you are actually taking away from inside and pushing it out to the external environment.

Cory: What about non exhausting coolers, like swamp coolers, I mean a simple one is a fan and a bucket of water basically and blowing over a mesh with a damp cloth on it.

Jocelyn: So, evaporation is taking the ordered liquid and spitting it out into the air as random evaporated molecules. There's one increase in randomness there.

Cory: It seems to be possible to cool a room without exhaust.

Jocelyn: So, when something evaporates, when it goes from liquid to gas it actually requires, it's taking energy to do that transition.

Cory: Ah ha, so you're sucking energy out of the room by evaporating water.

Jocelyn: Yeah, so this phase transition of liquid to vapor is actually taking energy out of the system and you must continually be putting water in and evaporating more water to keep this going. So you're always taking this liquid state and changing it into a more disordered gaseous state.

Cory: Right

Miles: I think we can relate, you know, the room example, you know back to Cory's question about basically the entropy (unintelligible) causes or if the lack of entropy (unintelligible)
Let's get back to the definition what were talking about. We are thinking about the second law of thermodynamics which we haven't mentioned it applies to, really, a closed system and you have to really think about, what is the system you are analyzing. And where are you dumping this waste heat, Or where are you getting this cold water from? Always has to be taken into consideration for room cooling. You should also think about this, you know, as a being appears to learn physics or (unintelligible) deaths, they appear to locally be contributing to the lack of entropy but they're part of a larger system or we think about life evolving we really have to think about the greater system and not just the living beings in it. So, often these questions for me come down to what is the system? And then that allows you to analyze a diversity of different systems.

Cory: So ignoring whatever latent energy there was embodied in the earth as it cooled the energy of the earth that I'm interested in talking about arises from photons striking the earth from the sun and also gravitational stresses. The only energy that we use is the energy that on the earth so all of these photons have already struck the earth and have done something to it and then we make use of them we turn them to do work and that work sometimes has exhaust heat and sometimes it doesn't but since we can't create energy and since we are only using energy that was already here to begin with, does that increase the entropy of the system that is, say, the solar system?

Jocelyn: Yes.

Cory: Where do we get the energy to increase the entropy of the solar system?

Jocelyn: From the sun. Let's simplify this radically and just say what if we just have to heat of the sun but we also have the relative coolness of space. And it's this difference between the two that lets us siphon off some work from this but as we do that the heating of space is increasing the overall entropy of the system.

Ben: So, Miles mentioned the word closed system earlier and right now, classically we are in open system because we can dump as much heat as we want off into space. So if we had surrounded the solar system with a great big sphere made of mirrors, okay so that all of the light emitted out into space bounced back towards the sun eventually we wouldn't be able to do any decent work, none of our machines will work. We would reach a level of maximum entropy inside the box.

Jocelyn: …everything was at basically the same temperature as the temperature of stuff leaving the sun and then we wouldn't be able to do anything. Aside from the fact that we I have problems living at the temperature of say at the solar surface but once we reach an equilibrium with the sun and the environment, if everything is at the same temperature then that is basically a sort of local heat death.

Cory: So I have heard entropy described as the point at which everything his cooled down, but it sounds like you're describing maximal entropy as the point at which everything has heated up.

Jocelyn: The point where everything is at the same temperature. And if you're averaging over everything in the universe that tends to be pretty cool.

[28:00]

Ben: So, if you have a locomotive, right, So the locomotive it's got this really hot chamber where you're shoveling coal into, if the outside of the locomotive was as hot as the inside of that chamber then the locomotive wouldn't be able to do any work. And we would describe that as a type of heat death because that system that has had heat death is one where there is no localized energy that you can kind of tax as it moves outward. So all of the ice cubes have melted, all of the fires have gone out, because all of our machines don't work on energy really, they work on kind of taxing the transmission of energy between somewhere hot and somewhere cold. And in some sense all life on earth does the same thing. It's absorbing photons that come from the really hot sun, we are taxing that energy as it moves out into space to run all of our organs and make our plants grow so that we can eat them.

Miles: Ben should we be skipping forward a bit more to like Maxwell's Demon.

Ben: Sure, let's talk about Maxwell's demon.

Jocelyn: So this is kind of a neat thought experiment. So even back when the first ideas of this idea that you are always transferring energy from hot to cold, that you can't, that you need this sort of constant increase in entropy all the time, that there was actually already some ideas of ways that this could be got around and so Maxwell proposed this thought experiment which was later called Maxwell's demon which says okay, well, I have a way to get around this constant increase in entropy. So we talk about how if you have a volume of air and you expand into twice the volume and the air all bounces out, it never will randomly bounce back in to just be on one side.

Cory: Right

Jocelyn: Or if you have a hot and cold side and you let them mix together then they won't just randomly separate out into a hot and cold side again.

Cory: Right.

Jocelyn: But then Maxwell said what if I have you know a little molecular scale entity sitting there and, people later proposed various sorts of mechanical apparatuses to make this more concrete. But you have your little demon sitting there and and the demons got a little window that it can open and close in reversible, smooth way. So it's got a very well sliding door that it takes basically no effort to slide it up, slide it down, and then the demon sits there and there's the gas on the right and gas in the left and whenever a particularly quick moving molecule on the right side is heading towards the door he lifts up the door and the molecule goes through and he closes the door again. And if a particularly slow-moving molecule is coming from the left, lifts up the door and lets the slow molecule through and closes the door again. And then through these individually reversible processes he has converted the average speed of the molecules to be fast on one side and slow on the other. And this seems to be countering this idea that you can't do that. He has decreased the entropy of the system because there are less ways where you can have all of the fast ones on one side and all of the slow ones on the other.

Cory: Right

Cory: So I am waiting for you to get to the part where you explain why that doesn't work.

Jocelyn: Well it is really interesting because it took a long time for people to figure out why that wouldn't work. And this is actually getting into an interpretation of entropy as it relates to information. So to do this, the demon basically has to make a measurement. It has to set up something in that system of the the opening and shutting the doors which correlates with the property of the molecule coming towards it so it has to record the properties of these molecules so we can simplify this down to say setting a bit and the thing that stops this from working, is so either you need to keep setting bits and bits and more bits, basically you're requiring more and more tape.

Cory: Why do you need to retain the state of the previous molecule as opposed to just knowing the state of the next one.

Jocelyn: I turns out to erase the previous state you need to increase entropy a little bit.

Cory: Ah.

Jocelyn: And this is exactly enough to counter balance the decrease in entropy going on in the main system. So the system of Maxwell's demon includes the demon’s memory and memory is the entropy increase that as a whole, the system as a whole, is not actually decreasing in entropy.

Cory: So this is the bit were I get slightly confused because my brain keeps trying to equivocate entropy and disorder and of course knowing about stuff is not what you think of when you think of disorder. The idea that somehow knowing a bunch of facts about molecules is disorderly and not knowing facts about molecules is orderly is weird.

Ben: You know so if you imagine Maxwell's demon sitting just outside the box with his piece of paper and his pencil and his open and close switch, so him writing things down on the piece of paper is increasing the disorder of the entire room that he's sitting in, including the box. So if he is sitting inside of the box, then him writing things down is increasing the number of possibilities that, you know, the various matter inside the box can take and then the whole ensemble of him recording the information plus all the stuff going on in the box.

Cory: You mentioned clever mechanical linkages before, What if, instead of a demon there is a channel leading out of the box that if a molecule comes at it really quickly it will just bounce out of and that's the slow channel and it leads to the slow box. And there is a channel leading out of the box that slow ones can't go fast enough to get through but the fast ones can and and that is the fast one and you can make…

Miles: Ah, now that is an interesting idea, sort of a velocity filter.

Jocelyn: You could do a mechanical velocity filter. You could just have spring-loaded trap door and say it only lets them through if they are moving (unintelligible) the door. Spring loaded trap door has to be cold enough to stay closed if it has balls bouncing off of it all the time they heat it up enough so that just starts bouncing around on its own.

Ben: Alright that was fun thanks Miles and Jocelyn you have pleased me your efforts have born fruit and that fruit is sweet. Here's some fruit Jocelyn you get an apple. Nom nom nom. And Miles you get the most entropic of all fruit, grapes. Nom, nom, nom.

Ben: Awesome. Alright I'd like to think my guest Cory Doctorow, thank you for coming on.

Cory: Thank you very much this was a very enlightening and interesting and fun.

Ben: I hope you had lots of fun.

Cory: I did.

Ben: Alright. Hi, Ti-Phi-ters, listen, you might want to contact us after all talking about physics is lots and lots of fun you can visit our webpage at www.titaniumphysics.com where I post notes on each show. If you want to keep abreast with what's new on the show you can follow some Facebook sometimes we post news stories and sometimes we chat there or you can follow us on Twitter #titaniumphysics. If you would like to join a community of like-minded fans you can sign up for the Brachio Board. It's an old-fashioned message board where we talk about science and culture. Finally you can email us directly, send me question about the show you can email me at barn@titaniumphysics.com if you would like to join my crew email me at physics@titaniumphysics.com and if you would like to send us an encouraging note try tiphyter@titaniumphysics.com. Okay that's it for the main part of the show, there's probably some more after the music and remember if you've enjoyed listening to scientists talk about science in their own words you might also listen to other shows on the BrachioMedia Network like Science Sort of and the Weekly Weinersmith. Today's show was edited in part by gentleman named John Heath - thank you very much John, your work is invaluable. The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Until next time my friends remember to keep science in your hearts.

[36:48]

Ben: Alright, Cory, have you ever heard the word entropy before?

Cory: I have, there's actually a great science fiction story I've been trying to find the name of it while I've been on the phone with you from the British anthology called Temps which the premise is that all of the good super heroes have gone to America and the remaining superheroes live in Britain with they're very bad powers they are licensed by the ministry of superpowers and one of them is called into investigate someone who has built an Enorpty ray what's turns out to be a badly spelled entropy ray and it's a very good story. Every time I hear entropy I think Enorpty!

Jocelyn: What did the entropy ray do?

Cory: Well, so the premise was that this nuclear power plant was falling apart because, because someone was using an Enorpty Ray against it to make it disintegrate, Well I'll give away the ending anyway no one's going to find this ancient anthology and it turns out that the whole thing was a scam cooked up by people who were smuggling parts out of the nuclear power plant in selling them and replacing them with the broken down parts and that they'd cooked up the Enorpty Ray to hide their action because of course in a world with superpowers you might have Enorpty Rays and it was to this person who had the superpower to discover and his super power turned out to be that he could make his pint glass want other peoples beer and when the villains tie him up in the end and have caught him, he convinces his pint glass that it wants their blood and he drains all of the blood out of their bodies and then they die.

Jocelyn: Wow that took a dark turn.

Cory: It does it takes a dark turn at the end. But it was a good series though. And they did one called European Temps which was about European temps with very bad superpowers who are regulated by a pan-European ministry of superpowers.

Jocelyn: Ok, so that's the idea of entropy, as something that is why things tend to break and don't tend to fix themselves.

Cory: The center not holding.

Ben: Yeah. It's interesting that you start out with a place in Europe and also a connection to beer because historically entropy came from a study of beer brewing and things like that in Europe.

Cory: Is this reversible in the same sense that people mean when they talk about reversible computation?

Jocelyn: Yeah.

Miles: It is in a very interesting way because, another, you can have an ideal system which is reversible, also microscopic systems sort of start approaching things that are reversible. And people have constructed computers or imagine what computers would look like if constructed out of things like billiard balls and then analyzed what it would take for such systems to be reversible. And it basically comes down to how much heat is dissipated in each logic … of your billard ball computer or something like that. And so it very much does relate to reversible verses un-reversible computation and we'll touch upon that later.

Cory: There’s a Rudy Rutger novel called *Post Singular* where the entirety of the earth is deconstructed and reassembled as (unintelligible) logic that then does a whole bunch of work and then reverses of the work.

Jocelyn: It just ends up in the same state that it started?

Cory: That’s right. Yeah so two thirds of the way through the novel there is this climax where everything is put back the way it was about a third of the way back.

Cory: So getting back to where this all started my four year old once she is not drinking goblin milk is very concerned about death and wants to know why we have to die and wants to know why we can't change that and so on and so forth. But it sounds like in an open system we just don't care about how much of the Sun's energy or how many different stars energy flow in, we could eventually get all of the food coloring out of the swimming pool. Is that right?

Ben: Yeah. You could pull out one teaspoon at a time of water that doesn't have dye until all that was left was a puddle of dye if you were patient enough.

Jocelyn: In some sense entropy is responsible for the passage of time. The fact that we die has some other biology to it which is sort of beyond the scope of just how things change.

Cory: Well I thought biology was just chemistry and chemistry was just physics.

Jocelyn: Right, right. But, in principle everything on the lowest physical description of the interactions of molecules is reversible.

Cory: Right

Jocelyn: And then we have stuff like say a cosmic ray goes through and messes up some of our DNA and then maybe we have some mechanisms in the cells that can repair this so yeah it's all physics but the fact is like how well those are biological system do at keeping itself repaired and going and what is it sort of evolutionary basis to justify the level of support for a long-term organisms lifespan. You know there is very long lived biological entities out there but it requires constant Energy input to maintain themselves.

[42:06]

Miles: And they also do very little.

Miles: Right, very slow moving your average (unintelligible) doesn't do a lot of running around.

Cory: I get this now. So getting back to brains and life and immortality and mortality, there is this reductionist singularity argument, not singularity like blackhole the other kind that goes, It's a kind of little puppet show between an interlocutor and a wise singulartarian and the interlocutor says I don't believe in the singularity nonsense, you can't put a person in a computer. And the singulartarian says what if I cut off the tip of your toe and replaced it with the computer with that still be you? Oh of course it would still be me. And working, you know by millimeters, the singulartarian works through the interlocutors body until he gets to the brainstem and then you know, one layer of cells at a time, and he says is this still you, is it still you? And then at the end the interlocutor has to admit why yes of course it's possible to put a human and a computer. But, you know, this actually seems to me not to be a very good argument because if you assume that, you know, the way that you would test to see if that was you in the computer versus you out in the real world, the only test that we really have in the literature for figuring out whether an AI is is really an AI is the Turing test where you at ask meat you and computer you a bunch of questions and see whether you answer them the same way. You would expose your selves to stimulus and see if your response was the same. And asked that way if you go up to a concert pianist who says I don't believe you can upload a person to a computer and the wise singulartarian says here I'm going to amputate both of your hands are you still you the answer would probably be no, right? There are a whole bunch of stimuli that you could feed concert pianist with hands and the concert pianist without hands and a concert pianist without hands would not respond to those stimuli in the same way that the concert pianist with hands would. The other example is a tomcat with testicles, a tomcat without testicles, Right.

So when I start thinking about this I realize not only could you not get the same answers out of you after amputating some important parts of you before amputating some certain parts, but you also couldn't get the same answers out of you over time. That 10 years ago you would answer some important questions very differently from the way that you now would answer them. And that while from moment to moment we are still us over longer timescales in the same way that like moment to moment French is French but over long timescales French becomes lots of different languages, or Latin becomes lots of different languages that no longer interoperate smoothly, or species become fully speciated. One of the things that you guys are talking about is discrete systems and what constitutes the boundary of a system and when a system is still the system and when it ceases to be the system because it's blended with the system next-door and I wonder if there's any neat concepts out of this theory that we can use to solve the conundrum of where the nexus of continuity of identity lives.

Miles: That is a very big question. May I take a stab at it?

Cory: Sure.

Miles: I think that there some interesting things I think though, that it really comes down to me always trying to think about what is the system. And why is it that as time goes on we seem to, a simple recording device will simply fit, you know in some sort of encoding, for our brain to learn physics or learn French or something like that and that seems to be order. And yet, we know that disorder should increase over time and it really comes down to what is the system, in my mind. And this really relates to, probably, the most philosophical aspect of entropy which is basically, there is this arrow of time, it's psychologically, we experience time going forward and never going backward. And it is believed, you know, a human brain or computer memory is sort of establishing correlations with its outside world. I mean, the human brain, might be getting more ordered or the computer memory might be retaining order assuming that it was in a random state to start with and not all initially set, to zero or one, and over time these correlations, these sort of form what is, you know, going to become memory or a record in the case of a computer medium. And so we think well the system is getting ordered. Well we have to also consider the outside world that we are interacting with. I think that starts us on the road for the chance to question can you do then start reducing the human being down to a bunch of information? It might be a matter of simply working out what are all the questions we need to interrogate and I'm not certain you'll ever see anything like that ever being done. But from an informational, theoretical perspective it might be entirely possible.

[47:10]

Jocelyn: So this is another tangent that's just something that I always thought was sort of interesting was that when we think of ourselves as discrete entities we usually do that at a single snapshot in time. If we look at ourselves over multiple periods of time, if we look at ourselves in the space-time perspective, not only is that a system that is, well this is a, there is a Buddhist quote but I don't remember where it's from but it's like “we are waves on an infinite ocean”. So we are a pattern, that slowly changing pattern, but the actual molecules comprising this pattern are constantly entering and leaving. So there is really no physically very precise, defined boundary that you can fit around yourself over a period of years because which particular atoms make you up are constantly changing..

Cory: So why distinguish between the pattern that we are for all the years during which “we are alive” and the pattern that we are when we're dead? Because we remain a pattern after we die.

Jocelyn: Yeah we do but we stop, when we die, I guess is this idea, yeah that maintaining the pattern in the way that we think of it requires this constant flow of energy and the constant repair of the system back to something like it was a little while ago.

Cory: But we don't maintain the pattern, that's the whole point.

Jocelyn: Well, we don't maintain it exactly but we maintain features of it.

Cory: Right, although you know we spend the first 20 years of your life are spent in the opposite of that right. The whole point of that first 20 years of your life is to replace the pattern as quickly as possible with other patterns and we call the growth. And then we reach this arbitrary point where we have to maintain that pattern. And then at some other arbitrary point we say, well these gross changes are occurring day today are not growth but are decay. We started this off with a physicist not being able to know the difference between the triangle of balls of the billiards game and balls after the break. You know the video of the breaking ball but is there some way some kind of Physics perspective that we can distinguish between the pattern that is growing and the pattern that is decaying.

Jocelyn: That’s they really nicely posed thing and I'm sure that someone it's thought about it but, so I want to say yes but I don't have a good formulation right yet. So, when we, when we decay then we are following the simplest path towards, well it's complicated because there's all sorts of these other entities absorbing bits of our matter and doing things with it. So…

Ben: Let me take a crack at this. So, at some point in time when we start to refer to ourselves, the very nature of our own identities is little bit philosophically ill-defined, right. I mean if we had really strong concept of what it meant to be a person it was alive and not dead and you know highly functioning and other things I'm sure that philosophically, world history would have evolved a very different way. And once we start to refer to ourselves just in terms of patterns it starts to ebb away at the very nature of ourselves as an individual, right? I mean so at one point in time does the avocado I ate start being a part of me and stop being a part of the avocado tree or the avacado system of life. At some point time I think you just start imagining it in terms of wars between little bits of DNA that you know somehow manage to sneak off to make new patterns of DNA once or twice in a lifetime of a large individual. Conversely if we want to argue to ourselves about patterns one thing that you can argue is that the universe, the world, everything we see in the universe today, could be constructed as a very large, but finite system of choices say, okay. So everything is made of quantum mechanical particles, and quantum mechanical particles make choices, kind of, okay. They can decide to be spin up or spin down or they can decide to be here and not there, on the left and not the right and kind of, I am anthropomorphizing here, but the choices they make kind of determine the causal evolution of the universe. So, because I as a person sitting here am in essence just sitting on a really large but finite set of choices, there is no reason the somebody, you know, billions and trillions of light-years away from me, somewhere else in this infinite universe, isn't sitting on the same stack of choices, right. There is no reason why there isn't another Ben Tippet sitting in front of a microphone doing his podcast indistinguishable from myself and all my friends but you know a gazillion light-years away.

[52:31]

Cory: Although, isn't that a bit like, the likelihood that all the oxygen in the room would find itself in the top southwest quadrant?

Ben: Oh, quite the opposite. I mean so there is there is a finite possibility that all the oxygen would find itself in the south east quadrant of the room for half the second right but the universe is infinite and it's infinite in such a way that the infinity of the size of the universe is much larger than the tiny possibility that all the particles could end up in the southeast corner of the room. So somewhere in this large infinite universe there is a little girl who can't breathe because all of the oxygen molecules are in the Southeast corner of the room. Just so someone else in the universe there's a Ben Tippet speaking on a mike. And so one could ask, what's the distinction between myself and this person that's really far away if all the choices that the particles leading up to my creation is sitting here made are indistinguishable from the ones that made me. So in terms of a pattern it's an identical pattern so am I the same person? I don't know! Is the person far off there, I think that this kind of demonstrates that the whole notion of identity is a little bit it's a castle built on sand when we try to probe around its roots we find that little bits of the argument fall off left and right.

Miles: Ben, is there more than one of me?

Ben: Oh no there is an infinite number of me.

Miles: Oh man.

Jocelyn: Wait, this is the idea of the infinite universe which isn't really empirical.

Ben: Why shouldn't there be? Okay so what would the end of the universe look like? It is clear that the universe can't have a boundary, if it did have a boundary what would be beyond that boundary? By its nature of the universe has to either be closed in on itself, maybe it's a gigantic three-dimensional sphere or it's just infinite. Cosmological tests tell us…

Cory: You talked about degrees of infinity maybe it's infinite but not infinite enough to have an infinite number of yous in it.

Ben: That's…. I think that you need, you only need a finite number of choices it's very very large but infinite to make a Ben sitting here. You only need you know particles bumping into each other in such and such a way to make me sitting on the earth circling the sun indistinguishable from me today.

Cory: So, I should get it running soon. I guess I want to close this out by asking you the question that I started with which was, or that I've been wrestling with, which is what I tell my four-year-old when she gets really upset with the thought of dying and wants to know if she could live forever.

Ben: I think it's wrong to tell her that nothing actually exists but our recognition that they exist. That's a little too deep.

Cory: Yeah. She has a babysitter who's dog died and the babysitter told her the dog went to Kevin. It took me a while to figure out what she meant by this. Kevin? Yes the dog went to Kevin. Everything that's dead goes to Kevin.

Ben: Wouldn't the dog go to Devin, and the cats go to Kevin?

Cory: That's right. I'm tempted to say that Kevin is where we all end up.

Jocelyn: So you could talking little bit about how the fact that there is change means that she could do everything that she can do. That change happens means that, there is this idea of that the things that don't die are pretty boring during their lives.

Cory: I think her answer would be I would like to change and not die.

Miles: So this, and as a parent I, my kid is coming up to one now. I have no experience in this matter but I have to get ready for it, is that in theory we could make it so she wouldn't have to die. In theory. It might not be, it's such a large task that you might not have the project ready in time and everybody else that she loves would being negatively affected by that choice.

Cory: She also wants us all to live forever too.

Miles: Yeah.

Cory: She solved that one. She doesn't want the animals in the zoo to eat other animals but she also doesn't want them to start to death.

Miles: This is, I mean there are questions in this world that are a lot harder than physics and many of them come out of the mouths of three to eight-year-olds.

Jocelyn: I'm not on understanding of entropy is really going to help with that kind of question.

Ben: No, entropy means that you're going to die no matter what you do.

Cory: This is the bit, yes, this seems to be the problem.

Ben: Unhelpful.

Cory: If only we had an Enorpty Ray.

[57:14]

Miles: Yeah, an Enorpty Ray actually sounds really awesome I need to find that. But this is for, you know, not speaking directly to your daughter, nor should we get between parenting a child when we are… trying to give you a framework potentially from which to answer the question and the answer is we don't have a clear one.

Cory: Right, so let's go for ice cream!

Ben: You could say something like entropy is something that drives people, as they get old, to get more and more frail and uncomfortable until the point where when somebody is 120 they are pretty much miserable all the time.

Jocelyn: That's not true.

Ben: 130?!

Jocelyn: Well, yeah.

Ben: There's a point at which all of your bones are brittle and your head hurts all the time and you can't remember anybody and all of these, kind of, the trail of all these entropy slugs wandering through your body over the course of your life and there is a nothing for it but I mean death at some point in time becomes kind of a sympathetic release to the horrors of enduring entropy.

Jocelyn: Well, that's a great thing to tell a four-year-old.

Laughter.

Ben: Thank god we don't have to become conscious as our bodies slowly…

Cory: On the plus side after you die we can put you under the pillow and the death fairy will leave us a pound.

Miles: Oh gosh, yeah, Ben, do not say sympathetic release around any of my children even though I only have one of them right now.

Laughter

Jocelyn: I have a thought actually okay so the thing is when we think about this four dimensionally again we think about the the pattern of ourselves going through our lives, does she get really upset that at some point she wasn't born?

Cory: No but she gets really upset that she's no longer able to go to day care when she wants. She loves school but there're days when she would really like to go to day care.

Jocelyn: So the thing is that, the fact that she wasn't in existence and she is in existence and then she, that there's no pattern and then there is a pattern until the pattern changes in death somehow, it sort of no more sensical to get upset about death than you do about someone not being there before they're born.

Cory: Yeah I don't think she's going to find that argument compelling, though I hear what you're saying. I mean I think that there is a certain personaless to, well you know what it is, it's loss aversion, now we're getting into behavioral economics. But you know we value things we've had a lot more than we value things that we've never had, even when there's no good reason to do so, we charge more in behavioral economics experiments to give up things then we would spend to get them.

Ben: Alright, I've got one last guess and it has nothing to do with thermodynamics, about what you can say. It has to do with four dimensional thinking. So imagine all of the atoms that make you up, composing your pattern, as weaving in and out and building your pattern. So that water enters and leaves your body apricots enter and leave your body, the molecules that make up Apricots you know, all of your cells replace themselves within a finite amount of time, seven years or something. And yet this pattern endures so if you think about it four dimensionally this pattern exists and will always exist and it will always have existed as a pattern on this large tapestry as the future weaves itself from different threads.

Cory: That's beautiful, I mean it's like the circle of life in the opening of the Lion King on a micro scale.

Jocelyn: We all will have lived.

Cory: Yeah.