Episode 44: Radiation oncology

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The Titanium Physicists Podcast

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Transcribed by John Robinson

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

[1:48]

Ben: Let's say your city gets attacked. Hedorah. Hedorah attacks your city. Hedorah is a pollution monster by the way. All of the pollution in your city decides that destroying people with asthma is too slow. So instead, the pollution glues itself together in to one big monster and starts smushing people. That right, smushing them like ants. Smushing. So, what are you going to do? You'll probably kill it with guns and bulldozers and chemicals, but that would take too long, and by the time you defeated it, the city would be smushed. So instead, what do you do? You summon Godzilla. Godzilla, if you haven't heard, is radioactive. It's the living embodiment of radioactivity, actually, and he's really good at killing things. REALLY good at killing things. Better at killing things than anything else in the world. So if you summon Godzilla, drag him up from the ocean, he'll deal with Hedorah. If you do everything just right, he won't crash your city on the way in or out. Today, we're going to be talking about this. Well, not specifically. Today, we're going to be talking about how physicists have learned to use radiation to deal with cancer. Chad Jones is the host of the *Collapsed Wavefunction* podcast. It's a show where a bunch of chemists talk about radical chemistry to each other, and also about culture and news. Does it sound like the familiar format? Yes, indeed. The *Collapsed Wavefunction* is one of the newest shows on the Brachiolope Media network, and Chad is a graduate student studying physical chemistry at Brigham Young University. Welcome to the show, Chad.

Chad: Hello!

Ben: So, Chad, for you today, I've assembled two of my finest titanium physicists. Magnificent. Arise, Dr. Ken Clark!

[Wooosh!]

Ben: Dr. Ken Clark did his PhD at Queen's University in Kingston Ontario, and he's currently at the University of Toronto where he studies neutrinos at IceCube. Now rise, Dr. Kiri Nickel!

[Quack!]

Ben: Dr. Kiri did her undergraduate degree with me at UBC. She did her PhD at Leiden University in the Netherlands. She's an expert at radiotherapy, and she's currently a magnificently clever but currently unemployed data scientist. So if you would like to hire a wonderful data scientist, get in touch with me, and I'll get you in touch with Kiri. All right everybody, let's talk about radiotherapy. So Chad, you know anything about radiation therapy?

Chad: I'd know a bit. I don't know like a whole lot. My mother works for a radiation oncologist, and I worked in a radiology lab for a couple of years, but just in the digital image management part of it.

Ben: So, analogously, if you worked in a gold mine, you'd be the person pushing the cart of gold, and not the person appraising its value.

Chad: Yeah, that's basically it.

[4:30]

Ben: Well, let's talk about all those carts of gold. Specifically, let's start talking about how radiation kills stuff, because that's what's really going on, right?

Chad: Right.

Ben: The idea here is that radiation is a better candidate at killing the cells in your tumor than anything else. How does radiation kill tissue, Ken?

Ken: Oh, that's really interesting stuff. So, the radiation that we'll probably be talking most about is gamma radiation. So that's basically high energy photons. So what happens is, these high energy particles, they shoot through your skin and go into the tissue. Once they're in the tissue, because photons interact with charged particles, they deposit a lot of energy that way. The really important part is that they'll deposit a lot of energy and blast apart the DNA in the cells. I mean, there's a few other ways that they can kill things but the main one is that they blast apart the DNA. Then that cell, it obviously can't replicate any more. Once your DNA is done, the cell is toast. It is not functional anymore, so that's in essence how that radiation kills cells.

[5:35]

Chad: Part of my research in my graduate program has been related a bit to cancer. I don't know, everybody's research is related to cancer if you're writing the right grant. Chemotherapy drugs, a lot of them work by crosslinking the DNA, getting them all jumbled up. The analogy that I thought of, is if you imagine you have a group of runners that are about to start a 100m dash. Those chemotherapy drugs are like a ninja that comes around and ties the shoelaces of the runners left shoe to their right shoe. So the runner, which in this analogy is DNA by the way, doesn't notice that anything was wrong until the gun goes off and they start the race. Instead of running, they fall flat on their face. That's like apoptosis. And then you have radiation therapy which instead of the ninja coming out and tying the shoelaces together, it just breaks the runners legs, so it's just ionizing radiation that blasts the DNA.

Ben: Oh, yeah!

Kiri: Maybe this is a good time to note that radiation and chemotherapy often get used together because the effect of the two of them together is more than you would get from just adding the effects of each one.

Chad: But why is that, though? Why isn't it just additive? The effects from chemotherapy plus the effects from radiation?

Kiri: That's probably actually a really profound question that I think people are trying to figure out.

Chad: Yeah, I would have guessed that it would just be additive. The effects from whatever the chemotherapy was plus the effects from whatever the radiation therapy was, but...

Kiri: The good news is that it's not, so...

Chad: Yeah, that is good news. Woo-hoo!

[7:03]

Ben: I was thinking that maybe the best way to start this discussion is, different types of radiation can be used to treat different types of cancer. Depending on what type of cancer it is and where it is in your body. So, Kiri, let's say I'd just gotten lung cancer. I go to the doctor. The doctor says, “Hey, you need radiation therapy.” What happens then?

Kiri: When doctors discover that a patient has a tumor, and they decide to treat it with radiation, the first thing they do is they send you off to have a CT scan [X-ray Computed Tomography], maybe an MRI scan. Then some doctors are going to get together and they're going to look, and they're going to try to decide where they think the cancer cells are, or were they think the tumor is in your body. This is a hard problem because you can't see individual cancer cells. You can only see, like on a CT scan, like 1mm resolutions. So the doctors use their knowledge of what regular anatomy looks like, and then they try to figure out where the tumor is. Then somebody, another technician, will go in and identify other organs. They actually draw contours around organs like your heart, your spinal cord, and your salivary glands. So tissues that are healthy that you don't want to give radiation to. Then you have to come up with a way to give as much radiation as possible to the tumor while minimizing the amount of radiation you give to the healthy tissue. Actually solving this problem is a problem that a computer has to do, and it takes the computer a couple of hours to figure out what the best way is to put the radiation in so that you get the most radiation on the tumor and minimize the radiation to healthy tissue. One trick you can use is you can rotate the source of the radiation around the patient. As the radiation source is rotating around the patient, it gives a little bit of radiation to the healthy tissue, and radiation to the tumor, but then it rotates so now it's giving a little bit of radiation to different healthy tissues but still giving radiation to the tumor. So by rotating the radiation source around the patient, you can give a lot more radiation to the tumor and minimize the dose to the healthy tissue.

Ben: So the deal is, Chad, you can kill a tumor with a shotgun, right? You just have to go up to the person and shoot them through the torso with a shotgun where the tumor is. What’s the problem with that technique?

Chad: Right. Well that's going to kill the person.

Ben: So, radiation poses and a similar problem. You might have a tumor on your lungs or something. It's surrounded with tissue that you don't want to destroy. So one of the interesting things about this particular technique, essentially their cooking the tumor with X-rays. But the trick is to do so in a way that doesn't destroy everything else. The first thing you have to do is kind of figure out where the tumor is. I'd like to think about this as like a fire. Imagine you've got a big mansion, one of the rooms in the library is on fire. The fire department comes and they are like, “Ok, we are going to put out the fire. Hold on, we're going to just smash down this wall and pour all the water in and that will put out the fire. And you say, “No, no. I've got a whole bunch of Faberge eggs behind that wall.” So one of the first things the fire department does is it likes, “Oh, fine. I guess we have to be careful about this. We are still going to pump water from our pumpey truck into the fire. How are we going to do it?” You take out a map of your mansion and you say, OK. You point it out on the map, this is the room where all the fire is. And they say, “OK I guess we have to shoot water at it.” And you say, “No, no, no. I've got very nice carpeting in this room and this room and this room.” So what they do is they say, “OK. We can shoot some water through this window, some water through this window, some water through this window. That way the carpets in those regions won’t get too wet but we’ll end up still pouring the same amount of water onto the fire.” Then you say “OK.” So these doctors, they take a three dimensional scan of your body, right? So a CT scan, that's like an X-ray. It's a three dimensional X-ray where they are rotating the beam of X-rays through you, and the computer is compiling all of them and figuring out where all your guts are, and your bones, and you liver and kidneys and stuff. Or they put you in an MRI machine which does...

[10:55]

Kiri: Maybe I can add that when you are in an MRI or when you get a CT image made of your body, the doctors, they have to figure out where all the organs are, they have to figure out where the tumor is. That's actually the hardest part of the problem because, to go to your analogy with the room on fire. Maybe you say the libraries on fire but maybe the bathroom next to it is on fire. Maybe the bedroom downstairs from the library's on fire as well, but you don't know that. The problem is with imaging, you can't tell where cancer cells are. You only can only see where the tumor is. So you have a pretty good idea what you need to give radiation to, but they still could be other cells rambling around which are cancer, which you don't know where they are, so you can't decide to give radiation to them.

Chad: So is that why you would want chemotherapy as well, to help with that? Because chemotherapy, you are targeting everywhere.

Kiri: That's right.

Chad: So, I know that... people that I've seen that have had radiation therapy, a lot of them have tattoos for targeting, right?

Kiri: When you go to get radiation therapy, they have to be able to line your body up with the beam of radiation. So if you have little marks on the outside of your body, it makes it easier for them to get you approximately in the right position relative to the source of radiation. And then what happens is a lot of hospitals is that they'll make a CT scan of your body, and they figure out where your bones are. And then they can move the table that the patient is lying on so that the position of the patient’s bones during treatment better matches the position of the patient’s bones on the planning CT. So you can use the patient’s skeleton as a proxy for the position of the tumor.

Chad: So, those tattoos aren't necessarily marking where the tumor is, it's marking so they can get back to the same position as the planning CT?

Kiri: Yeah, that's right.

Chad: Oh, OK.

Kiri: I mean, actually that's one of the bigger problems, too, is that if you have a tumor close to your bladder or close to your rectum or in your lung, then that tumor moves around a lot. So, the position of the tumor when the radiation dose it planned is actually probably going to be different during the treatment. So you have to have a bit of margin, you have to make the radiation dose strike some of the healthy tissue in order to be sure that you're going to be getting radiation to the tumor.

Chad: So we have this radiation beam. What’s like the diameter of the beam?

Kiri: It depends actually on the size of the tumor. The smallest tumor you can really see on a CT scan would be like 2 or 3mm, and you can actually control the shape and the size of the beam. You can set it to be just a little bit larger than the tumor.

Chad: So when you said control the shape, I just imagine it shooting a star shaped beam… I know you probably meaning like more of an ellipse, but I'm picturing a star.

Kiri: As the machine that delivers the radiation is rotating around you, they can actually change the shape of the radiation beam as the machine is moving. You don't really ever have a perfectly round tumors, so as the machine rotates, you can change the shape of the beam to match the outline of the tumor in profile in that direction.

Chad: How much of that is done in real time, and how much of that is just based off of plan. You get into the machine and this is the program we were going to run or is there a technician that's changing the beam profile in a real time?

[14:17]

Kiri: OK, this is a problem that a computer has to solve. It takes about hours for the computer to figure out what the most optimal solution is for putting radiation into the patient. The computer controls the rotational position of the machine as its rotating around the patient. It controls the shape of the beam, so when the radiation beam is emitted you can change the shape of it by covering up parts of it. All that is done by the computer prior to the patient coming in for treatment.

Ben: It's kind of like, you know, if you have a flashlight and you wanted to make the shadow of a bunny on the wall? You would cover up part of the beam with your hand I guess. Your hand would absorb that radiation and the rest would hit the wall?

Chad: Yeah.

Ben: They’re cool. Well, they’re computer controlled but essentially they're leaves of, what are they, lead?

Kiri: I think.

Ben: They just block off the beam, and they're dynamic, so the computer moves these lead leaves in and out to block off parts of the beams essentially to make a shadow so that the... Coming out of the machine is like your regular ellipse or circle or whatever shape. Then it goes through this kind of beam shaping device that makes essentially a big shadow so that it can block off the part that would otherwise hit your spleen.

Chad: So I joked about making a star shape, but you're saying if you happen to have a star shaped tumor that would be possible?

Kiri: Yeah, you could actually. The beam shaper, it looks like a bunch of fingers and you put one hand up in front of you and the other hand upside down on top of that. You can kind of slide your fingers up and down relative to each other and you can make different shapes just by moving your fingers in and out. Yeah, I think it's even called the finger.

Ben: I want to paint a little picture of what this device looks like. You've been in a CT scan machine, or an MRI machine. The doctor now has a three dimensional map of what your guts look like, and where the tumor is. You get brought in and you get laid down on a bench. They can move the bench back and forth up and down a little bit to position you a little bit. Then the device itself that emits the radiation is kind of like a c-clamp sort of shape, right? It's shaped like a C and then it rotates around your body and so it will rotate around your body axially. It will shoot the shaped beam of X-ray through your body from all angles as it rotates around your body so that it's not cooking your spinal cord. It's not cooking your heart, but every chance it gets its shooting a beam through so that the place where all these beams will overlap, the center of where it’s rotating, your tumor, will get the large goes of radiation. The rest of the things only get lightly burnt.

Kiri: That's the idea.

Chad: Ok.

Ben: So this machine is called a radiation therapy machine. A nice therapeutic subtitle for what it is.

Chad: So what’s making the X-rays? What is the material that’s sending out these X-rays?

[17:25]

Ken: That's actually pretty cool, too. What it is, it's an accelerator, so essentially what you do is you take electrons and accelerate them so they’re going really fast. Then you smash them into a target. So you get this thing, the name is called Bremsstrahlung. What really happens is as electrons interact with the nuclei and stuff in the target, they slow down. Because they slow down, that energy has to be conserved, they produce these X-rays. So they use this Bremsstrahlung to create all of these X-rays. Bremsstrahlung is interesting in that it has a unique signature in terms of its energy spectrum. You get a fairly well defined energy spectrum for the X-rays that come out, which is one of the reasons why they use it.

Chad: And by well defined energy spectrum, you mean in that it's not like broadband X-rays. It's narrow?

Ken: Yes. Comparably narrow. You get X-rays focused at certain energies, basically. Because you can do that, I assume it makes it easier to determine the dose and what you should do with these X-rays. So that's one of the reasons why it would be used for radiation therapy.

Chad: So it's hitting the target. What the target made of? What material?

Ken: I think the target can vary. It will be a metal of some kind, so you get a metal that's not dense enough that it interferes with the X-rays leaving, but it has a lot of heavy nuclei and free electrons so that the accelerated electrons can react with it.

Chad: And how fast are these electronics going? Because you said fast, but now I'm curious as to what that means.

Ken: Yeah, that's a good question. How fast are these electrons?

Ben: Are they look it up on Wikipedia fast? Or just look it up in your head fast?

Ken: No. If you want an actual number, for the speed, it's probably look it up in Wikipedia fast. Because normally you would give their kind of energy in terms of GeV [gigaelectronvolt] or something like that. That's not a number that's really very useful. So to convert that to actual velocity... fast?

Ben: Let's stick with fast.

Chad: Back to the question. I'm thinking about how the X-rays are made. It seems to me just like the opposite of the photoelectric effect. Because you have photons of a given energy coming in for the photoelectric effect, and then electrons coming in and photons coming out.

Ben: Ok. So in the photoelectric effect, a photon comes in and one atom grabs it. Ok? And then, as that atom grabs, an electron takes all that energy and says, "I'm moving out." It jumps on the electron, OK? That's a little bit different than Bremsstrahlung. It's German for breaking radiation as in breaks up the car and not smashing. So Bremsstrahlung, what happens is if you have a charged particle moving really fast through a medium of water or a desk or a big piece of metal, what happens is as it's moving, it's a charged particle, it's surrounded with other things that are charged, other electrons and protons. They don't token to the fact that this electron is moving so fast among them. They kind of grab their little hooks into it. And so it kind of an overall effect, it comes from the bulk, this compendium, this large group of atoms instead of just interacting with one single one. So the net effect is, as the electron passes through, it will generate a whole bunch of electromagnetic waves in the direction that it was moving. In essence, all of its kinetic energy gets turned by the fact that it's surrounded by other charged particles in these atoms into photons. So all of its kinetic energy goes into electromagnetic waves and it slows down, it breaks.

Ken: Yeah, that's right. The photoelectric effect is a nuclear effect. It just involves the atoms themselves and the energy levels of electrons. Whereas Bremsstrahlung, it really is exactly what Ben said. Because you're decelerating these electrons that are moving really rapidly, you have to produce some kind of energy, and you produce it in these waves of high energy photons. It's like running on a beach, and are trying to run very quickly. So let's say you're on pavement and you hit the beach. When you hit the beach, you're going to start spraying sand everywhere. You're giving off this energy into the sand. It's a lot harder to move through the sand than through the pavement or something.

Ben: Hey, Kiri. Do you want to say anything about what types of cancers you use this on?

Kiri: So, when you are treating somebody with cancer, you have a couple of different choices for treatment. You can give them chemotherapy. You can do surgery to remove the tumor, or you can give them radiation. Often a combination of two or more of these methods are used. In cases where is it possible to physically remove the tumor for breast cancer, when the patient is healthy enough to be able to recover from surgery, then surgery is a first choice. Then the doctors will go along and give some chemotherapy and radiation therapy to catch any cancers cells they may have missed when they removed the tumor physically. In some cases, when the patient is too old to recover from surgery or when the tumor is in a place where you can't really just go in and chop out the tumor, then radiation and chemotherapy are better choices.

[22:52]

Ben: OK. Let's start talking about brachytherapy. So the deal is there's other types of radio therapy that we can give to somebody with cancer. Not just cook their insights selectively with the X-rays.

Kiri: So another way to kill tumor cells with radiation is to use a radioactive source that you actually just put inside the patient and leave it there. This is done for breast cancer and for prostate cancer. You get a little radioactive seed, so it’s only like a few millimeters big, then you just poke it inside the patient and that little particle will emit radiation for like a centimeter or a centimeter and a half around the particle. That will kill the cells that are close to that radioactive seed, but the radiation will be completely weakened by the time you get to a centimeter or a centimeter and a half away from that seed. So then you don't do harm to the tissue outside of that little area around the seed.

Ben: Its equivalent to what we were talking about, spraying through the windows with hoses. Its equivalent to going in to the house that burning and throwing water balloons where the fire is. So you're not damaging anything past the splash radius which is fairly small of the water balloons. Anything you're killing is already on fire.

Ken: Do you know any fireman?

Ben: No? [laughter]. Do you?

Ken: Yes! I don't think that's how they fight fires.

Ben: Fight fire with water balloons.

Chad: I mean, my son would probably fight fire with a water balloon.

Ben: Maybe a ceiling sprinklers is a better metaphor, but whatever.

Kiri: I was going to add that when you're treating somebody with cancer, you want them to survive. But at the same time, you want to kill the cancer cells so they survive, but you want to make sure that they have a decent quality of life for a long time after you treat them. You want to make sure that you don't go around exploding water balloons in places, go around giving radiation to places where there's no cancer because people will up with burns and they'll have problems going to the bathroom and have problems swallowing. That really spoils your life. So you want to make sure you kill the tumor, but you don't want to damage peoples healthy cells so badly that their life becomes really unpleasant after their treatment.

[25:09]

Chad: Now that you bring that up, I know people that have gone through chemotherapy, so I know personally the effects that that has on people. How does radiation therapy compare as far as, the medical term is morbidity?

Kiri: That's actually a good question. I'm not super sure I can give a great answer to, but I can give an OK answer. So chemo destroys the ability of cells to reproduce themselves, but if they can recover from that, they can go on, they're not as affected. With radiation therapy, you're actually damaging the DNA. Effectively you're burning somebody. When you get a sunburn, that's a kind of radiation burn. You can give a person a burn that cells can't really recover from. It would be like an eternal burn on the inside. Also, because you're damaging the DNA, you are ruining the ability of the cell to repair itself. You are actually increasing the chance that a couple of years down the road, that a person can develop a cancer that's related to the radiation that you are giving them to try to kill their previous cancer. You run that risk as well.

Ben: So there are other types of radiation that we can use to cure cancer. One of the funnest ones is proton therapy, right Ken?

Ken: Absolutely, yes. Proton therapy is great. Photon therapy is really cool because you get to use all these accelerators that really important physicists get to play with. One of the advantages, so instead of using gamma rays, you can use protons instead. You can accelerate them and should them into where the cancer is, which can only be in certain places, which maybe I'll come back to later. One of the advantages is as protons travels through matter, they start to deposit energy. As they slow down, the cross section increases so as they slow down, they get more and more likely to deposit their energy. So what ends up happening, it if you think of them depositing, they will go for a while, depositing a little bit of energy, and all of a sudden just deposit all of the energy all at once, because their cross section has become so large. So you can use this to really target tumors, the problem being is that if you want to use protons, it has to be a place that is very constant density all around so you can really calculate where the energy is going to be deposited. So one of the big uses that they have for these things is in cancer in your on eye. They can use this proton therapy to actually target the depth at which they want all this energy to be deposited. So it's kind of like what Kiri was explaining earlier, where instead of just cooking all of the tissue on the way in so you have to move your X-ray gun all around, you can just shoot these photons in and know they will deposit almost all that energy within a very short distance of where you want the tumor to be. So it ends up being a really cool way to get at the tumor.

Chad: So I guess my question on this would be is the difficulty in targeting. So if you are talking about an eye, I'm just imagining somebody lying on a table. Is that how the patient is in these?

Kiri: I think they're actually sitting up. To make the protons you need a particle accelerator. So the protons are traveling parallel to the surface of the earth, so that means you have to be sitting up, and then you basically look at the beam, and then the beam comes into your eye and dumps the energy.

Chad: Oh, OK. For proton therapy, what's the proton source and how is that made?

Ken: This I think is one of the issues with proton therapy. You essentially need one of the big accelerators. It needs to be done at a location, mostly universities, where we were talking earlier. TRIUMF in Vancouver does it, and I know [Falck Cancer Center?] does proton therapy and those kind of things. So it's just… essentially you have the giant ring where you separate the protons and use these electromagnetic fields to accelerate them really quickly. Then you just divert them into the eye, I guess, eventually. So it's not something that can be done anywhere. You need a lot of equipment to be able to pull this off.

Kiri: You need a particle accelerator.

Ken: Yeah.

Ben: And not like the chintzy ones in radiation therapy machines.

Ken: Well, those are cool in their own right.

Ben: They are cool, but they are not, you know, great big, melt something, particle accelerators.

Ken: No. Here you'll need, storage ring and proton, you need a lot of equipment to be able to do this sort of thing.

Chad: So obviously we're not talking about an accelerator the size of CERN [*Conseil Européen pour la Recherche Nucléaire, or the* European Organization for Nuclear Research], but how large of an accelerator are we talking about for proton therapy?

Ken: In terms of actual size?

Chad: In terms of the size of the area it would be in.

Ken: You wouldn't need one the size of CERN, but you're talking like building size at least.

Kiri: Like a hockey arena.

Ken: Yeah.

Chad: I mean, that's still really impressive to me.

Ken: Oh, it's very cool, it's neat stuff.

Kiri: And I just say that even though it it's pretty amazing that you can kill cancer cells with radiation, because the side effects are so shitty, it's best to not get cancer in the first place. The dream is in 50 years, we won't have to give radiation to anybody to treat cancer because there will be biological tools, genetic tools that we can use to kill cancers on a cellular level rather than just having to carpet bomb all the tissue using radiation.

[30:17]

Ben: Well, that was fascinating. Thank you, Ken! Thank you, Kiri! You've pleased me. Your efforts have borne fruit, and that fruit is sweet. Here is some fruit. Ken, you get a Dragon fruit, the most Godzilla of all the fruits.

Ken: [Munch munch]

Ben: Kiri, you get a Lychee.

Kiri: Oh, Yumm!

Ben: I'd like to think my guest Chad Jones from the *Collapsed Wavefunction* podcast.

Chad: Yes! That's it.

Ben: Thank you chad! Wonderful, wonderful!

Ben: Hey, everybody! Hey, Ti-Phi-ters. I love the show, and I hope you do, too. But for every listener to the show, I know there are 100 other people who would love to listen but they don't know how. I wanted to spread the word. There are three ways you can do this. The first is through iTunes. Please, please leave us an iTunes review. Not only do I like reading about what you have to say about all the hard work that we do, I also know that the more reviews we get the higher on the ranks we go, so please, to increase our rake, give us an iTunes review . The second is to teach people how to listen to a podcast. Everybody has a smart phone or tablet these days. There are a variety of ways you can make the listen to us very easily. There's the **Stitcher** app. Download the **Stitcher** app, look for our show, really easy. Another way is the **Podiversity** app, lots of fun! Download the **Podiversity** app. It has the *Titanium Physicist*, and we get a cut from every time somebody listens to our episode. Last way is to tell people a lot about us. The internet's full of people trying to explain physics to each other. Just get in there and tell everybody about our show. Well that's it for the main part of our show. Remember, if you like listening to scientists talk about science in their own words, you might like other shows on the Brachiolope Media Network, Like *Astrarium* about astronomy, or *Science, Sort of* about science, sort of… Or *technically speaking* about engineering, or the *Collapsed Wavefunction* about chemistry, yeah! Editing for the *Titanium Physicist* podcast is provided by a gentleman named John Heath. Thanks, John! The intro to our show is by Ted Leo and the Pharmacist, and the end song is by John Vanderslice. Until next time my friends, have a good day, and remember to keep science in your hearts.