Big Picture Podcast – Episode 09

Nuclear Fission and Fusion, Chapter 5C

John: Welcome to the Big Picture podcast. We're going to start digging into the latter half of the nuclear chapter with a focus on nuclear fission and fusion, which sound a lot alike but are not the same thing.

Tracy: Okay. Where do you wanna begin?

John: Well, let's start with the definition. What is nuclear fission?

Tracy: Fission is usually when you break things apart.

John: Yeah. And the term was borrowed from biology rather than calling it cellular fission. They called this nuclear fission. And so that's the division of the atomic nucleus.

Tracy: So the splitting of atomic nuclear.

John: Yeah, splitting the atom. Now, here's an important distinction. We've been talking about radioactivity that's like a nucleus losing an electron or losing an alpha particle. The atom is not splitting in half. When we talk about nuclear fission, we're talking about the nucleus actually splitting in two large fragments like it's splitting in half. That's the distinction between nuclear fission. In plain old nuclear radioactivity.

Tracy: Sounds good.

John: What are you doing?

Tracy: Oh.

John: Here are the main points. Not every nucleus is susceptible to fission. In fact, there are only like 3 isotopes that are susceptible to nuclear fission. They are uranium 235, plutonium 239 and uranium 233. It works like this. You might think of a large nucleus hard as a bowling ball. It's not a better analogy is to think of it like a big ball of taffy. And what can happen is if you shoot a neutron, just a neutral neutron toward that nucleus, like a big ball of taffy, bruv, it elongates, right? What was once a beautiful sphere turns into this oblong thing. Now, can you think of any issues that might arise when suddenly you're stretching out an atomic nucleus?

Tracy: The distance is going to affect the strong nuclear force.

John: Ha! So if you're protons on opposite sides of that elongation, think about what that elongation does to the attraction you have for each other.

Tracy: That's going to decrease the attraction than the electric force is going to have a greater influence on it.

John: Yeah, the electric force is going to suddenly win out. Remember, it's a battle between the electric force of repulsion and the strong nuclear force of attraction. And so if you have a nucleus that's able to bend out like a ball of taffy when hit by a neutron, you're going to find. What happens is it splits apart. And why is it split apart? It splits apart because of the electrical force of repulsion. It splits apart because the nucleus has elongated in the strong nuclear force from nuclear runs on the opposite sides weakens quickly because, you know, distance is key when it comes to the strong nuclear force. And then you have two positively charged nuclei next to each other and they themselves scram away from each other as fast as possible. It turns out when it divides like that, it's not typically a clean division. Like half of it goes here and half of it goes there. There are neutrons that are scattered and alpha particles that are scattered, beta particles that are scattered about. I did mention neutrons, didn't I?

Tracy: I was in the new trend that was splitting it apart.

John: One neutron goes in, splits it apart, and because it's not a clean division, you can have like three neutrons come out. So one neutron goes in, three neutrons go out. And guess what those three neutrons coming out can then do.

Tracy: Well, then they they turn into protons.

John: They would, but if

Tracy: Oh,

John: It's quick enough.

Tracy: They can hit other uranium nuclei.

John: Yeah. And so one neutron goes in, splits a uranium nucleus and outcome three additional neutrons. Any one of those neutrons can hit another uranium, which would generate three more. So one begets three, which begets nine. That's

Tracy: It's a chain reaction.

John: A chain reaction

John: Which gets twenty seven, which begets whatever. Yeah. We call that a chain reaction. Here's the key. We're assuming you've got 100 percent uranium, 235 in nature. There's not much uranium, 235 at all. Mostly in nature, which you've got is it's milder cousin uranium to thirty eight. It's like out of every 140 uranium atoms. Only one of them is uranium 235. Uranium 238 is not seasonable. It has a balance of protons to neutrons that make it more stable than the uranium 235. So we don't have much uranium 235 out there. It's mostly uranium 238. So how are you going to build a nuclear bomb?

Tracy: Oh, is that what is meant by enriching uranium?

John: Yes,

Tracy: They have plants

John: Chance to

Tracy: To

John: Enrich

Tracy: Enrich

John: The.

Tracy: The uranium from now from 238 to 235. Yeah.

John: Yeah. What you need to do is enrich the uranium 235. That is, make it more concentrated. And here's the big problem. How are you going to separate uranium 235 from uranium to thirty eight? They're both uranium. They're the same thing. You're trying to separate the same thing from the same thing in chemistry when we try to isolate something. We take advantage of the differences in physical or chemical properties between the two substances. Now, the uranium, 235 and 238, they have the same chemical properties because they're both uranium. The only way they are different is that the uranium 235 is a little bit lighter, but not by much.

Tracy: And so you really have to find one out of every 140 uranium atoms.

John: Yeah.

Tracy: Wow.

John: And you react the uranium with fluorine and you make a uranium hexafluoride, which is a gas. So you essentially gasify it and then you put it in these big centrifuges and you spin it, you spin the gas round and round. And what happens is the heavier uranium 238 goes to the outside and the uranium 235 stays in the inside. And then you blow that concentrated uranium 235 into another chamber and you do the whole thing again and then you blow into yet another chamber and another and another another chamber. And each time you do that, you get less and less material. You see, which makes sense because there's not much of the uranium 235 in there to begin with. But you do that through a series of centrifuges. So maybe you'll hear about that in the news. Maybe like with a ran in there trying to concentrate uranium, 235 nuclear regulatory powers on this planet are wanting to prevent them from doing that. That means minimizing the number of centrifuges they have on hand, because the more centrifuges you have, the more uranium 235 you can generate. But you don't need to get to 100 percent in order to have a bomb grade material. You can do it with much lower percentages.

Tracy: And I just wonder if we are now on the radar for national security.

John: How to make the bomb is well known. It's the technical hurdles, the engineering that thankfully is the major obstacle. Let's forget all this talk about bombs. OK. If you have uranium enrich just to 3 percent. Turns out you're going to have some chain reactions going on within that lump of 3 percent uranium 235. What you can do is if you have a lump of uranium, that's 3 percent. You know, it's not going to blow up like a nuclear bomb. It's just not concentrated enough. But there's enough chain reaction going on in there that it's hot, quite hot. You don't want to hold in your hand. So what you do is you drop it into a bucket of water. Normally, when you throw like a hot rock into water, the rock just cools down quickly and the water heats up. Makes sense to take a lump of uranium that's enriched in just 3 percent, uranium 235. You throw that into the water. It's going to heat up the water. But the lump of uranium never cools down.

Tracy: Well.

John: It stays hot. And the reason it stays hot is because there's nuclear fission reactions going on within that 3 percent uranium 235.

Tracy: Ok. But after a thousand years or so.

John: No. After three years.

Tracy: Ok. Plus

John: Three

Tracy: Years.

John: Years? Yeah. What's that? What happens there is after a year, you're not at 3 percent uranium 235. You're at 2 percent uranium 235. And then you get a 1 percent uranium 235. And you know what? It just doesn't hit the water quite as nicely.

Tracy: Ok. So then you really want to get new you.

John: You know, you

Tracy: They're

John: Want

Tracy: Called

John: To.

Tracy: Rods,

John: You want

Tracy: Aren't

John: To freshen

Tracy: They?

John: Up.

Tracy: Yeah.

John: Yeah. So in a nuclear power plant. That's how it works. We just described how a nuclear power plant works. You throw a lump of uranium 235 3

Tracy: Or

John: Percent.

Tracy: Rod. Right. The column

John: Iran.

Tracy: Writes,

John: Yeah, they have

Tracy: Right.

John: Rods. You can look all that up. But the main idea is that you're exposing three percent uranium, 235 to water and it heats up the water. The water turns into steam. The steam rises and turns a turbine, which generates electricity. A nuclear power plant in a coal fired power plant. Operate by the same principle of getting water to boil, to turn into steam, which turns a turbine, which generates electricity that we use to turn on our lights.

Tracy: Because it's moving magnets across each other.

John: Yeah,

Tracy: Yeah.

John: Me. Excellent. Now, the difference is the source of energy for coal fired power plant, which by the way, is emitting lots of radioactive particles that are inherently within the coal into our atmosphere, the source of energy is the burning of the coal. The combustion of the coal, which, by the way, generates a lot of carbon dioxide, which is not helpful to the climate.

Tracy: Ok. But we know that there is still an issue with nuclear power reactors.

John: Ok. Let's go into where that issue is. So.

Tracy: What do you do with those rods when they're not heating up the water the way

John: Yeah.

Tracy: You want them to?

John: So it's

Tracy: Now

John: It's

Tracy: What do

John: Got

Tracy: You do?

John: To 1

Tracy: One.

John: Percent, you know, and it just doesn't eat up the water as efficiently. What you need to do is you get a shut down the entire plant. Pull out those 1 percent rods and put them somewhere.

Tracy: For a long, long,

John: And

Tracy: Long

John: And who's who's

Tracy: Time

John: Back? Who's backyard?

Tracy: Back.

John: You know, it's not just the uranium. Remember, the uranium has a very long Half-Life, so it's not that dangerous. But when you split here, this is this is really cool. Get this, when you split a uranium nucleus. Right. You're making two smaller nuclei. We call them daughter. nuclei. Now, what do you know about heavy nuclei?

Tracy: They're not so stable.

John: They need a lot of neutrons, don't they? Because they're so unstable. You need a lot of neutrons. Right. But smaller nuclei don't need those extra neutrons. So get this, when you split a uranium atom into a smaller nucleus, it has all these extra neutrons in the nucleus is going, but I don't need all these extra neutrons because I don't have that many protons anymore. What you end up with is a daughter isotope that's really radioactive. And that is not a problem.

Tracy: What?

John: It's not a problem. I have to do is put in the back of the plant and within a week it's no longer there. Yeah. Put it in a pool of water, put in as a cement and maybe in some glass and it's no longer there. It's not a problem. What is a problem is that there are daughter. isotopes that have half lives on the order of 10000 years. That's not good because it's not going to just bubble bloom real quickly in front of you, but it's going to still be very radioactive. Ten thousand years is much more radioactive than four billion. Half-Life of 10000 years is much more radioactive than a half life of four billion years. So what are you going to do with this material for 10000 years and beyond 10000 years? Because after 10000 years, you just have you have half of what you had. You got another 10000 years that it's a fourth of what she had another. So we're to a hundred thousand years. Then you're okay. Where are you going to put this stuff for a hundred thousand years?

Tracy: There is nowhere that you can safely put such a highly radioactive materials anywhere.

John: It's a problem the students will ask, well, why did you send it? Send it up into outer space?

Tracy: That's sort of interesting.

John: Yeah, well, just don't

Tracy: Let's

John: Send it up to

Tracy: Send

John: Outer

Tracy: It

John: Space.

Tracy: Back to where it came from.

John: No, it came from. Yeah. Originally way, way, way, way back when the two problems of that one, we hope the there's no accident as the rocket is going up into outer space and to the sheer number of tons of this stuff, we now have millions and millions of tons of this. You can't get all that into outer space with present day technology. It's

Tracy: So

John: Not practical

Tracy: Now

John: Or

Tracy: We're just

John: Just

Tracy: Really

John: Really stuck

Tracy: Stuck

John: With

Tracy: With this

John: This.

Tracy: On

John: Yeah.

Tracy: Our earth

John: Yeah.

Tracy: Affecting

John: Yeah.

Tracy: All living

John: Living

Tracy: Organisms.

John: Organisms. We want it contained. Right.

Tracy: There is no safe place to contain it.

John: Safety

Tracy: There is no

John: Is a relative

Tracy: Way.

John: Thing now, isn't it? We talk about the risk factors. The risk benefit ratio and all that. And these are important questions for us to consider. Is it worth going forward with this nuclear fuel

Tracy: No.

John: When it emit when it emits zero carbon dioxide? How are we going to supply energy to modern civilization?

Tracy: There

John: There

Tracy: Are

John: Are plenty

Tracy: Plenty

John: Of

Tracy: Of

John: Ways.

Tracy: Ways.

John: There are plenty of ways. We've got to work on those. But what are we going to be doing in the next five, 10, 15 years, 20 years out? It takes time for those technologies to get on board. Yet we're growing so fast.

Tracy: We could do it.

John: All right.

Tracy: Yeah,

John: I'm I'm.

Tracy: I'm

John: I'm for

Tracy: For

John: It.

Tracy: It.

John: I'm for it.

Tracy: It can be done. I think this is just yeah, I mean, I'm sure I have no doubt that we could take care of our

John: And

Tracy: Energy

John: Energy

Tracy: Needs

John: Needs

Tracy: In

John: In

Tracy: Other

John: Other

Tracy: Ways

John: Ways and

Tracy: And not

John: Not

Tracy: Be

John: Be

Tracy: Stuck

John: Stuck with

Tracy: With

John: This.

Tracy: This tons and tons of toxic material. I have a question I wonder. I wonder if at some point maybe someday this material, somebody will actually figure out a use for it.

John: Oh, absolutely. Are you ready? A lot of that material contains uranium 238 member, it's only 3 percent, uranium 235. It's got a lot of uranium 238 still in it. So when you're storing it away at Yucca Mountain or some somebody else's backyard, it's really radioactive. That's true. But it's also got a lot of uranium 238. And you can take uranium 238 and transform it into plutonium 239. You can use that as more nuclear fuel for plutonium based power plants. Nuclear power plants, because guess what we're running out of?

Tracy: You can't say uranium.

John: Uranium, you know, North America's already depleted its primary aluminum ores in the United States now gets it primarily from Australia. At this point, I mean, we are impacting the planet. We're running out of high quality uranium ore. We've mined it all. Yeah. And so now we have all that uranium sitting in these containers next to the power plant. So what about that? You could take the uranium 238 and transmute it to plutonium 239.

Tracy: And then that would also heat up water and act

John: Yeah.

Tracy: As acted in reactor.

John: Yeah. You can make a plutonium based power plant just as you can make a uranium based power plant. And in France, interestingly enough, about 70 percent of their electricity comes from nuclear power plants. And they have a type of power plant called a breeder nuclear power plant where you put in the uranium and you use that as a fuel. But then it transforms into plutonium 239, which you use again as a fuel. So it's like a fuel begetting a fuel issue with those types of breeder reactors is that it's fairly easy to develop nuclear bombs from them. And so for security reasons, we've focused primarily on the uranium 235 nuclear reactors. You know where I'm going next, don't you? We can sidestep all of this by forgetting about plutonium 239 and uranium 235 and instead focusing on that third isotope that can undergo fission, which is wait for it. Uranium 233. You're giving you a to look. Uranium 233,

Tracy: As

John: As everyone

Tracy: Everyone

John: Knows,

Tracy: Knows,

John: Is

Tracy: Is created

John: Created from

Tracy: From.

John: Thorium late. I overslept. Thorium,

Tracy: Forreal.

John: Thorium tonight. Talk about thorium earlier. Yeah,

Tracy: Yeah,

John: We

Tracy: We

John: Were

Tracy: Were even

John: Talking,

Tracy: Talking

John: But

Tracy: About thorium reactors.

John: We're here. We're here. We're finally here. Thorium reactors, there's four times as much thorium on this planet than there is uranium. Thorium is abundant. Now, what you do is you take thorium to 32 to a neutron and it transmutes into thorium 233, which beated decays into.

Tracy: Uranium 233

John: Uranium

Tracy: Hearing.

John: 233. That's it. And uranium 233 is that third isotope that can undergo nuclear fission without going too much into the technology here. You can create a reactor that uses uranium 233 instead and it operates at much lower temperatures. You can have a much smaller nuclear reactor in the byproducts of the reactor itself, have half lives that are no longer than cesium 137, which requires only like decades for safe storage because its half life is much, much shorter than the products of, say, uranium and plutonium reactors.

Tracy: Ok, so with a shorter half life, it's going to be more radioactive, so a little bit more dangerous.

John: But it doesn't hanging around as long. The half life for the byproducts of the thorium reactors. You just need to store it for like decades as opposed to millennia. And that issue is, though, is that during the transmutation, you also generate thallium to 0 8 isotope, which emits gamma rays really well. And they tried to make a nuclear bomb out of the 233. But there is all this thallium to 0 8 and it's a gamma emitter and it simply fried the electronics, just made the nuclear bomb. Testi it didn't work very well. And because you couldn't make a good nuclear bomb out of the uranium 233 coming from the thorium. So they stopped the research.

Tracy: Really?

John: Yeah, that's my understanding, but it's coming back slowly but surely.

Tracy: Where's it coming back?

John: There are few private companies in the United States. You get China, you get the UK, you get India are sponsoring research into the thorium reactors.

Tracy: And so the the volume

John: Thallium 2

Tracy: To

John: 0

Tracy: Eat

John: 8.

Tracy: The thallium to A is that also very radioactive and dangerous.

John: It's dangerous. Yeah, because it's a gamma ray emitter. And as it's produced within the reactor. What you do is nothing. You just leave it in there in the energy it's producing helps to generate the energy.

Tracy: And does it can it fry the reactor?

John: No,

Tracy: No.

John: You just do not going to have to have circuitry that the reactor operates in the liquid phase at only about three 400 degrees as opposed to hundreds and hundreds of degrees. And it's a liquid. And because it's a liquid, the fluid itself, the reacting fluid itself can be the source of heat, of heating up the water to create steam as a liquid and not getting super hot. You just don't you're just not going to have large explosions. And guess what? As it gets hotter, it shuts itself down, kind of like you're on a sailboat and you let go of the sail, the boom. Then he sailors out there, the sailboat immediately goes up wind and slows down. Just like go of everything that's called a passive safety mechanism. And so if it gets too hot inside the nuclear reactor, what happens is the thorium stops producing 2:33. The thorium starts producing other isotopes of uranium that don't undergo fission, which means

Tracy: That

John: Itch.

Tracy: Stops,

John: It

Tracy: Stops.

John: Stops. If it gets too hot, it stops. Another thing you can do is put a plug underneath this, this big hot liquid. And if it gets too hot, the plug melts and outports the liquid into a container to cool back down. You can build these on small scales or bunch of them lined up on larger scales. They don't produce carbon dioxide. You're able to remove the products from it while it's running. You don't have to shut the whole plant down in order to clean it up. You can remove the byproducts by distillation or electrolysis during the operation of the plant. That's the thing about like a uranium plant. You got to shut it down for a fair amount of time in order to remove those 1 percent rods. So there are all sorts of technical advantages to using an economical advantages to using thorium as your basic fuel for the thorium based reactor.

Tracy: Yes. All

John: All I'm

Tracy: I'm

John: Saying

Tracy: Saying.

John: Is check

Tracy: Check it

John: It out.

Tracy: Out.

John: Do a web search on thorium reactors. The L.F. TR the liquid fluoride thorium reactor and you're going to get a lot of very interesting information

Tracy: Okay.

John: There.

Tracy: Yes.

John: We're about to jump into. Equals m._c squared energy and mass are the same thing. Like one mouth that can either smile or frown.

Tracy: So when you say equal, you mean the same thing.

John: And that's what we mean by equal. It's a relationship and this equals that. This is the same is that E equals M.C. Squared is telling us energy is the same as mass times, speed of light squared. The two can inter convert.

Tracy: That is very cool. Let's talk about this.

John: That was the Einstein thing. We're gonna do a little mind exercise here in my left hand. I've got a 1 kg magnet and in my right hand I've got another one kilogram magnet. See that? Mm hmm. All right. What's the total mass out

Tracy: In both

John: Of all of

Tracy: Ends,

John: Them?

Tracy: You

John: You have

Tracy: Have

John: To

Tracy: Two kilograms,

John: Kill to kill. Two

Tracy: Two

John: Point

Tracy: Point

John: Zero

Tracy: Zero

John: Killian's

Tracy: Two

John: Point

Tracy: Point

John: Zero

Tracy: Zero

John: Three kilograms.

Tracy: Kilograms.

John: Now, now, if I bring them together, are they just going to come together like two Styrofoam blocks or because they're magnets might be a little different as

Tracy: As

John: They

Tracy: They

John: Get

Tracy: Get

John: Closer,

Tracy: Closer,

John: They're

Tracy: They're

John: Going

Tracy: Going to

John: To

Tracy: Be

John: These.

Tracy: They're gonna be attracted together.

John: Yeah, they're going to come together like that, they're going to accelerate toward one another. And as they accelerate, you've got an increase in kinetic energy. Right. And they hit and heat is released once they're together. Go ahead and put that on an ultra precise balance. And guess what? The mass will be more than 2.0, 2.0 or less than 2.0.

Tracy: All right. Well, you just said that he was

John: Release.

Tracy: Really some kind of

John: And

Tracy: Actually

John: Guess

Tracy: Guess

John: That

Tracy: That

John: It's

Tracy: It's less

John: Less

Tracy: Than two point zero

John: Because

Tracy: Because

John: You

Tracy: You

John: Recognize

Tracy: Recognize

John: The

Tracy: The

John: Heat,

Tracy: Heat.

John: The energy release, kinetic energy, heat, energy, light energy, all that energy that was released came from somewhere. It came ultimately from the conversion of some of that mass. I'm going to exaggerate the numbers here. You put them together, it all adds up to one point eight kilograms. So a one kilogram magnet and one kilogram magnet apart, that adds up to two kilograms. But let them come together. It now has a mass of 1.8 kilograms. And you're like, well, where did that point two kilograms go? Answer.

Tracy: Into heat energy.

John: Energy was

Tracy: Energy.

John: Released, Yeah,

Tracy: Yeah.

John: It's all adds up to 2 kg, but point 2 kg was transformed into energy. Here's a case where the mass was converted to energy and then the numbers I used there just are exaggerated. It's not to that extent,

Tracy: All

John: But

Tracy: Right.

John: Let's

Tracy: Let's

John: Do

Tracy: Do

John: The

Tracy: The

John: Reverse.

Tracy: Reverse way. I want to

John: Ask

Tracy: Ask

John: A

Tracy: You

John: Question.

Tracy: A question first.

John: Yeah, but.

Tracy: So if you take them apart again, I know you said let's do the reverse.

John: Or Syria

Tracy: So you're about

John: To

Tracy: To

John: Do

Tracy: Do

John: This?

Tracy: This,

John: Yeah.

Tracy: But will you still wind up with one 0 1 kilogram in each hand?

John: Let's have two magnets together in the total mass, say one point eight kilograms, and what you're going to do is pull them apart. Here, let me give them to you. OK. You got it right. Now go ahead and try to pull those two magnets apart.

Tracy: They're

John: They're

Tracy: Really

John: Really sticking.

Tracy: Sticking there really

John: It's hard,

Tracy: Aren't

John: Isn't

Tracy: Really

John: It's?

Tracy: Stuck

John: It's

Tracy: Cars.

John: Hard. They're

Tracy: Ok,

John: Really

Tracy: Whaley's

John: Strong

Tracy: Sticking magnet.

John: Magnets.

Tracy: Got it.

John: You got it. OK. Now they're apart. How do you feel? Tired?

Tracy: Yeah.

John: Yeah. Do you recognize it required energy from you to pull them apart?

Tracy: Yes,

John: Yes.

Tracy: For

John: Yes.

Tracy: Sure.

John: Guess where that energy went?

Tracy: Back into the mass of the magnet.

John: Yes.

Tracy: Yes,

John: Back

Tracy: Really?

John: Into the mass of

Tracy: The

John: The magnet.

Tracy: Magnet?

John: Yeah.

Tracy: Yeah. That's crazy.

John: The magnets

Tracy: Magnets.

John: Aren't just going to come apart from each other on their own. You got to put an energy to pull them apart. And guess what? It's the same amount of energy that was released when they came together. It all

Tracy: Yeah, that makes sense.

John: Adds up.

Tracy: Yeah.

John: Yeah. There's

Tracy: There's

John: A

Tracy: A

John: Blog,

Tracy: Constant.

John: Energy conservation there. So for magnets, the forces aren't much. And so it's totally not noticeable. But we'll get to the world of the nucleus. It is noticeable. And the evidence has been before you. Through this whole. Time, whenever you look at a periodic table, look to the mass of hydrogen from the periodic table caywood you see their massive hydrogen.

Tracy: 1 point 0 0 7 9

John: All right.

Tracy: Something.

John: How do you how

Tracy: How do

John: Do

Tracy: You

John: You make

Tracy: Make.

John: A helium atom?

Tracy: You take two hydrogens together. You have to squish them together.

John: Two protons and two neutrons.

Tracy: And two electrons.

John: Two electrons, yes. Give you a helium atom.

Tracy: Mm hmm.

John: So for argument's sake, let's say that protons and neutrons have the same mass. They don't, but it's close enough. So essentially hydrogen is 1 point 0 0 7 9.

Tracy: 1 point 0 0 7 9.

John: Multiply by that by four you should get the mass of a helium atom, so four-point point 0 3 2 should be the mass of a helium atom, right?

Tracy: Right. Correct.

John: Correct. Yeah, because you're just taking four of those nucleotides and putting them together.

Tracy: Bright

John: You're

Tracy: Red.

John: Ready. Looked at periodic table. What do you see for helium? What's it's mass.

Tracy: Its mass is 4 point 0 0 3.

John: That's less.

Tracy: That's definitely less.

John: That's way less, actually. You see what's happened here. You're taking those four nuclear Enns, two protons, two neutrons, putting them together to make helium. You might expect masked be conserved. And you looked at the periodic table and you see that it's not.

Tracy: So wait. If it's lost. Then they actually wanted to go together like it released energy

John: When

Tracy: With.

John: They went together, you got less mass in the region, you got less mass is because what was released.

Tracy: Energy.

John: Energy. Yeah. So that's the analogy we were using with the with the magnets. It's the same thing when you look to the elements of the periodic table. Is that cool or what?

Tracy: That is very cool. I I have to think about this for a while.

John: Yeah. Go back to the magnets. I find that really helpful is that when you bring them together, they accelerate. And energy is released. You feel it's warmer. That means it's going to be lighter when you try to pull them apart. It requires energy to do that. And that energies is being transformed into the added mass. Take four nucleotides, scrunch them together to create a helium atom, and you're going to find the total mass is less because energies released, you're bringing together these nuclei and we call that nuclear, not fission, but nuclear.

Tracy: Fusion.

John: Fusion.

Tracy: You're fusing it together.

John: Yeah. Yeah. Now there's a real important graph. We like to call it the most important graph in the entire universe.

Tracy: So the y axis is mass per nuclear on

John: Because

Tracy: Kerslake

John: Think

Tracy: Of.

John: About that mass per nuclear on

Tracy: Sumbitch

John: How much mass

Tracy: Mass.

John: A nuclear on has. You might think a neutron is a neutron is a neutron. Well, it's not the mass of a neutron. Depends upon where it is. If the neutron is in a helium atom, it's got less mass. We saw that in the periodic table. If the neutron is in a hydrogen atom, it's going to have more mass. So not all neutrons have the same mass. The mass of a neutron depends upon where it is. Same thing with a proton. Now that y axis you said was mass per nuclear on. What that means is how much mass a nuclear on has.

Tracy: Ok. And then the x axis is the atomic number. Which is the number of protons.

John: Yeah. Okay. Now, now for our podcast audience. Describe the curve on this graph. Plotting mass pro-nuclear on an atomic number.

Tracy: All right, I'll give it a shot. So the curve starts with a higher mass per nuclear and so a high nuclear en mass.

John: So moving left to right. It starts really high.

Tracy: Sturtz really high and then it quickly drops even at low atomic numbers and then it starts to increase very slowly as

John: So

Tracy: The

John: It

Tracy: Atomic

John: Curves

Tracy: Curve's.

John: About right there and then starts going back upward.

Tracy: Right in the mass of the nucleus will increase as the atomic number gets larger. Now it's very slow of gradual curve.

John: After that quick drop.

Tracy: So Krick job. And then a gradual increase.

John: Yeah, it's like that. So you quickly jump off the edge and then it slowly starts to creep back upward. What that shows is that a nuclear Iran has the greatest mass when it's in the smallest atom of all, which is hydrogen. And as you move from hydrogen to helium, the mass per each nuclear on quickly drops. What happens with that quick drop is that you're losing a lot of mass. And that means you're gaining a lot of energy. So as you lose, mass energy is released. But then, as Tracy pointed out, the graph after that quick drop, it starts to slowly creep back upward. And what that means is if you put two nuclei together, they now have a greater mass. What that means is the fusion. In that case, you're losing energy. It's an uphill battle to take like a uranium atom and put it together with another uranium atom. Yeah. You might be able to cut him in half. But to put two uranium atoms together, this graph is showing that that's an uphill process. To fuse heavy nuclei together requires the input of energy. That's a paradox. When you have light nuclei and you try to put them together, that releases energy. So when we talk about nuclear fusion, nuclear fusion is energy releasing only when you're talking about light nuclei.

Tracy: This is so cool.

John: When we talked about nuclear fission, we're only talking about those really heavy elements. Nuclear fusion applies only to like uranium, plutonium and another uranium isotope. That's it for nuclear fusion. If you want to get energy out of it, you got to go simple. You got to look to the simplest element, which is hydrogen. Take hydrogen. Put it together with another hydrogen plus two neutrons and you create helium. And as per this chart, you're losing mass, which means a lot of energy is being released.

Tracy: So that's what's happening in the sun.

John: Yes, hydrogen is being crunched together with hydrogen to form helium. Now, here's the deal. How you going to get a positively charged proton next to another positively charged proton they repel. Do they not? How are you going to get them to come together like that? They don't want to. They're both positively charged. That magic tweezers to squeeze them together. The closer they get together, the stronger the electrical force, the harder it becomes. It's very difficult thing to do. To get those two hydrogen nuclei to fuse requires a lot of input of energy. So this is how you do it. You take one and you fire it really fast at the other and they're moving toward each other so fast that their inertia overcomes that barrier and click. They bond it as soon as they bond, the fusion happens. Tons of energy are released. They stick together. And you've got.

Tracy: Helium.

John: Helium.

Tracy: You.

John: Now, getting those hydrogen atoms moving really fast means what, relative to temperature?

Tracy: They really hunt.

John: Yeah, you got to get it really hot in order to have it. Fuse in with a star, which you've got is gravity pulling all that mass together, compressing that mass together, like you mentioned the last episode. When you compress, it heats up and it's gravity that's compressing all that hydrogen in space together. And it's large enough such that at the core of that star, it is hot enough for the fusion to take place. Bam, you have the source of energy of all stars.

Tracy: Cool.

John: Hot, actually.

Tracy: That's very cool.

John: Yeah.

Tracy: Very hot.

John: So. So

Tracy: So.

John: From the hydrogen, you generate helium in that? Oh, you get into the cool stuff about the life cycle of a star and the star will put three helium atoms together to form carbon. Right. And that's actually the fate of our star, the Sun. What's the name of our star?

Tracy: The sun.

John: Also known as soul. And that's why it's

Tracy: Ok.

John: The solar system.

Tracy: It's

John: So

Tracy: Soul, so.

John: So. Yeah. Right. And it creates carbon. That's the ultimate fate of our star. Little turned into a big red giant. And collapse into a white dwarf, which is a big ball of carbon. Fascinating stuff from hydrogen. You get helium. From helium, you beget carbon. Add another alpha particle. From carbon, you get oxygen, which you get it. So you see that you are creating your elements of the periodic table through this thing called fusion, nuclear fusion. And this occurs within the stars.

Tracy: So all of the elements up until what you had said before is made by people. All of those are created in a star.

John: Yes, including the uranium, but not just any star. Here's the deal. If you look back at that graph, the lowest, lowest point of the mall is where the nuclear on has the least mass of all. And that is a special position held by the iron atom. With iron, you have this optimal distance within the nucleus such that the strong nuclear forces as strong as it can be. It's like if you want to be as small as possible in your nucleus and go to an iron atom and you will be as small as possible is to say if you want to split an iron nucleus in half. Good luck because it's going to gain weight if you want to fuse two iron atoms together. It's not going to work either because it's now going to be each nuclear on his is going to be heavier. Iron is the end point for any normal star because as you fuse from hydrogen to helium is released. Right. Does your star, as you fuse hydrogen into carbon, energy is released. Right. That's your star. You're still lighter than iron and you're still going to be getting energy as you fuse heavier and heavier elements until you get iron. Once you get to iron, the star can't generate anything more.

Tracy: So where do elements heavier than iron come from?

John: A long time ago, you have occasionally these stars that are about a hundred times more massive than ours. And when those stars reached the end of their life cycle, they collapse in one huge explosion where there is for a moment an abundance of energy. And from that abundance of energy, you can have fusion of elements heavier than iron. And from those brief moments, you create the gold in your ring, the platinum at the uranium, the thorium we hope to be using on this planet. All elements heavier than iron in the periodic table were created not in stars, but in supernova.

Tracy: So that's a big explosion at the end of a star's life cycle.

John: Not just any star, but a star that has a mass of like 100 times more than ours. Ours will collapse into what's called a white dwarf. It won't undergo a supernova. It'll just collapse into a white dwarf, which is essentially a big ball of diamond. Yeah.

Tracy: But for a very large star that's is producing the iron. Where does that go? It

John: It just

Tracy: Just goes

John: Goes

Tracy: Into

John: Into

Tracy: Space.

John: Space space and it will accrete into form planets,

Tracy: Ok.

John: You know. So

Tracy: So

John: Look

Tracy: Look

John: At

Tracy: At

John: The

Tracy: The.

John: Iron here on Earth that came from Star, likely a supernova. And I can guarantee you that elements heavier than iron did come from a supernova. And here's a fun fact. Turns out, have a fair amount of gold here on this planet compared to other parts of the galaxy where other parts of the galaxy there's gold is even much more rare. The reason we have as much gold as we do here on this planet is because we formed in an area of the Milky Way galaxy where there happened to be this supernova way before our time that created these heavier elements that accreted into our sun and its solar system.

Tracy: That is definitely very cool.

John: Yeah, so

Tracy: So

John: Nuclear

Tracy: Usually.

John: Fusion is what drives the stars. Any nuclear power plant is not doing fusion today. It's fission. And I guess this brings us back to Rocky Flats because the types of bombs that they were working toward, there were not fission based bombs. They were what we call fusion based bombs working with hydrogen. Right. So remember, it takes a lot of energy to to squeeze two hydrogen atoms together. Yeah. So. Turns out you can get to those really hot temperatures, not with gravity, but when they blew up the first fission bombs, they noted it was hotter than the sun inside those vision bombs. So they thought, why do we do this? Take a little vial of hydrogen and surround it with a bunch of vision type bombs and then it'll be hot enough for that hydrogen to fuse into helium. Then we should get much more energy out of it. And they did that. That was in the nineteen fifties. So in order to create those bombs that triggered the the fusion of hydrogen, you had to have plutonium. That's what they made at Rocky Flats. Those plutonium buttons they call column

Tracy: Yeah,

John: Pucks.

Tracy: I did.

John: Yeah. Those pucks at Rocky Flats, they were generating the plutonium that would be used for the fission bombs that would ignite the fusion bombs. That's

Tracy: Just

John: Scary.

Tracy: Stop making bombs. Come on.

John: Yeah, but let's look on the bright side of things. Imagine you're around a campfire and you're getting all this warmth from the burning logs. The logs, the releasing, the energy they contain. So from where did the logs get this energy? Well, the log was part of a tree. Right. So so really, where did the tree get this energy from?

Tracy: Well, from the sun.

John: Yeah, via photosynthesis, it collected this energy from the sun. So from where did the sun get this energy?

Tracy: The energy is coming from the fusion,

John: Fusion, nuclear

Tracy: Nuclear

John: Fusion.

Tracy: Fusion, from the

John: Right.

Tracy: Nuclear fusion.

John: So when you're feeling that warmth from a campfire. That energy is ultimately from the nuclear fusion within the sun. It's all connected. All right, so. That wraps it up for this chapter on on the atomic nucleus. And what's coming up in the next podcast. Tracy?

Tracy: Is it an interview with Mike Lucas?

John: Mike Lucas.

Tracy: Oh, that's gonna be very cool.

John: Rocket engineer and we'll be talking about the application of a lot of the science to the engineering world.

Tracy: Alright

John and Tracy: Good chemistry to you.

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