Big Picture Podcast – Episode 05

Subatomic Particles, Chapter 4B

John: Welcome back to the big picture podcast. This is the do the review segment for Chapter 4.

Tracy: What's the topic?

John: Subatomic particles.

Tracy: What's the main idea?

John: Well atoms you see they're made out of electrons protons and neutrons. Those are the subatomic particles.

Tracy: All right

John: A quick note. We are here in chapter four. But this of course is episode five because there's quite a bit of material to cover. We've just splitting it up into smaller episodes so for this next episode episode five we'll be doing the first half of the chapter 4 and in Episode 6 we shall get into the heavy second half of chapter 4 quantum mechanics. Ready?

Tracy: Let's do it.

John: Section four point one physical and conceptual models. What's a model?

Tracy: Something on a different scale.

John: Ok. So you're thinking like a toy airplane is a model of a real airplane. Great.

Tracy: Right.

John: So what you're looking at there is what we call a physical model it's simply the real thing built on a different scale. You're just reproducing the physical structure on a scale that you're able to hold in your hand or appreciate better. So that's a physical model. We're not talking about physical models or in chemistry. Our focus is on another type of model we call the conceptual model.

Tracy: Tracy. So the conceptual has to do with how something actually works.

John: So think of the weather.

Tracy: Okay.

John: We have conceptual models on the weather to help us determine if it's going to rain, or snow or be sunny. So the conceptual model describes how all the different components within the system are behaving. And if you can understand the behavior of that system then you're in position to be able to predict future behavior of the system. Think of a hurricane.

Tracy: Ahh

John: So a good conceptual model of how a hurricane behaves allows you to predict where that hurricane might make landfall. So we distinguish a physical model from a conceptual model a physical model just replicates it on a different scale. The conceptual model actually describes how the system behaves. And so here's where we have to get something out of our heads. We know atoms are really really really small and we're tempted to want to ask the question well what does the atom look like. We're going to want to build a physical model of what that atom looks like. Well turns out the atoms are smaller than the wavelengths of visible light. So the very question of what the atom looks like is not really something that makes sense

Tracy: Why is that?

John: That you can't see it even with the most powerful optical microscope the light passes right by it. And so you say well let's just shorter wavelengths let's use x rays as soon as you use x ray you zap it from where it was. It just boggles the mind. It's not something you can see because it's too small to be seen. So the idea of using a physical model to replicate the atom which is ultra ultra ultra small It just doesn't make sense but really we need to ask the question of why would you need that physical model. You really want to be able to predict the behavior of that atom in so rather than a physical model really what we need. I mean really what we need is a conceptual model of that atom. Consider it's a system just like the weather is a system of different components. You know humidity wind speed temperature atmospheric pressure the atom is the system of subatomic particles electrons protons and neutrons. There's electromagnetic forces there's what we call a nuclear force. How do all those components behave together. And when you got that you're going to be able to predict the behavior of that system of that atom and that's what we really won because once you understand how the atom behaves you can control it. That's what we call chemistry.

Tracy: I'm wondering not only is the atom too small but the atom starts crossing over into different

John: Behaviors.

Tracy: So that's

John: What

Tracy: When we're

John: Looking

Tracy: At

John: Quantum mechanics

Tracy: Context

John: Right but

Tracy: That

John: It's

Tracy: Not

John: Even

Tracy: It's hard to create a physical model not just because of its size but its it seems to me it's more because its behavior is falling in and out of the physical material realm between light and waves

John: An

Tracy: And

John: Energy. Excellent it's crossing into the energy realm and what we'll be talking about in this do the review when we get into quantum mechanics is exactly that the atom is not a hard tiny little particle thing that you might think it is. It's an interplay between mass and energy. How do

Tracy: So as soon as we create

John: A static

Tracy: Form or a

John: Model of an atom

Tracy: Then

John: It's just

Tracy: A very

John: Limited. You're on

Tracy: The

John: Particle side of the equation. The reality is there's the energy side of the equation too. Oh can

Tracy: All right

John: We talk

Tracy: Let's

John: About

Tracy: Move

John: It right

Tracy: Forward.

John: Now.

Tracy: Go

John: No

Tracy: Ahead.

John: No no. We hold ourselves back. We'll get there. Let's talk now about a little bit of

Tracy: The

John: History right of how we got

Tracy: Here

John: In

Tracy: The

John: First

Tracy: Place.

John: That

Tracy: Seems really

John: Important especially

Tracy: In

John: Learning

Tracy: How

John: Other people

Tracy: Learned.

John: So section four point two the electron was the first subatomic particle discovered. This whole notion that there are these things called atoms put forth by Dalton in the early eighteen hundreds was quite difficult for people to accept. Remember the idea of if you have particles that means you have nothing in between the particles but empty space. So that was a big question of the eighteen hundreds. Well just as they were solving that question of whether elements are made up of these tiny particles called atoms. Along came evidence that there was potentially something even smaller than the atom and that totally freaked people out. They're having a hard enough time accepting the idea of atoms let alone particles even smaller than atoms. Yet that was a discovery that started with what J.J. Thompson in the late 18th century fits. So J.J. Thompson worked with the cathode ray tubes and you'll see videos of that at conceptual Academy and long story short those cathode rays within those tubes were just a beam of these tiny particles called electrons. And of course it was also with the work of Millikan Robert Milliken his evidence and the evidence laid out by J.J. Thompson put those together came up with the idea that you have something that has a mass less than that of the smallest known atom hydrogen.

Tracy: Okay wait. So just for entertainment sake and for lubricating our conceptual imagination. Can you describe the oil experiment.

John: Ok so you know those little perfume bottles that your mom had

Tracy: Grown

John: When you're growing up

Tracy: Maybe

John: Your grandmother

Tracy: Or

John: A

Tracy: Great grandmother.

John: Great grandmother

Tracy: Really.

John: Like that and it sends out a mist that's called a nebulizer and you're just basically pumping air through a liquid pushes the liquid through tiny little nozzle and it spits out these tiny little droplets. That's what Millikan did. He had a little nebulizer it's called in the he made all these little oil droplets. Now the thing is the oil droplets kind of float through the air you know like a cloud but they would slowly drift downward they would drift through a little hole in metal plate that he had charged. And as those little tiny oil droplets would fall through that hole they would pick up a charge let's say a negative charge. And then he would take the charge of that plate and flip it. And so those tiny little negative charged oil droplets would suddenly be attracted to a charge that was above them because they've already passed through that little hole so the poor little oil particles are in a conundrum. There's gravity pulling them downward but there's an electrical force of attraction pulling them upward in see what Millikan could do is he could play around with the the strength of the electric force he couldn't play around with the strength of the gravitational force but he could play around for the strength of the electrical force and he could make some of those oil droplets hover because he could make it so that the electrical force upward match the gravitational force downward. So he was able to make those tiny little oil droplets hover. Are you with me so far so

Tracy: Okay. So these little oil

John: Droplets are going they're getting sprayed into a container.

Tracy: They're falling

John: Through

Tracy: A

John: Buka

Tracy: Metal

John: Athlete

Tracy: Plate a

John: Hole a hole in a

Tracy: And

John: Middle

Tracy: As

John: Plate.

Tracy: They go

John: Through that plate

Tracy: The

John: Plate is

Tracy: Charged.

John: So they pick up that

Tracy: Charge

John: Surge

Tracy: And

John: They

Tracy: Continue

John: To

Tracy: Fall after

John: They go through that plate. Yeah.

Tracy: And then Milliken

John: Millikan Well

Tracy: Will

John: Seems

Tracy: Change the

John: Charge of that

Tracy: Plate

John: The

Tracy: Flaherty

John: Polarity

Tracy: The polarity so

John: Rather than it being a positive charge say

Tracy: Which

John: Watch the

Tracy: Little oil droplet now

John: Picked up a positive charge.

Tracy: He

John: Would change

Tracy: It to a

John: Negative charge.

Tracy: So

John: Now

Tracy: The droplet is falling but

John: Suddenly it

Tracy: Has

John: A new attraction to that negative

Tracy: Charge

John: Upward

Tracy: A

John: For

Tracy: Port

John: It.

Tracy: On

John: That plane

Tracy: Play. Is

John: Yeah

Tracy: That right.

John: That

Tracy: You

John: Got it. Excellent. And so he could play around with the degree at which that plate was charged and he could get different droplets to hover because some droplets were heavier somewhere lighter. Right. But he did as he took the readings of the charge of what it would take to make one of those droplets hover. So he took tons of readings of of how much charge was needed to make them hover. And he noted something very unusual about the numbers. The reading on the charge there were like numbers like 5 10 15 15 forty five sixty five seventy five. What are all those numbers have in common. One hundred and five ninety

Tracy: 85

John: Five ninety

Tracy: 90 divisible

John: By five. They're all factors of five. Likewise he looked at all those numbers. They weren't no factors of five was factors of something else. But he found it was a factor in turns out that number he came up with was the fundamental charge that you can possibly have those a very tiny amount of charge but it was a fundamental unit of charge that he came up with. And knowing that fundamental unit of charge he was able to backtrack to JJ Thompson's experiment to calculate the mass of one of the tiniest particles known as the electron in its mass was found to be less than that of a hydrogen atom which just blew people's minds.

Tracy: Wow.

John: Fascinating.

Tracy: Okay so

John: There we

Tracy: Go.

John: Some

Tracy: History.

John: In terms of the discovery of

Tracy: A

John: Subatomic

Tracy: Particle. I

John: Think

Tracy: It's really

John: Important

Tracy: Too.

John: And

Tracy: Fascinating

John: To see

Tracy: Something

John: That

Tracy: Seems like me.

John: What

Tracy: Is

John: He doing is

Tracy: He's just

John: Passing

Tracy: Oil

John: Droplets through a plate

Tracy: But that

John: He kept taking it further and further and

Tracy: Was

John: Able to

Tracy: Really

John: Add to our

Tracy: Understanding

John: Of the

Tracy: Phenomenal

John: World I

Tracy: See

John: Creativity I see analytical thinking I see.

Tracy: Endurance.

John: Yeah it's just persistence. Just go on after it. The drive Wow. A hero. Section four point three goes into little bit more history. Ernest Rutherford. Discovering the atomic nucleus. OK so now we have this idea that there's the subatomic particles we're talking about what the structure is of the atom right. Keep in mind physical models versus conceptual models here. What Rutherford did was he had a tiny thin gold foil a property of gold is that you can pound it to very ultra thin sheets so thin it can be just several atoms thick. And what he did was he passed these particles called alpha particles which were actually much larger than a hydrogen atom but they were known particles from radioactivity which we'll talk about in the next chapter. He directed these alpha particles through this thin gold foil and he expected that the alpha particles because they're so large and massive would just plow right through those gold atoms. And indeed they did mostly but occasionally one of those alpha particles would bounce off of those atoms in a reverse direction. And that freak the mound it was to him akin to firing a cannonball at a paper tissue in the cannon ball bouncing backward. What did that cannonball hit the cannonball of course being the alpha particle in the tissue being the very very thin gold foil. Well

Tracy: So I want to just

John: Ask

Tracy: A

John: Question.

Tracy: Let's you say he

John: Is

Tracy: Has a

John: Source

Tracy: Of

John: Alpha

Tracy: Particles. I

John: Wouldn't know where to get a source.

Tracy: Of alpha particles. I don't even know what that is. Okay.

John: Understand when one is making discoveries they're not doing it in a vacuum. For say there's prior knowledge. By the time of the third there had been work with Madam Curie in this realm of radioactivity learning that some elements emit these particles that can be harmful that can do bizarre things. So at that time Madame Curie had done a lot of her work with radioactivity. And what was found is you have these materials like radium is an element she discovered that's emitting this radiation in one form of that radiation is this tiny alpha particle so well Rutherford did was to to shoot alpha particles at the gold foil. You took a lead block and drilled a hole in it and dropped some radium. I think it was radium at the bottom of that little hole. It would naturally shoot now alpha particles. Well because it's in the bottom of a hole the alpha particles are just going to shoot straight up outwards and so essentially he made himself a little

Tracy: Of

John: Alpha particle gun.

Tracy: God. Okay.

John: And

Tracy: I

John: He pointed that toward the gold foil. Now how are you going to see whether the alpha particles passing through it or not he put around a fluorescent screen because whenever the alpha particle would hit the screen you get a little blip right. So there's the idea of fluorescence which was also known about by this time. And so you see he's taking previous discoveries and using them and of course in this way science builds upon itself

Tracy: Then he starts measuring the angles that the alpha particles go through.

John: And is only conclusion was that most of the mass of an atom is concentrated in its center. He discovered what we now call the atomic nucleus. And it's said like this if an atom were the size of a baseball stadium the nucleus would be like a baseball on the pitcher's mound. Mostly what you've got is empty space. If you want to find where the mass of the atom is it's on the pitcher's mound in that tiny little baseball as small as a baseball is to an entire major league baseball stadium is as small as an atomic nucleus is to the size of the atom. The Atom he discovered is mostly empty space. Its mass is concentrated in yet another particle at the center which was dubbed the atomic nucleus the atomic center

Tracy: Okay

John: Ok

Tracy: So now

John: We're going to learn some

Tracy: Vocabulary.

John: Oh we're looking now at Section four point four. We've introduced the electron and the atomic nucleus. Let's just cut to the chase and point out how it is that the atomic nucleus itself is made up of even more subatomic particles.

Tracy: They

John: Are the

Tracy: Protons

John: And

Tracy: The

John: Neutrons.

Tracy: Neutral

John: Here's a generic term for you ready. Nuclear on what's a nuclear on

Tracy: Proton

John: Or neutron. So nuclear on is any subatomic particle found within the nucleus. Two examples are the proton in the neutron. So the atomic nucleus is made out of nuclear bonds and there are two types of protons and neutrons who vocabulary.

Tracy: Okay is

John: What is

Tracy: A neutron.

John: Neutron as its name implies doesn't have an electric charge which in fact is why it wasn't discovered till later is neutral it wasn't behaving with an electric fields right and it would just slip right on by. Was Chadwick who discovered the neutron. That's another story. The neutron is neutral and the proton carries a positive charge and we get to talk more about why we have protons and neutrons and in chapter 5. It's fascinating. But for now we're just looking at what is there in the atomic nucleus. The protons and neutrons

Tracy: So

John: At this point

Tracy: In our vocabulary

John: We

Tracy: Would call a

John: Proton

Tracy: Subatomic particle that carries

John: Is

Tracy: A positive charge.

John: Yeah.

Tracy: And so

John: It's a nucleus. It's a subatomic particle. It's found in the atomic nucleus. And it has a positive charge. So that is the definition of a proton. Yeah.

Tracy: Okay

John: I like

Tracy: Yeah.

John: That. I like that. And then there's the starts with L named for subatomic particles. And the students will go protons neutrons the atomic nucleus and also another one it starts with L..

Tracy: Electron

John: The electron the electron has a negative charge its negative charge is exactly opposite to the positive charge of a proton they're equal and opposite in charge. The electron is not a nuclear on the electron is really really really really small. The electron has a mass about 1 2 thousands of that of a proton a neutron. When you think of a proton a neutron. Think of these big subatomic particles like of a unit of 2000. When you think of the electron you get this tiny little tiny little thing has a massive only one and no one is much smaller than two thousand right. So that's to say the protons and neutrons they've got all the mass. Look where they're located they're in the atomic nucleus. What about the electron the electron doesn't have much mass it has mask but not much. The electron however has the VA va va Velocity Rose of volume volume volume.

Tracy: All you that seem to have is

John: The volume it defines the volume of the atom right. It defines the volume of the baseball stadium. If the the nucleus is the baseball on the pitcher's mound the electron is a tiny flea that can zip around the entire baseball stadium within the atom. The electron is indeed zipping around at high high high speeds around that nucleus and as it does so it sweeps out this volume of space that is essentially the diameter of your atom. So you get the idea that the atom is mostly empty space. You've got a tiny tiny tiny electron that's moving around. Now although the electron doesn't have much mass it does have much

Tracy: Turd.

John: Charge

Tracy: Charge.

John: And that charge extends outward beyond the diameter of the atom. So really the atoms diameter is defined by the space that the electron sweeps out as it whizzes around that most massive atomic nucleus and dense and tiny atomic nucleus at the center of the atom.

Tracy: How come it

John: Doesn't get any closer to the pictures.

Tracy: Pitcher's mound. Why would it stay out in the way

John: We.

Tracy: A poor stadium.

John: You mean the

Tracy: Bleachers

John: Electron is negatively charged and the proton is positively charged. How come that electron just doesn't fit right into the nucleus where it's attracted.

Tracy: Yeah

John: It does.

Tracy: Then what keeps it out in

John: Features

Tracy: The bleachers.

John: Quantum

Tracy: Mechanics.

John: We're not

Tracy: There

John: Yet. We're

Tracy: Okay

John: Heading

Tracy: Okay.

John: There.

Tracy: Okay

John: So in section four point four.

Tracy: We've got

John: Gosh we've got protons neutrons and nucleotides. The atomic nucleus. And here's a

Tracy: Good

John: One for you. Atomic number.

Tracy: Okay. Pause.

John: See if you can define for yourself

Tracy: Proton

John: Neutron the bullet deployed

Tracy: Nuclear

John: On the atomic nucleus. Anything

Tracy: Else.

John: Starts

Tracy: Stretch

John: With

Tracy: A little

John: El

Tracy: Electron.

John: These

Tracy: Five things see if you can define those five things right now. He has

John: It's

Tracy: A

John: Vocabulary right.

Tracy: Okay.

John: And then let's add on top of that atomic number atomic number pretty darn important. It's the number of protons in the nucleus

Tracy: The

John: Number

Tracy: Of

John: Protons.

Tracy: In a nucleus

John: Yeah. Just count

Tracy: Killed

John: The number of protons there and you have your atomic number.

Tracy: Just

John: Yes

Tracy: The

John: Proton

Tracy: Protons.

John: Just

Tracy: Atomic

John: The protons

Tracy: Number protons

John: Yeah but

Tracy: The

John: That in

Tracy: Flush

John: Your flash card. You see we define an atom by its atomic number. That is to say we define an atom by the number of protons it has within the nucleus. That's just our convention. So the atomic number is important. It's what we used to define the atom and you'll see the atoms of elements in the periodic table are listed in order of their atomic number. Hydrogen has one proton so it's atomic number one Helium has two protons so it's the atomic number two and so forth down the line. All right. So hey let's add even more shall we. Okay. Mass no

Tracy: Mass

John: No

Tracy: No

John: Mass. No sounds an awful lot like atomic

Tracy: Number

John: No

Tracy: Doesn't

John: It doesn't.

Tracy: It. It sure

John: Does. It's not.

Tracy: It's another

John: No

Tracy: Number

John: It's not the same thing. So the atomic number is the number of protons

Tracy: Right.

John: Atomic

Tracy: Number is the

John: Number of proton

Tracy: Protons.

John: Mass

Tracy: That

John: Number is the number of nucleotides

Tracy: Nucleotides we remember is protons and neutrons

John: Yeah. So you have to add up all the protons and all the neutrons within an atom and that will give you the mass number. So here do a quiz. Ion 56 now is the ion dash fifty six that fifty six that you see there is the atomic mass number ion 56. Take a wild guess how many nucleotides are in iron 56

Tracy: Six fifty six.

John: And how many nucleotides are in iron

Tracy: Fifty five fifty five.

John: Wait a second aren't they both iron.

Tracy: Way you said.

John: Well if it's

Tracy: Iron

John: And how many protons does it have

Tracy: Okay. Looking at the periodic table looks like it has 26.

John: Six. There are twenty six protons in any iron atom by definition. Right. So how can it be that you have iron fifty six and iron fifty five. You see the number of protons is always going to be the same which is twenty six. Here's the key. The number of neutrons can vary.

Tracy: Okay so

John: You're telling me

Tracy: That

John: The

Tracy: Mass

John: Number

Tracy: Is the

John: A number of

Tracy: Nucleotides

John: Yeah. And

Tracy: The

John: Atomic number

Tracy: Of iron

John: Is counting

Tracy: Just

John: The number of protons. Yes.

Tracy: And so the

John: Atomic number of iron has twenty

Tracy: 26

John: Six

Tracy: Protons

John: The atomic number

Tracy: Numbers

John: Is

Tracy: Twenty six

John: Because

Tracy: Camps

John: It has

Tracy: Twenty six.

John: Protons.

Tracy: Got it.

John: So we have

Tracy: Iron

John: Fifty six

Tracy: And iron 55.

John: Fifty five.

Tracy: So

John: There's two different mass numbers. Yes.

Tracy: Okay

John: So there can be different numbers

Tracy: Of neutrons

John: Yeah. You

Tracy: With

John: Got it in

Tracy: That iron atom.

John: To stay

Tracy: Say

John: There

Tracy: They're

John: Are different types of iron atoms there iron atoms they have thirty neutrons in the nucleus there are iron atoms that have twenty nine neutrons in the nucleus they're all iron atoms they're all siblings they all have twenty six protons but the number of neutrons can vary not for any one atom but you're gonna have an iron atom that has thirty neutrons over here and then over there you'll have an iron atom that has twenty nine neutrons the number of neutrons can vary that's all I'm saying okay so how do we distinguish between iron 56

Tracy: Six

John: And iron 55

Tracy: Fifty five.

John: They're both forms of

Tracy: Iron

John: But they're different somehow

Tracy: And

John: That's where we introduced the term isotope

Tracy: I

John: Iso

Tracy: So

John: Means

Tracy: Mean

John: Same Tope means I have no idea but ISO

Tracy: I so

John: Means it's the same they're both

Tracy: Iron

John: Atoms right they're different forms of the same thing when we say isotope that's literally what we're meaning the different forms of the same thing that thing here being ion ion 56 in ion 55 are both different forms of the same thing how are they different by the number of neutrons that they have in them. So we talk about the iron 56 isotope or we can talk about the iron 55 isotope they all have 26 protons the iron 56 isotope has 30 neutrons the iron 55 isotope has twenty nine neutrons.

Tracy: How

John: Many different isotopes

Tracy: Can you have for iron.

John: There are a

Tracy: Lot

John: Of different isotopes but here's the deal. Some isotopes are more stable than others let's simplify a bit and moved back down to hydrogen there are three two dominant isotopes of hydrogen the most abundant hydrogen atom we've got is the hydrogen one isotope hydrogen one the mass number of one but it has an atomic number of one watt plus one equals one plus one equals

Tracy: 1

John: 0

Tracy: 0.

John: The number of neutrons

Tracy: In

John: And hydrogen one is zero there are no neutrons in hydrogen one Okay so we're simplifying things here so hydrogen 1 is the most predominant isotope of hydrogen that you'll find in nature you also have hydrogen atoms that do have one neutron that's H two then there are some hydrogen atoms that have actually two neutrons so two neutrons plus one proton that adds up to three. So that's the H

Tracy: Re

John: 3 isotope

Tracy: Okay

John: So H1

Tracy: Each one

John: H2

Tracy: Is two

John: In H

Tracy: Each

John: 3

Tracy: Three

John: They all have one proton but they vary by the number of neutrons that they've got one has zero the other is one the other has two. Now what do you have most of mostly what you've got are each one out of seventeen hundred hydrogen atoms you're going to find one of them is a H two and then there's h three H three is really really rare. Turns out it's also radioactive it's also known as tritium H two is known as deuterium in H1 they call that podium. Okay so those are the three different isotopes of hydrogen and we have different abundance is of those isotopes and a lot of that is dependent upon the history of the universe as well as the stability of the isotopes themselves H3 is not very stable so guess what. We don't have very much of it in this corner

Tracy: Of the universe. So two atoms are isotopes of

John: So

Tracy: Each

John: They're

Tracy: Other. If they

John: The

Tracy: Have the same atomic number

John: Yeah

Tracy: But different number

John: No.

Tracy: Of neutrons

John: Yeah. So

Tracy: That

John: Wraps up Episode 5 also

Tracy: Known as

John: Chapter

Tracy: 4

John: B. What's next.

Tracy: We'll

John: Be

Tracy: Going

John: Into

Tracy: Quantum mechanics

John: Quantum mechanics. Ooo.

Tracy: A heads up listeners. Make sure that you listen after a good night's sleep.

John: You mean no cramming late at night the night before the exam?

Tracy: No way.

John: Thanks for listening. Theme music by Zach Geoffrey. Musical flourishes by and in memory of Charles Paxton. For more of his music, look for Char-el, that c h a r dash e l at places such as Spotify. Production assistance from Gregg Simmons and CPro music for show notes and more please visit conceptual science scum a note of appreciation to all instructors using conceptual Academy. Thank you for your support into the hardworking student. Our thanks to you as well for your learning efforts which we see as the path to making this world a better place. There is a bigger picture that's good chemistry. Till next time.

John and Tracy: Good chemistry to you