The History of the Twentieth Century
Episode 246
"The Great Debate II"
Transcript

[music: Fanfare]

By the 1920s, modern science had not only proved the existence of atoms, but had begun to pick them apart into smaller particles. But it turned out that the world of the atom was quite different from the familiar world on the human scale. Not only different, but unsettling, even to those who studied it most closely.

Welcome to *The History of the Twentieth Century.*

[music: Opening Theme]

Episode 246. The Great Debate, part two.

Back in episode 221, which I called "The Great Debate, part one," we looked at the question of things very large. The scale of the Universe and our place in it, a subject human beings have pondered, probably since the first time one of our ancestors looked up at the night sky. In the decade of the 1920s, human science finally uncovered the full—and humbling—reality of just how large the Universe really is.

For almost as long as humans have wondered how big was big, they also wondered how small was small. If you take a small quantity of, say, water, and divide it in half, and then divide it in half again, can you continue this process endlessly and produce infinitely small quantities of water, or would you reach some fundamental stopping point, where you had the smallest amount of water there could possibly be, a quantity that either could not be divided any further, or perhaps it could, but then it wouldn't be water anymore?

This latter hypothesis, that there was such a thing as a fundamental particle of water, came to be known as the atomic theory and the particles themselves as atoms, from a Greek term that means "indivisible." Atomic theory was little more than a philosophical debating point until 19th-century chemists worked out that chemical elements always reacted with each other in certain fixed proportions. For example, if hydrogen and oxygen react to form water, the reaction always consumes twice as much hydrogen as oxygen by volume, which suggests that the chemical elements hydrogen and oxygen are made up of atoms, and that water "molecules" are made of two hydrogen atoms and one oxygen atom.

The fact that chemical reactions generally consume their ingredients in small integer ratios makes a convincing argument that the chemical elements are each made up of their own kind of atom, and that other materials are compounds made up of molecules which are in turn composed of clumps of atoms in specific ratios, like the 2:1 of hydrogen and oxygen in water.

Nineteenth-century chemists were even able to work out the atomic weights of different kinds of atoms, as well as the periodic table of the elements, which graces every chemistry classroom in the world to this day. It's always fun to look at when the lecture gets boring. Chemists of the time noticed that the chemical elements sorted themselves out roughly by atomic weight, which surely meant something. They also began to assign each element an integer "atomic number," which at first was just a semi-arbitrary sorting method. Hydrogen is number one, helium is number two, and so on.

By the beginning of the twentieth century, chemists were firmly convinced of the atomic theory, but experimental proof of the existence of atoms remained elusive. That changed in 1905, the year of wonders, episode 37, when Albert Einstein demonstrated mathematically that the mysterious phenomenon of Brownian motion, in which small particles suspended in water jiggle about for no discernible reason, was in fact caused by random motions of water molecules.

So atoms and molecules definitely exist. Oddly enough, even before Einstein proved this, physicists were already picking away at atoms and determining that, far from being indivisible, they were themselves made up of even smaller particles.

That process began with the discovery of electricity and the development of electricity into a power source by the late 19th century, and also with the inventor Thomas Edison and his electric light bulb. In the course of his light bulb experiments, Edison discovered that if you put a metal plate into a light bulb, electricity will flow from the hot filament to the metal plate, but it won't flow in the opposite direction. This was dubbed the Edison Effect.

Thomas Edison is justly famous for inventing the light bulb, but in the history of modern science and technology, the Edison Effect is probably more important. The Edison Effect led to the development of vacuum tube diodes that made AM radio feasible, and later to vacuum tube triodes that made electronic amplification possible. Diodes and triodes made commercial radio receivers possible and led directly to the radio boom of the 1920s. Lots of people made lots of money off the new technology of AM radio, but Thomas Edison was not one of them, much to his annoyance.

The Edison Effect was also of great interest to physicists. Electricity was becoming a part of everyday life by the late 19th century, but physicists still didn't know exactly what it was. But whatever electricity might be, it was definitely the stuff that was passing through these vacuum tubes, and that just might be the first step toward figuring out what it was. They called it cathode rays at first. Then the German physicist Wilhelm Roentgen discovered in 1895 that high-energy cathode ray tubes produced another kind of ray, one that he called x-rays. I told you that story in episode 15, where I also mentioned that Roentgen won the first Nobel Prize in physics in 1901.

But x-rays were a side effect. The real story was that stuff that was passing through the vacuum tube. Was it a massless wave, like light, or was it a stream of tiny particles? At the turn of the twentieth century, the most important research into cathode rays was happening at the Cavendish Laboratory at Cambridge University in England, under the direction of Sir Joseph John Thomson, who is known to history as J.J. Thomson. Thomson won the Nobel Prize in Physics in 1906, and no fewer than eight of his research assistants would go on to win Nobel Prizes of their own in physics or chemistry, including such figures as Niels Bohr, Max Born, Owen Richardson, and Ernest Rutherford. Thomson's son would also win a Nobel Prize in physics.

So the Cavendish laboratory at this time was not only a premier research facility but an incubator for geniuses.

In 1897, Thomson reported that cathode rays were actually very tiny particles that carried a negative electric charge, and suggested these were sub-atomic particles, that is, they were one of the ingredients that made up an atom. Thomson called them corpuscles; another physicist proposed the name electron, a portmanteau of electric ion, and that was the name that stuck.

But the thing was, electrons were really, really tiny. Thomson could not measure their mass or charge directly, but he could measure the ratio of the two, which was enough to indicate that an electron was less than one-thousandth the mass of an atom. So if it was a building block, it was a very small one.

In 1904, Thomson proposed what was called the "plum pudding" model of the atom. My fellow Americans might be better off thinking of it as the "raisin bread" model. He suggested that atoms were clumps or clouds of positive electric charge with electrons embedded in the interior, like raisins in a pudding or loaf of bread, although Thomson imagined the electrons moving around within the atomic interior.

In 1910, an American physicist named Robert Millikan was able to pin down the charge on the electron by observing microscopic oil droplets floating through the air, and the effect an electric field had on them, an experiment which earned him a Nobel Prize in 1923. If you'll indulge me for a little reminiscing, when I studied atomic physics in college, we had to duplicate the Millikan oil drop experiment in the lab. We did it, and the lab tech pointed out to us that if we had done it 70 years earlier, *we* could have won Nobel Prizes.

That's as close as I'll ever get to a Nobel.

Ernest Rutherford was a New Zealander who worked with Thomson at Cambridge and then accepted a position at McGill University in Canada. Working there at the same time Marie Curie was studying radioactivity in Paris, episode 9, Rutherford discovered that if you subject the radioactive emissions of radium to an electric field, some of the emissions bend in one direction, indicating a positive charge, while others bend in the opposite direction, indicating a negative charge. Rutherford called these alpha rays and beta rays. Later, it was determined that there is a third kind of emission that is unaffected by the electric field, which Rutherford dubbed gamma rays. I'm sure you recognize these terms; we still use Rutherford's nomenclature today.

Physicists were keenly interested in identifying what these rays were, as this would be the key to figuring out what radioactivity was, which was one of the biggest scientific mysteries of the time. It was soon determined that gamma rays were high energy photons. Now, that's what x-rays are. The only real difference between x-rays and gamma rays is whether they're produced artificially or by natural radiation, although x-rays are best known as a diagnostic tool in medicine, and of course you don't want to irradiate your patient with anything more than the absolute minimum of energy necessary to get an image, so x-rays are typically less energetic than gamma rays, which are produced by natural processes that don't care whether you get hurt or not, so stay away from those gamma rays. (I'm sure Bruce Banner would back me up on that.)

Beta rays were determined to be electrons, the same stuff as cathode rays. What's more, further experiments showed that electrons are all identical, no matter how they are produced.

And alpha rays were determined to be helium ions with a positive charge equivalent to two electrons.

In science, every time you answer a question, you get a bundle of new ones. One remarkable aspect of this discovery is that radioactive substances like radium or uranium emit the same two types of rays that physicists were already scratching their heads over in other contexts: x-rays and cathode rays. Only, the devices that create these rays artificially need a considerable amount of electric power to produce them, while uranium is just a lump of metal sitting on a table. Where does it get the energy to emit those rays?

Albert Einstein provided the answer in one of the papers he published in his 1905 Year of Wonders, episode 37: $E=mc^2$, the most famous equation in science. The energy comes from the mass of the uranium itself. Ernest Rutherford proposed this as the power source that keeps the sun going, which was a question early twentieth-century science was also wrestling with. No known power source could keep an object the size of the sun burning for as long as the sun has apparently been burning. Rutherford was on the right track here, but it will take a while longer to solve that mystery.

Another question these results raise is whether these various particles emitted by radioactive materials are in fact produced from within the atoms that make up that material. J.J. Thomson speculated along those lines with his plum pudding model of the atom. Marie Curie did too, but it was Ernest Rutherford and his associate, Frederick Soddy, who first proposed in 1903 that radioactivity was actually the spontaneous disintegration of atoms into smaller fragments. This was a radical idea; everyone was used to thinking of atoms as constant and unchanging. It was right there in the definition. This work won Rutherford the Nobel Prize in chemistry in 1908.

In 1913, the English physicist Henry Moseley, who was experimenting with x-ray spectroscopy of the chemical elements, was able to demonstrate a relationship between the x-ray spectra of the chemical elements and their atomic numbers. This was significant because it demonstrated that atomic numbers were not just arbitrary labels; they represented some physical property of the atom they referred to.

Moseley made this discovery when he was just 25 years old, making him already Nobel Prize material, and he surely had a promising future in research, but alas, it was not to be. The Great War came, Moseley felt duty-bound to volunteer, and he was killed at Gallipoli in 1915 at the age of 27. Science writer Isaac Asimov suggested that Moseley's death was the single most costly death of the war to the human race generally.

Alas for the loss of Moseley, but Ernest Rutherford was still hard at work, and he actually made his most important discoveries after winning that Nobel Prize and returning to England to take a position at Victoria University in Manchester. In 1911, Rutherford experimented with firing alpha rays at a thin sheet of gold foil. Most of the positively charged alpha particles passed through the foil unperturbed. Only a small fraction were deflected, but some of these were severely deflected, ninety degrees or more. From these results, Rutherford concluded that Thomson's "plum pudding" model of the atom was incorrect. The positively charged portion of the atom had to be a small and dense structure deep inside.

Rutherford proposed a new and different model of the atom, the familiar one, in which the atom has a small, dense, positively charged nucleus, around which circle a number of negatively charged electrons, which are bound into orbits around the nucleus by electrical attraction, in an arrangement analogous to our solar system, where planets circle the sun because they are bound to it by gravitational attraction.

In his experiments bombarding materials with alpha rays, Rutherford also detected the production of hydrogen ions. Hydrogen is the lightest atom, with an atomic number of one and an atomic weight of one, more or less. Some chemists had suggested as far back as the nineteenth century that larger atoms were in fact clusters of hydrogen atoms. Rutherford proposed a similar but more refined version of this idea in 1911, which was further refined by other physicists, until by 1920 it looked like this: the nuclei of larger atoms are clusters of hydrogen nuclei, which are the fundamental building blocks of atomic nuclei. Rutherford dubbed these hydrogen nuclei protons, from the Greek word for first. Thanks to Moseley and others, we also know that the atomic number of each element represents the number of protons in the nuclei of its atoms.

The trouble with this suggestion is that the weights of larger atoms increase by more than their atomic number. Helium nuclei, for instance, have an atomic number of two and an electric charge twice that of a proton, but they have four times as much mass. Rutherford's answer to that objection was to propose the existence of a third kind of particle, which he dubbed a neutron, which weighed the same as a proton but did not carry an electric charge. These neutrons, he suggested, might serve as a kind of glue that hold together the protons in an atomic nucleus, which would explain an otherwise troublesome objection to his model: why these positively charged protons inside the nucleus stick together and don't just fly away from each other by electrical repulsion.

Rutherford's model of the atom was not widely accepted at first, but when neutrons were finally discovered in 1932, he was vindicated.

Before 1932, physicists used protons or alpha particles to pry into the secrets of the atom, but since both of these particles are positively charged, they are repelled by atomic nuclei, which limits their usefulness. But the discovery of the neutron led to techniques to create neutron beams, which are electrically neutral and therefore not repelled by atomic nuclei. In contrast to protons and alpha particles, neutrons readily interact with atomic nuclei. They can be absorbed, which changes the isotope of the atom; it might even lead to changing it into a different element. If they are sufficiently energetic, they can even split an atomic nucleus into fragments, also resulting in the production of new elements. Think of it. The ancient dream of transmutation of elements might finally become a reality.

Research with neutron beams greatly accelerated—sorry, I couldn't resist—greatly accelerated atomic research in the 1930s, and over the next fifteen years, led to…well, you already know what it led to.

But that is most *definitely* a story for another episode.

[music:

So in 1911, Ernest Rutherford, who has to count as one of the great names in science in this or any century, gave us the familiar model of the atom, one we still teach today, at least in the introductory courses: a small nucleus consisting of even smaller protons and neutrons clumped together, with a collection of electrons whizzing around it. This iconic image can be found in many places, even in our time, such as the logos of the US Atomic Energy Commission and the International Atomic Energy Agency. Even in the logo of the US television series, *The Big Bang Theory*.

The most important insight the Rutherford model gives us is the nature of the atom. Atoms were originally conceived to be of many types. Later chemists came to understand that there were only as many kinds of atoms as there were chemical elements. Now Rutherford's model tells us that these ninety or so different kinds of atoms are merely different configurations of just three fundamental particles. Very simple. Very elegant.

But the Rutherford model is only a crude approximation. First of all, the scale of a real atom is way off from how we usually visualize them. If you imagine enlarging a hydrogen atom until the single proton that makes up its nucleus is the size of a golf ball, then its single electron would orbit it at a distance of about a mile. An atom is mostly empty space.

Now that I've given you that mental picture, you might want to complete it and ask me, well, how big is that electron, and how fast does it move in the six-and-a-quarter mile circumference of its orbit around the golf ball?

And I won't be able to answer that question. Because here is a crucial point: there *is* no answer to that question. Electrons are not tiny little spheres that have a fixed location and move at a particular velocity. Electrons do not have a position or velocity, as we understand those concepts. In the model I just gave you, the electron exists more as a set of probabilities. It is somewhere in a spherical shell of possible locations centered on the golf ball and about a mile in radius. Where it is at any given moment, and where it's going to be in another moment are questions that do not have simple answers.

We'll come back to that. There are still problems with the Rutherford model, the biggest one of which was apparent as soon as Rutherford proposed it. The analogy between an atom and a solar system doesn't survive even casual scrutiny. A planet can circle its sun for millions of years in a perfectly stable orbit, no problem. But that's because planets don't carry an electric charge. Or if they do, that charge is infinitesimally small compared to the mass of the planet. An electron, on the other hand, has a much, much higher ratio of charge to mass, and when an object with an electrical charge is made to move in a curved orbit, it emits electromagnetic radiation. That means it loses energy, which would make it fall. An electron orbiting a proton in the way we usually mean when we use the word *orbit* would lose its momentum and fall into the proton in less than a second.

The Danish physicist Niels Bohr didn't exactly have an answer for that problem, but he did have an insight that took atomic physics a step closer to the answer. Bohr looked at the work of Albert Einstein, episode 37, in which he showed that light behaved in some ways like a particle, and applied it to Rutherford's model of the atom. Each type of atom absorbs and radiates light at certain frequencies. That's how spectroscopes work. Those frequencies correspond to specific energy levels. Bohr proposed that electrons could and did gain or lose energy as they orbited the nucleus, but only at certain discrete levels. An electron might absorb the energy of a photon and leap up to a higher orbital level, and then later emit a photon with the same amount of energy and drop down to a lower level.

The key point was that electrons could not orbit at just any level. There were only certain specific levels that were possible. Nothing in between. Why were those specific levels and only those levels stable? Bohr didn't have an answer for that, but the beauty of his model was that Bohr could work out the electron levels for a hydrogen atom and demonstrate mathematically the specific spectral emission and absorption lines that had already been observed in the laboratory.

Unfortunately, the Bohr model didn't work so well for any element other than hydrogen, and Bohr didn't have an answer for why that was the case either, but still, the Bohr model was a big step forward, and it earned him the 1922 Nobel Prize in physics.

But we still don't have an answer to the question of why these particular orbits—and only these particular orbits—are stable. The insight that provided the answer to that question came from the French physicist and aristocrat Louis de Broglie. Remember that in 1905, Einstein demonstrated that light, which was known to be a wave, in some aspects behaved like a particle. Fourteen years later, de Broglie flipped that breakthrough around and wondered whether electrons, which were known to be particles, might in some aspects behave like a wave. If they did, then they would only fit into certain orbits that matched their wavelengths. And that explained why electrons behaved the way the Bohr model required.

That breakthrough, made when de Broglie was just 31 years old, won him the 1929 Nobel Prize in physics. Remarkably, it wasn't just that de Broglie was relatively young; this was his Ph.D. thesis. The reason he was still working on his Ph.D. in his early thirties was that he had spent five years in the French Army during the Great War as a radio technician.

From there we move on to the Austrian physicist Erwin Schrödinger. Following up on de Broglie's hypothesis in 1926, Schrödinger set aside the particle aspect of the electron and treated electrons instead as entirely wave phenomena. He worked out the wave function, known as Schrödinger's equation, which described the various possible states of an electron. This equation proved far more successful than Bohr's model at predicting the spectral lines an atom could produce, and won Schrödinger the Nobel Prize in physics in 1933.

It also proved far less successful in giving us a mental image of what goes on inside an atom. What does a wave function even mean? What does it look like? What does it represent? Just one year later, in 1927, another, German, physicist, Max Born, showed that Schrödinger's equation was in effect a description of the probability that the electron would be at any particular place at any particular time. I tried to tell you few minutes ago. Electrons don't so much orbit an atom as exist in a cloud of probabilities, which might be spherical, or elliptical, or dumbbell shaped, or donut shaped. Since these aren't orbits in a classical sense, we now call these mathematical functions *orbitals.*

Max Born picked up his Nobel Prize in 1954.

Also in 1927, German physicist Werner Heisenberg demonstrated that one of the consequences of Schrödinger's equation was that there was a fundamental limit to how precisely you could determine such properties of an electron, such as its position or its momentum. Heisenberg got his Nobel Prize in 1932.

This last discovery is commonly known as Heisenberg's Uncertainty Principle, and I find when I talk to people about this, there's a lot of confusion, so I want to emphasize one important point. Heisenberg was not merely saying that there is a limit to what humans can observe, or that the devices we use to study subatomic particles have some fundamental limit on their precision. He is saying that precise locations and momenta of small particles like electrons *do not exist*. It's not that we can't measure them, it's that there's nothing to measure. As Gertrude Stein might have put it, there is no *there* there.

Or as the British biologist J.B.S. Haldane famously said, in that very same year, 1927, "the Universe is not only queerer than we suppose, but queerer than we *can* suppose."

Modern physics had demonstrated that at the atomic level, the properties and behavior of matter are very different from physical matter as we experience it in our everyday lives. In the 19th century, physics was reducing our understanding of the Universe into a few elegant equations that accounted for every phenomenon humans could observe. Now, twentieth century physics is handing us complex differential equations only a few people can understand that tell us that nothing we think we know is actually real. This is going to have both scientific and cultural repercussions.

This indeterminate, probabilistic view of how the Universe works on a subatomic scale was disturbing even to the physicists who developed it. Schrödinger himself said of it, "I don't like it, and I'm sorry I ever had anything to do with it."

The consensus view of physicists of the time has come to be called the "Copenhagen interpretation" of quantum mechanics, apparently because Bohr and Heisenberg had worked together in Copenhagen for a time, although this term didn't appear until the 1950s. There is no definitive statement of what the Copenhagen interpretation is, but in essence it amounts to this: that the properties and behavior of subatomic particles are intrinsically undeterminable. We can describe these particles only in terms of wave functions and probabilities.

But wait. Forget about atoms for a minute and take the simpler case of an electron traveling through empty space, say in a vacuum tube. The wave function tells us that the probability of the electron being at any given place spreads out over time, until after a while we essentially have no idea where it is. But we can detect it with an instrument, and then we know where it is. Maybe not exactly, but we have more information than we did a minute ago. How do we account for that? Looking at it through the perspective of the Copenhagen interpretation, we must conclude that the detector has increased our knowledge of the system by changing the wave function.

That's a really weird explanation, since it implies that we can affect a subatomic particle or process merely by looking at it. But that's what the Copenhagen interpretation is telling us. It seems inconceivable, paradoxical. You might try to wriggle out of this problem by saying, well, okay, subatomic phenomena are really strange, but all these things go on at a very small level. It doesn't have any consequences for our day-to-day lives. Schrödinger himself rebutted that answer, though, with his famous thought experiment involving a cat. You put a cat in a box with a mechanism that will kill the cat if an electron is detected over here, but will spare the cat if the electron is detected over there. Let's say there's a 50-50 chance of either outcome. Now, the Copenhagen interpretation tells us that as long as the box is closed, the cat exists only as a cat wave function that embraces both of those possibilities until we open the box, at which time the cat wave function will change into either a cat-alive wave function or a cat-dead wave function.

Weird, huh? Not to mention disturbing. The point is that we can't dismiss quantum mechanics as merely a subatomic phenomenon. It has implications even for the behavior of objects in our everyday world.

The physicist who was bothered the most by the bizarre implications of the Copenhagen interpretation was the biggest name of them all: Albert Einstein, who won his own Nobel Prize in physics in 1921, by the way. Einstein struggled with quantum mechanics and the Copenhagen interpretation. He never really reconciled himself to them. In a series of debates beginning in 1927, Einstein attempted to poke holes in this understanding of quantum mechanics. It fell to Niels Bohr to play defense. We can think of this as the second great debate in twentieth century science, after the first one over the scale of the cosmos that I told you about in episode 221. Like that debate between Harlow Shapley and Heber Curtis, the debate between Albert Einstein and Niels Bohr was not a hostile confrontation, but a calm and professional examination of the state of the field.

It's not that Einstein disputed the truth of the findings that led to the Copenhagen interpretation. It's that he believed the picture was incomplete. This was just an approximation, one that could eventually be refined into something simpler and more elegant. But Bohr and his colleagues disagreed. They argued that the indeterminate, probabilistic picture of what goes on at the subatomic level represents a fundamental understanding of processes that underlie our entire Universe.

Einstein's refusal to accept a probabilistic picture of quantum mechanics is summed up in his famous quip, "God does not play dice with the Universe." The only response Bohr could come up with to that was to retort, "Nor is it our business to prescribe to God how He should run the world."

A lot of people still don't understand what Einstein meant when he said, "God does not play dice with the Universe," and think he was advocating something like predestination. "There are no accidents; everything that happens is part of God's plan." Not at all. This was not a theological statement. And if you'll indulge me for yet another one of my trips down memory lane: when I was in college, a friend of mine, a liberal arts major, wrote a paper on the theme that Einstein was wrong, because of course the world includes the random and unexpected. I tried to explain to him that Einstein was not advocating predestination, he was quarrelling over the Copenhagen interpretation, and he, my friend, was misinterpreting Einstein's assertion. He actually laughed at me and said, "Well, Mark, if I'm misinterpreting it, then a lot of people are misinterpreting it."

I said, "Yes, that's exactly my point." He still didn't believe me, so I'll take my revenge now by telling you about it, fifty years later. Also, Einstein was not a particularly religious man. He was using "God" as a metaphor for the mechanics of the Universe. He meant only that he couldn't accept that random chance would play so large a role in the workings of reality. But he was wrong.

At the time my friend and I had that argument, the Copenhagen interpretation was fifty years old and a lot of people outside the field were still struggling with what it meant. I like to think most educated people are better informed today, but it highlights the fact that at the time, quantum mechanics was a field understood by very few people. Most in 1927 went about their lives with little or no understanding of these incredible theoretical breakthroughs. It would take until the atom bomb made its appearance before the general public would be forced to confront how much their world had changed.

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The study of radioactivity and quantum mechanics had few practical applications in the 1920s. But one of them was glow-in-the-dark phosphorescent paints. I already told you about wristwatches in episode 47. Most men of the Belle Époque era preferred pocket watches and disdained the wristwatch as unmanly. But they were very useful on the battlefield; soldiers could check the time even when their hands were full. After the Great War, pocket watches became thought of as old fashioned and wristwatches would supplant them.

But it was during the war that someone got the idea of painting markings on the watch face with phosphorescent paints. Even better, if you added a little radium to the paint, the radioactivity from the radium would keep the paint glowing for years, allowing soldiers to easily check the time even in the dark.

A company called U.S. Radium painted watch and clock faces at its plant in Orange, New Jersey, beginning in 1917 as part of the war effort and continuing into peacetime in the 1920s. It employed about 70 women to do the painting. Within a few years, the company began to have concerns that the luminous paint might be dangerous. The company shared its information with medical researchers, but kept it from its workers, who were told all along that the paint was perfectly safe. These women were coached to moisten their paintbrushes in their mouths to get a nice, fine tip on the brush before applying the paint. Many of the workers thought the paint was fun to play with and would do things like paint their fingernails with it. One woman painted her teeth with it before going on a date, so she could show her boyfriend a glow-in-the-dark smile.

A little bit of radium on your wrist might not be very dangerous, but ingesting radioactive material certainly is. The radiation can do a lot more harm to your body on the inside than it can coming from the outside.

By the early 1920s, many of these women, still in their twenties, began experiencing serious health problems, often in their mouths and jaws. One employee had a tooth pulled, but the socket wouldn't heal. Others experienced fractures and decay in their jawbones, symptoms that came to be called "radium jaw."

By 1923, these "radium girls" as they were called at the time, began dying slow, painful deaths in what is supposed to be the prime of life. In March 1925, the New York *Times* picked up the story when one of the "radium girls" filed a $75,000 lawsuit against the company, which still maintained that the paint posed no health risk. In 1927, the New Jersey Consumers League, a branch of the National Consumers League founded by women activists like Florence Kelley and Jane Addams, organized five of the "radium girls" into a joint lawsuit against the company.

The lawsuits and the adverse publicity forced the company to settle, which set a precedent in American law that employers could be held liable for occupational illnesses of their employees. Dial painters eventually got proper protective equipment, and clocks and wristwatches with glow-in-the-dark paint were made and sold into the 1960s. I had some when I was a kid.

We'll have to stop there for today. I thank you for listening, and I'd especially like to thank Jonathan and Brendan for their kind donations, and thank you to Chelsea for becoming a patron of the podcast. Donors and patrons like Jonathan and Brendan and Chelsea help cover the costs of making this show, which in turn keeps the podcast available free for everyone, so my thanks to them and to all of you who have pitched in and helped out. If you'd like to become a patron or make a donation, just visit the website, historyofthetwentiethcentury.com and click on the PayPal or Patreon buttons.

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And I hope you'll join me next week, on *The History of the Twentieth Century,* as we take a different look at science in the Roaring Twenties. By this time, Darwin's theory of evolution by natural selection was accepted as fact among biologists. Nevertheless, believe it or not, there was still resistance to the idea in some quarters, even sixty years after the fact. Inherit the Wind, next week, here, on *The History of the Twentieth Century.*

Oh, and one more thing. This Rutherford model, in which an atom looks like a tiny solar system, was superseded almost as soon as it was proposed, but it stuck in the popular consciousness. It also attracted the attention of science fiction writers.

One example is Ray Cummings, who worked as a technical writer for Thomas Edison during the Great War. In 1919, as Rutherford and others were putting the finishing touches on that model, Cummings published a short story titled “The Girl in the Golden Atom,” expanded into a novel published in 1922, which was about…well, you can guess what it was about from the title. This novel is best remembered today for the line, “Time…is what keeps everything from happening at once,” which is often quoted, and often misattributed to Albert Einstein.

This story was an early example of science fiction, though it was not until 1926 that the term “science fiction” was coined.

I would be remiss if I did not also mention Henry Hasse’s classic science fiction story, “He Who Shrank,” published in *Amazing Stories* in 1936. The narrator is an unfortunate lab assistant who becomes an involuntary subject for his boss’s experiment when he is injected with a drug that causes him to perpetually shrink. As he grows smaller, he is threatened at first by small animals, then insects and microbes before shrinking to the atomic level, when he finds himself floating in space, gradually approaching an inhabited planet, where he becomes small enough to interact with the natives, then smaller still, and the cycle repeats, over and over again.

Along the way, he encounters our world. Cleveland, Ohio, to be exact, where he leaves a record of his experiences, presumably the source for the story we are reading, before shrinking into invisibility once again. What I remember most vividly about this story is him scoffing at arrogant human theories about an expanding universe, which were cutting edge science in 1936. This fellow knew better. He knew from personal observation that our universe is merely a puff of smoke within a higher reality.

[music: Closing Theme]