The History of the Twentieth Century
Episode 278
“Chain Reaction”
Transcript

[music: Fanfare]

The discovery of the neutron in 1932 was a breakthrough in atomic physics. But it was a subtle discovery. Only specialists understood what it meant. To the average member of the general public, it was just an intellectual curiosity, like a duck-billed platypus. Interesting that scientists discovered this, but it doesn’t actually change our lives.

Not yet.

Welcome to *The History of the Twentieth Century.*

[music: Opening Theme]

Episode 278. Chain Reaction.

Back in the early days of this podcast, we talked about radioactivity, which was one of the biggest scientific mysteries at the beginning of the twentieth century. In the first two decades of the century, the physicist Ernest Rutherford determined that the emissions from radioactive materials consisted of what he dubbed alpha rays and beta rays. Later investigation would add gamma rays to the mix. Upon further investigation still, alpha rays proved to be helium nuclei, beta rays electrons, and gamma rays high-energy electromagnetic radiation, comparable to x-rays.

We talked about atomic physics most recently in episode 246, in which I told you how physicists bombarded matter with these rays as a means of investigating the structure of the atom. By 1921, Rutherford had sketched out his famous model of the structure of an atom: a small, dense, central nucleus with a positive electric charge, surrounded by a large volume of empty space in which electrons orbited that nucleus.

This is basically how we still think about atoms today, although the Rutherford model is way oversimplified. It does have the advantage of offering a basic understanding of how subatomic particles come together to form an atom, but it doesn’t take into account the peculiarities of quantum mechanics. Electrons are particles, but they also behave like waves, or they are waves that also behave like particles, take your pick, but in 1926 the Austrian physicist Erwin Schrödinger worked out the electron wave function, from which can be derived the probability of an electron being in a certain location. Because electrons don't have fixed locations, but exist as a sort of cloud of probabilities around the atomic nucleus.

We'll come back to electrons, but for now let's set them aside and focus on the atomic nucleus. The simplest atomic nucleus is that of hydrogen, which has an atomic number of one, a positive charge of one, and is orbited by one electron. I should say, holds one electron in a probability cloud around it, called an orbital.

As part of his model, Rutherford proposed that the nuclei of atoms with higher atomic numbers are clusters of that number of hydrogen nuclei, making the hydrogen nucleus the fundamental building block of larger atoms. Rutherford dubbed hydrogen nuclei *protons,* from the Greek word for first.

The difficulty with this suggestion is that it accounts for the electric charge and the number of electrons in larger atoms, but it doesn't account for mass of larger atoms. A helium nucleus, for example, has an electric charge of two, which is consistent with the idea that it is made up of two protons, but it has a mass about four times that of a hydrogen nucleus. As we go up through the list of elements in order of atomic number, the two times rule holds for many of the lighter elements: for instance, the oxygen atom has an atomic number and electric charge of eight, but a mass of sixteen, and so on. When you move on to heavier elements, the mass increases even more than double the increase in atomic number. So for example, when you get all the way up to the top of the list, which is uranium, with an atomic number of 92, you find a nucleus with an atomic weight of about 238, which is about 2.6 times the atomic number.

Rutherford addressed this problem by proposing the existence of a third kind of particle, which he called a neutron. These neutrons would have the same mass as a proton, but they would be electrically neutral, hence the name. Rutherford proposed that neutrons might serve as a kind of glue that holds the protons in a nucleus together, which would explain why protons, which are positively charged and should therefore repel each other, remain stable within the nucleus and don't just fly away from each other and disintegrate the atom.

And that's about where I left you at the end of episode 246. I should emphasize though, that when Rutherford hypothesized the existence of a third subatomic particle, the neutron, this suggestion was not generally accepted. I highlight it because he was right, but in 1921, most physicists studying atomic structure thought it more plausible that the glue that held atomic nuclei together was electrons, negatively charged particles that attracted the positively charged protons around them.

To illustrate: nitrogen has an atomic number of seven and an atomic weight of fourteen. Rutherford is proposing that the nucleus contains seven protons and seven of his hypothetical neutrons. Other physicists saw no reason to invent a new particle when you could just as easily explain the nitrogen nucleus as a clump of fourteen protons and seven electrons.

Over the decade of the 1920s though, as investigation into the structure of atoms and the wild and wacky world of quantum mechanics advanced, new discoveries were making the proton-electron model of the atomic nucleus untenable. One such development was Erwin Schrödinger's derivation of the electron wave function that I mentioned a minute ago. Once Schrödinger presented his description of the electron, naturally other theoretical physicists tried to apply it to the circumstances of an electron embedded in an atomic nucleus, and what they found was unexpected.

Well, by now everyone was used to the unexpected in the wild and wacky world of quantum mechanics, but here's what they learned: in our everyday world, if an object with a negative electric charge gets stuck to an object with a positive electric charge, they remain stuck together unless and until some external force pries them apart. But in the wild and wacky world of quantum mechanics, where electrons don't have fixed locations and exist only as a cloud of probabilities, an electron embedded within a clump of protons could quite possibly probability itself right out of there and into free space, a process known as quantum tunneling. One instant, the electron is safely embedded within the atomic nucleus, like a little kid snuggled in bed for the night, the next minute the electron is liberated from the nucleus and whizzing through free space, like the same little kid caught downstairs in the kitchen, raiding the cookie jar, five minutes later. At least, that's what always happened in my house.

The upshot is this: if atomic nuclei are composed of clumps of protons and electrons, the electrons should be able to escape, causing the nuclei to disintegrate, which implies that matter is unstable. Since we know matter is in fact stable, something is wrong with this picture.

And here's another problem: In 1924, the Austrian theoretical physicist Wolfgang Pauli, proposed that electrons had a property called *spin*. As the name implies, spin was originally conceived as the electron spinning in the ordinary sense, but since electrons are not really particles, they can't really spin in the ordinary sense, but even in the wild and wacky world of quantum mechanics, electrons can spin, meaning they can carry angular momentum, but they can only spin at one speed: one half. (Don't ask me one-half of what, just go with it, okay?) They can spin in either of two directions, so an electron spin can be described as minus one half or plus one half.

Pauli made this proposal because it helped explain molecular spectra. It also helped explain the behavior of electrons. It seems electrons in atoms or molecules like to pair off by spin in the same orbital. It also seems that you can never have two electrons with the same spin in the same orbital. This came to be called the Pauli Exclusion Principle, and this work won Wolfgang Pauli the Nobel Prize in physics in 1945.

It turns out protons also have spins, which also can be plus or minus one half. When experimental physicists worked out how to measure the spin of an atomic nucleus, the results were perplexing. When you have two subatomic particles, their spins might be opposite, which would add up to zero, or they might be the same, which would add up to minus one or plus one. This implies in an atomic nucleus, the nucleus should have an integer spin if it contains an even number of particles or an integer plus or minus one half if it contains an odd number of particles.

Remember the nitrogen nucleus as I described it a few minutes ago? If the nitrogen nucleus is made up of fourteen protons and seven electrons, that makes 21 particles in total, so the spin shouldn't be an integer. But it was. The spin of a nitrogen nucleus is one. That should be impossible if a nitrogen nucleus is made up of 21 particles, but if a nitrogen nucleus was made up of seven protons and seven neutrons, it made perfect sense.

Because of these results, by 1930, the proton-electron model of the atomic nucleus was in serious trouble. None of this proves the existence of neutrons, mind you, but it does suggest that there is something going on inside an atomic nucleus that we don't yet understand. It might be neutrons, or, as some suggested, it might be that when a proton and an electron come together, they behaved differently, for some reason. But this suggestion comes pretty close to accepting the neutron hypothesis, doesn't it?

But it still isn't proof. The easiest way to prove the existence of neutrons is to detect them alone, in isolation from atomic nuclei. On the other hand, if a particle has no electric charge, how exactly do you detect it?

By its mass. At this time, the most important tool experimental physicists had for investigating the structure of the atom was alpha rays. There were also beta rays and gamma rays, but alpha particles are much larger and heavier, large enough and heavy enough, in fact, that when you shoot them at the nucleus of an atom, the nucleus feels it. That's because alpha particles are in fact nuclei themselves—helium nuclei to be specific.

Anyway, experimental atomic physicists of this era busied themselves firing alpha particles at everything and anything, just to see what happened and perhaps unlock some of the secrets of the atom. Recall that Ernest Rutherford had worked out his rough model of the structure of an atom from the results of alpha particle bombardment. Other experimenters made other discoveries.

The two simplest elements are hydrogen and helium, atomic numbers one and two, respectively. The next simplest are lithium, atomic number three, beryllium, atomic number four, and boron, atomic number five. In 1930, two German researchers, Walther Bothe and Herbert Becker, tried firing alpha particles at these atoms. They found that when they did this to any of these materials, but especially beryllium, it produced a powerful form of radiation. This radiation was unaffected by electric fields, as alpha or beta rays would be, so they figured it was gamma radiation.

In 1932, French researchers Irène Joliot-Curie and Frédéric Joliot tried firing this new and not well understood form of radiation at paraffin wax and found that it caused the paraffin to give off protons. Paraffin contains hydrogen atoms, so it seemed reasonable that the unknown radiation was knocking hydrogen nuclei right out of the molecules of the paraffin.

It was hard to conceive that gamma rays could be powerful enough to do that. Across the Channel, at Cambridge University, where Ernest Rutherford was still running the Cavendish Laboratory, his assistant director and former student James Chadwick repeated the experiment and after studying the behavior of the protons ejected from the paraffin, concluded that the best explanation was that the unknown radiation consisted of particles of about the same mass as a proton, but lacking an electric charge. The elusive neutron had been revealed. This finding won Chadwick the 1935 Nobel Prize in physics.

The discovery of the neutron shed light on another nuclear mystery. By this time, researchers had determined that not all atoms of a given element had the same atomic mass. As spectrographs became more sensitive, it became easier to demonstrate this, most dramatically in 1931 when American chemist Harold Urey demonstrated the existence of deuterium, a kind of hydrogen made up of atoms with twice the mass of a typical hydrogen atom. In order to do this, Urey had to develop a technique for distilling liquid hydrogen in order to increase the concentration of the heavier deuterium molecules. This was no small feat, and it earned him the 1934 Nobel Prize in chemistry.

It turns out that one out of every six thousand hydrogen atoms on Earth is actually a deuterium atom. Over the next few years, chemists devised techniques for separating out deuterium from hydrogen, and even combining deuterium with oxygen to make a special kind of water, which became known as "heavy water," because chemically it is identical to ordinary water, but it's just a little bit heavier.

The discovery of the neutron provided an explanation for this. A typical hydrogen atom had a nucleus consisting of a proton, but a deuterium atom has a nucleus that consists of a proton and a neutron. Similarly, variations in atomic mass among atoms of other elements can be explained by variations in the number of neutrons in the nucleus. Atoms of the same element, that is, with the same atomic number, but with different atomic weights, are called *isotopes*, so for example, deuterium is an isotope of hydrogen.

Now that physicists had not only proved the existence of neutrons, but discovered a way to generate beams of neutrons, they had a new tool for probing atomic structure, in addition to alpha particles and protons. Those particles have positive electric charges, so they are repelled by atomic nuclei, which in turn means you have to fire them into the atom at a very high energy to get them to interact with the nucleus. Neutrons, by contrast, could be shot into an atomic nucleus with much less energy, at a lower velocity, making them a gentler tool for investigation. Imagine that someone gave you a wrapped present and you were trying to figure out what's inside the box without unwrapping it. You could hit it with a sledge hammer and that might tell you something, but tapping it with your fingers will likely tell you more.

[music: J.S. Bach, *Two-Part Invention No. 8 in F major*]

Experimental physicists were learning how to investigate atomic structure with an expanding tool kit, but they were still limited to particle streams generated by naturally radioactive materials. That also changed in 1932, with a second discovery made at the same place, the Cavendish Laboratory at Cambridge, just weeks after Chadwick did his study of neutron radiation.

British physicist John Cockcroft and Irish physicist Ernest Walton constructed one of the earliest particle accelerators, which used steep electric voltages to accelerate protons. This technology allows for the creation of particle beams without relying on naturally occurring radioactive materials, and if you crank the voltage up high enough, you can generate streams of particles far more energetic than what you can get from naturally occurring radiation.

Cockcroft and Walton tried bombarding lithium with their proton beam and found this produced alpha particles. A lithium atom consists of three protons and four neutrons. A proton from the beam enters the nucleus and breaks it into two pieces, each consisting of two protons and two neutrons—which are the constituents of an alpha particle.

In other words, they had built an electrical device that could break atomic nuclei. When the discovery was announced, this accomplishment became known in the newspapers as "splitting the atom." And not only that, but it turns out that when you split a lithium nucleus, the reaction produces more energy than was introduced by the proton. Rutherford explained this when he announced the result to the press, and remarked that theoretically you would be able to generate power by splitting lithium atoms, although he quickly added that such a technique would never be practical.

Also at Cambridge University was an eccentric math professor and theoretical physicist named Paul Dirac. In 1928, Dirac modified Schrödinger's wave equation for the electron to introduce Einstein's theory of relativity. The Dirac equation thus allows for a description of an electron moving at speeds close to that of light. Paul Dirac would share the 1933 Nobel Prize in Physics with Erwin Schrödinger for this equation.

An interesting sidelight of the equation is that it can be solved for an electron with positive energy or one with negative energy. A negative-energy electron sounds like an impossibility, but in the wild and wacky world of quantum mechanics, you never rule something out just because it's hard to understand in terms of our everyday world. In a follow-up paper, Dirac explored the question of what the negative-energy solution might mean. It meant such a particle would have a positive electric charge. Dirac raised the possibility that this solution represented a proton, except that a proton has a much larger mass than an electron, so that doesn't quite fit.

American theoretical physicist J. Robert Oppenheimer pointed out another problem. The implication of the Dirac equation was that if a positive-energy electron and a negative-energy electron interacted, they would annihilate each other. We know that doesn't happen between electrons and protons, because atoms exist, so that seemed to rule out the proton as the solution to the problem.

In 1931, Dirac published another paper, further developing the idea of a negative-energy electron. He dubbed this hypothetical particle an "anti-electron," and predicted it would have the same mass as an electron, but a positive charge, and if it came in contact with an electron, both particles would be destroyed.

American physicist Carl David Anderson produced experimental confirmation of the existence of this particle in August 1932. He used a device called a cloud chamber, which was an important tool for the study of subatomic particles in the mid-twentieth century.

In brief, a cloud chamber is a sealed container containing air that is supersaturated with water or alcohol. When a charged particle passes through this air, it triggers condensation of the water or alcohol vapor, which produces a trail, something like a miniature version of the contrail a jet plane makes. If you apply an electric or magnetic field to the cloud chamber, it will cause the particles to change direction as they pass through, and the curvature of their path provides information about their mass and electric charge.

Anderson was using a cloud chamber to study cosmic rays and found a trail left by a particle with a positive charge and the mass of an electron. When he published his result, the editor of the journal proposed the name *positron* for the newly discovered particle. For a while, the suggestion was bandied about that an ordinary negatively charged electron be called a *negatron*, with the word *electron* to be redefined as a category of particle, either negatrons or positrons.

For his discovery, Carl David Anderson won the 1936 Nobel Prize in physics. That same year, he discovered another new subatomic particle, the muon, but you know, there's a limit to how many different subatomic particles I'm willing to talk about, and I may have just reached it.

And by the way, when Paul Dirac received his Nobel Prize in 1933, he gave a Nobel lecture in which he speculated about the existence of anti-protons. These were proven to exist in 1955, and anti-neutrons were discovered in 1956. In his lecture, Dirac considered the possibility that the fact that our world and presumably our solar system were made up of protons and electrons might be mere happenstance, and that other stars and worlds might be made up of antimatter. Since the light emitted by antimatter stars would look just the same, there would be no way for astronomers on Earth to tell the difference.

I would add that if you consider the fact that cosmic rays, which originate beyond our solar system, contain positrons, you might be tempted to take that as evidence of the existence of antimatter solar systems. But in fact, in our time, it is believed that no known object in the universe is made of antimatter, because if it were, the radiation created where antimatter interacts with regular matter would be intense enough to be detected by modern astronomical instruments, so even though matter and antimatter look symmetrical in theory, in fact the Universe appears to have a strong bias in favor of matter and against antimatter, for reasons not well understood even in our time.

I told you in episode 264 about the discovery of Pluto, and how once it was discovered, it was possible to find Pluto in older astronomical photographs that had detected Pluto, only to have it mistaken for a star. Similarly, once the positron was discovered, it was possible to review earlier cloud chamber results from other researchers and find positron trails that those researchers had overlooked or misinterpreted, including the team of Irène and Frédéric Joliot-Curie in Paris. And in case you're wondering, yes, Irène is indeed the daughter of Marie and Pierre Curie. She and her husband Frédéric were hoping to make their name in the study of radioactivity and atomic physics just as her parents had, episode 9. Unfortunately for them, they just missed out, on both the opportunity to discover the neutron and the positron.

Don't feel too sorry for them, though. In 1934, they demonstrated that alpha particle bombardment can be used to change an atom of one element to an atom of another element, two atomic numbers higher. So for example, the nucleus of an atom of aluminum, with an atomic number of 13, will absorb an alpha particle and become a phosphorus nucleus, with an atomic number of 15. The alchemists of old dreamed of transmuting other elements into gold; now the Joliot-Curies had shown a way in which it can actually be done.

This method of transmutation isn't practical for manufacturing elements in large quantities. You couldn't make gold this way, not economically. You might as well extract gold from seawater the way Fritz Haber proposed, episode 108. But that hardly matters, because you can use this method to create something far more valuable than gold. For instance, in the example I just gave of transmuting aluminum into phosphorus, you don't get a stable isotope of phosphorus; you get a radioactive isotope.

This is important because until now, chemists and physicists researching radioactivity had only naturally occurring radioactive materials to work with. This involved mining radioactive ores and extracting the radioactive elements, a process pioneered by Irène's parents, Marie and Pierre Curie. This process was often complex and tedious, as it involved extracting a tiny amount of material from literal tons of ore. The Joliot-Curies had discovered a method for creating artificial radioactive materials without going through all that drudgery. Even better, by bombarding various elements with alpha particles, or protons, or now neutrons, you could create radioactive isotopes of every one of the 90 naturally occurring elements.

That's a lot of different materials to experiment with, and researchers would spend the rest of the 1930s bombarding anything and everything, just to see what happens. As for Irène and Frédéric, they won the 1935 Nobel Prize in chemistry for this discovery, making them the second husband-wife team to win a Nobel Prize. The first was of course Irène's parents.

One of the experimenters who set to work on this was the Italian physicist Enrico Fermi, who tried bombarding uranium nuclei with neutrons. In 1934, he announced that using neutron bombardment of uranium, the largest known atom, with an atomic number of 92, he had produced small quantities of two previously unknown elements, with atomic numbers 93 and 94. Not everyone was persuaded, though. Other atomic physicists argued that perhaps what Fermi had actually done was break uranium nuclei apart into nuclei of known elements with lower atomic numbers. We'll have to look into that one further and get back to you.

Even so, this finding was important enough to win Enrico Fermi the 1938 Nobel Prize for physics.

And that brings us to Hungarian physicist Leo Szilard. He was born Leo Spitz to a Jewish family in Budapest in 1898, but as longtime listeners are well aware, back in the days of the Dual Empire, everyone in the Kingdom of Hungary was required to have a Hungarian name, so the Spitz family became the Szilard family. It means *solid* in Hungarian; as a name, it can also be read as a cognate to Constantine, as in the Roman Emperor.

Leo studied engineering and joined the Army in 1917. He was sent for officer training, then fell ill with influenza as so many did in 1918 and had to be hospitalized, which likely spared him an even worse fate on the battlefield. After the war, Leo attempted to resume his engineering studies, but in an even more nationalist Hungary, he was barred from university because of his Jewish heritage, although it seems Leo himself was not religious.

Unable to pursue his education in Hungary, Leo moved to Berlin, at first to study engineering, but he soon changed majors to physics and attended Friedrich Wilhelm University, where he studied under Max Planck and Albert Einstein, among others. He received his doctorate in 1922, taught physics, and became a German citizen in 1930. This last development proved to be ill timed. When Hitler became chancellor, Szilard was quick to recognize that the new Germany was not a safe place for immigrants, especially Jewish immigrants, and he packed his bags, moved to Britain, and urged others to do the same. Between 1933 and 1939, Leo Szilard worked to help academics fleeing the repression in Germany to find work and build new lives in the West.

On the morning of September 12, 1933, while the now-35-year-old Leo Szilard was living in a hotel in London, he came across an article in *The Times* about Cockcroft and Walton and their research at the Cavendish Laboratory in Cambridge in using protons to split lithium nuclei, which I told you about a few minutes ago. The article included that quote from Ernest Rutherford, who noted that although the splitting nucleus released more energy than the proton supplied, he insisted it would be impractical. He dismissed any suggestion that you could produce power this way as "talking moonshine."

Rutherford's words annoyed Szilard, whose own research work involved both particle physics and thermodynamics, so he was in a position to know, and to him, Rutherford's dismissal seemed way premature. To the contrary, Szilard saw the question of generating power from subatomic particle interactions as already demonstrated. Scaling it up was a mere engineering problem. He got to thinking about it, and as Szilard so often did when he needed to think, he went for a walk. Famously, as Szilard stopped to wait for a traffic light where Southampton Row meets Russell Square, just a hop, skip, and a jump from the British Museum, it came to him.

The recently discovered neutrons were known to be present in every nucleus of every element, apart from hydrogen. Szilard imagined a neutron striking the nucleus of some atom. Suppose this interaction generates more energy than was provided by the neutron. Suppose too that the reaction results in the liberation of two more neutrons. Then suppose that these newly liberated neutrons themselves strike more nuclei of the same chemical element and liberate four neutrons. Then eight. Then sixteen. In a fraction of a second, what began as one neutron striking the nucleus of one atom would cascade into an enormous atomic reaction involving billions of atoms and liberating huge amounts of energy. It would be like a bomb going off!

A bomb going off…

In 1914, H.G. Wells published a novel titled *The World Set Free.* In its opening paragraphs, it discusses early twentieth-century research into radioactivity—it even name-checks Ernest Rutherford—then describes how in the far future year of 1933, a researcher discovers how to use the power of the atom to build explosives of tremendous destructive power fueled only by minute quantities of material. Wells called these new inventions "atomic bombs" and the novel describes how they are used in a terrible war that almost destroys civilization.

Leo Szilard had read *The World Set Free* just a year earlier, and on that London street corner found himself suddenly filled with horror at the thought that in the now very real year of 1933, he had just stumbled on the mechanism that would turn H.G. Wells' nightmare weapons into a reality. He called the process he had just imagined a "chain reaction," by analogy to chain reactions in chemistry, and proceeded to patent the idea, in the hope that he could thus prevent anyone else from using it.

The only piece missing from Leo Szilard's vision of how to build an "atomic bomb" in 1933 was that there was no known atom that when struck by a neutron would give off two or more neutrons plus energy. But the neutron had only recently been identified. Atomic physicists everywhere were experimenting with neutrons in every way imaginable, just to see what would happen. There were only 90 naturally occurring chemical elements. If any of them were a candidate for a neutron chain reaction, then it would be only a matter of time before somebody, somewhere figured that out.

And one thought in particular made Jewish refugee Leo Szilard's blood run cold: what if that somebody was a German?

We'll have to stop there for today. I thank you for listening, and I'd especially like to thank Matthew for his kind donation, and thank you to Alex for becoming a patron of the podcast. Donors and patrons like Matthew and Alex 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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Next week is a bye week for the podcast. If you find yourself with nothing to do while you wait for the next episode, I invite you to read my short story, "The Boy Who Didn't Know How to Recognize a King," now available as an Amazon Kindle Single for 99 cents, or free if you join Kindle Unlimited. It's available in a number of countries, not everywhere, sorry about that, but I invite you to check it out, and let me know what you think.

And I hope you'll join me in two weeks' time, here on *The History of the Twentieth Century,* as we turn our attention to what's going on in the United States. By 1932, some of the world's major economies, notably those of Britain and Germany, were beginning to show signs of recovery from the Great Depression. But in the US, things were only getting worse. GDP was still shrinking, unemployment still rising, and as if that wasn't bad enough, another wave of bank closures is beginning. No one in power seemed to know what to do. Perhaps what the US economy needs is some Persistent Experimentation. That's in two weeks' time, here, on *The History of the Twentieth Century.*

Oh, and one more thing. The practical uses of neutrons and of splitting atoms are well known in our time; the practical uses of the positron less so. Researchers in our time are taking the first steps toward creating antimatter, but it is terribly expensive and tedious to produce, and even more expensive and tedious to store.

Modern medicine uses positron emission tomography, or PET scans, for imaging and to track a patient's metabolic processes. PET scans rely on radioisotopes that emit positrons, which give away their location within the patient's body by annihilating an electron and disappearing into a gamma ray, which can then be detected by instruments.

In 1940, a 20-year-old American science fiction writer named Isaac Asimov published a short story, titled "Robbie," in which he envisioned a robot nanny. Science fiction was becoming an established short story genre by this time, and many writers were inspired by the robots in Karl Čapek's 1920 play, *R.U.R.,* which I talked about in episode 241. Most of their stories envisioned the robots turning on humanity, as they had in Čapek's play; in devising a tale about a robot nanny, of all things, entrusted with the care of small children, Asimov was consciously subverting this common trope.

In the story, the titular robot had what we would now call artificial intelligence, although it was not able to speak. Asimov accounts for the robot's ability to think by explaining that the robot had a "positronic brain." The existence of the positron had just been confirmed eight years earlier, and since positrons are analogous to electrons, Asimov imagined positronics as a future technology analogous to electronics, although of course it can do so much more.

Since positrons had only just been discovered and were not well understood, such a suggestion was perfectly reasonable for the time, and much more importantly, since no one knew very much about positrons at the time, no could say with authority that what Asimov was postulating was impossible. And that, dear listener, is how you write science fiction.

"Robbie" would be only the first of a large number of stories and novels about robots that Isaac Asimov would write over his career, and he became famous for them, as well as for the Three Laws of Robotics, which he would develop as an explanation for why his robots were always friendly and helpful and not at all like the robots other writers were imagining.

This imaginary technology of the "positronic brain" as a means to create artificial intelligence became so familiar that other writers of science fiction picked up on it and incorporated it into their own works. There are numerous examples in fiction, film, television, and videogames; perhaps the most famous science-fiction robot who uses a positronic brain outside the work of Isaac Asimov is the android Data from the American television series, *Star Trek: The Next Generation.*

[music: Closing Theme]