THE MYSTERY OF MATTER: SEARCH FOR THE ELEMENTS

EPISODE 2 (OF 3): UNRULY ELEMENTS
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Joseph Priestley (identified on screen) blows out a splint, which then bursts back into flame when put in a vessel.

VO

Previously on *The Mystery of Matter …*

Priestley stoops down and looks in wonder at the burning split.

BIOGRAPHER STEVEN JOHNSON, partly in VO

He realizes that something fundamentally different has happened. This air is some kind of super air.

JOSEPH PRIESTLEY

How could I explain this?

As his wife watches, Antoine Lavoisier (identified on screen) lowers a bell jar over a candle. It too burns brightly.

ANTOINE LAVOISIER, partly in VO

This subject is destined to bring about a revolution in physics and chemistry.

Lavoisier and Marie Anne are delighted when a piece of wood throws out sparks in this new gas.

HISTORIAN ALAN ROCKE VO

The discovery of oxygen really served as a starting gun for a worldwide race for new elements.

Humphry Davy (identified on screen) experiments with his first voltaic pile.

NARR: Davy had found a powerful new tool for the discovery of elements: the battery.

Davy watches the bubbles generated by electricity in water.

HUMPHRY DAVY VO

Nothing promotes the advancement of knowledge so much as a new instrument.

Funder Credits

Episode Title: Unruly Elements

Fade up to reveal a single flame. A wire loop held in the flame burns bright yellow. A wide shot reveals the host holding the loop in the flame.

HOST

One of the oldest tricks in the chemist's toolbox is called the flame test.

He now puts a different substance into the flame. It burns red.

HOST

More than a thousand years ago, Arab alchemists discovered that every substance gave off a telltale color as it burned.

He now puts in a series of elements that all burn shades of green.

HOST

But as the number of elements grew, this test became less and less useful, because some elements gave off such similar colors it was hard to tell them apart.

Host motions to photo of Bunsen and Kirchhoff

HOST

One day in 1859, a German chemist named Robert Bunsen described this problem to his good friend, physicist Gustav Kirchhoff.

He motions to parts of spectroscope, then moves an element into the flame of the Bunsen burner.

HOST

A few days later, Kirchhoff came to Bunsen's laboratory with an instrument made from two telescopes, a wooden box and a prism. They used Bunsen's latest invention – the Bunsen burner – to heat their samples. Light from the burning element passed down the barrel of this telescope to the prism, which split the light into a spectrum of colors.

Host now leans down to look into the eyepiece.

HOST

What they saw when they looked into the eyepiece was a revelation.

We cut to his point of view, revealing what he sees.

HISTORIAN ALAN ROCKE, partly in VO

You see a whole collection of sharp bright lines at very particular wavelengths, and that map of lines is distinctive for every element.

Animation reveals spectra of four distinct elements

PHYSICIST DAVID KAISER, partly in VO

It's almost like each element has its own barcode. It's a unique way of saying: this is that element and not some other.

Closeups of the spectroscope and host peering into it

NARR: Like Humphry Davy's battery, the "spectroscope" kicked off a whole new round in the discovery of elements …

Composite image of Bunsen and Kirchhoff and the spectra of cesium and rubidium

NARR: … starting with *cesium* and *rubidium*, discovered by Bunsen and Kirchhoff themselves

Composite image of the discoverers of thallium and indium and the spectra of those elements

NARR: … quickly followed by *thallium* and *indium*, discovered by other chemists who seized on their new tool.

Image: Astronomer looks into spectroscope attached to a telescope.

NARR: Astronomers, too, embraced the new technology, turning the spectroscope to the heavens.

Image of the solar eclipse and the spectrum of helium

PHYSICIST JIM GATES, partly in VO

In fact, there's one element that we found by first looking at the sun. We didn't even know it was here on earth. It was helium.

Animation showing unruly garden of elements

PHYSICIST DAVID KAISER, partly in VO

By the middle of the 19th century, there had been an explosion in the numbers of new elements that had been found. And this was exciting, but it also led to a kind of muddle that seemed to have no order, no reason behind it.

HISTORIAN ALAN ROCKE VO

Chemistry looked like an unruly garden, a jungle of bewildering details.

HISTORIAN LAWRENCE PRINCIPE, partly in VO

Human beings like to make things simple. And part of the whole, scientific enterprise is to bring order out of what appears to be chaos, to bring simplicity out of complexity.

NARR: But the ever-rising number of elements – now up to 63 – promised chemists just the opposite of simplicity: more and more variety, with no end in sight.

HISTORIAN ALAN ROCKE

How many elements were there? Was this going to continue forever?

Footage of Mendeleev working in his study

NARR: The man who would finally bring order to the elements was a young Russian chemistry professor named Dmitri Mendeleev. He didn't set out to be a savior. He was simply trying to organize the textbook he was writing. But as he grappled with this challenge over one weekend in 1869, Mendeleev would make a discovery for the ages:

Animation of the Periodic Table. We fly through the gap in the middle to discover a photo of Mendeleev.

NARR: The Periodic Table of the Elements. Today it hangs in every chemistry classroom in the world – one of the most familiar images in all of science. But behind the table is a fascinating untold story. Who *was* this man, and how did he do it?

Image of St. Pete U and footage of Mendeleev moving into his new office as housekeeper lays out the rules.

NARR: Mendeleev had recently been named a professor at the University of St. Petersburg, the leading institution in Russia's capital. But getting there had been a long, improbable journey from humble beginnings.

Cut to map showing Tobolsk in relation to Moscow, St. Petersburg and the rest of Siberia

BIOGRAPHER MICHAEL GORDIN, partly in VO

> Mendeleev was born in Tobolsk, Siberia, which is basically smack in the middle of Russia, if you look at it on a map. It's very much the boonies of Imperial Russia.

Painting of Mendeleev's father

NARR: His father, the headmaster of the local high school, went blind during the year of Dmitri's birth, leaving Mendeleev's mother to support and raise about a dozen children.

Painting of Maria Mendeleeva

NARR: Maria Mendeleeva sensed something special in her youngest child.

Glimpse of sleigh in snow, then dissolve to graphic map showing the long trip from Siberia to Moscow and St. Petersburg. Photo of sleigh on snowy St. Petersburg street.

NARR: So in 1849, she set out with her 15-year-old son on a 1500-mile trip by horse-drawn sleigh in search of a school that would accept him. Like most students from the provinces, Dmitri was turned away in Moscow. But in St. Petersburg he landed a spot in the teacher training school his father had attended. Exhausted by the journey, Maria died a few months later.

Mendeleev places picture of mother on shelf.

On screen: ***Words spoken by the characters in this film are drawn from their writings.***

DMITRI MENDELEEV, partly in VO

She took me out of Siberia and sacrificed what remained of her money … her life … so that I could get an education. From her I learned that it is through work – not words – that we must seek divine *and* scientific truth.

Photo of young Mendeleev in a group of other students

NARR: Scientific truth was elusive for any young chemistry student in the mid-1800s.

Photo of chemistry students in lab

NARR: There were deep divisions in the field over even the most basic concepts – particularly the atomic weights of the elements.

Animation of atoms of different elements

NARR: Most chemists believed each element had its own unique kind of atom, and ever since the early 1800s they'd been working to determine how much an atom of each element weighed.

HISTORIAN ALAN ROCKE, partly in VO

That's how one distinguished on element from another. So it was crucial to understand what were the correct atomic weights for each of the elements.

In the animation, hydrogen is assigned a weight of 1. But then differing weights for the other elements appear in columns to the right. Among them are the weights Gordin mentions for carbon.

NARR: Everyone agreed that hydrogen, the lightest element, should be assigned a weight of 1, and that heavier elements should have proportionally higher weights. But that's where the agreement ended.

BIOGRAPHER MICHAEL GORDIN, partly in VO

Did carbon weigh six or did it weigh 12? Did it weigh four? That depended on who you talked to and when you talked to them. By the late 1850s people were incredibly confused.

HISTORIAN ALAN ROCKE

This was an unsupportable situation. Something had to be done.

Map of Germany highlighting Karlsruhe

NARR: Hoping to sort out the mess, chemists organized their first-ever international meeting, held in Karlsruhe, Germany, in 1860.

Image of young Mendeleev

BIOGRAPHER MICHAEL GORDIN, partly in VO

Mendeleev, being a young, enterprising student, goes to this meeting, and he hears a very important speech by an Italian chemist, Stanislao Cannizzaro.

Cannizzaro photo and animation of new weights

NARR: Cannizzaro laid out a persuasive case for a new, uniform system of atomic weights.

DMITRI MENDELEEV

I still remember the powerful impression Cannizzaro made. He seemed to advocate truth itself!

Karlsruhe image

BIOGRAPHER MICHAEL GORDIN, partly in VO

After Karlsruhe, something astonishing starts to happen. Within a few years of the congress you start seeing lots of different attempts to organize the elements that are all based on these new, post-Karlsruhe weights.

Animation of the barber pole

NARR: A French geologist arranged the known elements in a spiral along the outside of a cylinder, like the stripes on a barber pole, and found that elements with similar properties tended to fall into columns.

Animation of the Law of Octaves

NARR: An English chemist arranged the elements by atomic weight in rows of seven, and found that their properties repeated like musical notes one octave apart.

Animation of the five men who sensed an order among the elements; they pop up in their respective countries on a map.

NARR: By the end of the 1860s, five different European scientists had detected glimmers of a hidden order among the elements. But no one could quite put the puzzle together.

Mendeleev continues moving into his office.

NARR: That’s where things stood when Mendeleev finally landed a professorship at the University of St. Petersburg. One of the duties of his new post was to teach introductory chemistry.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He has to teach this class, hundreds of students, and he has to give them a textbook. There are no up-to-date, Russian language, college-level textbooks available.

Mendeleev writes in his study.

NARR: So Mendeleev set out to write his own: *Principles of Chemistry,* in two volumes.

Image of Volume 1

NARR: He completed the first volume in 1868 …

Re-enactment: In his study, Mendeleev hands a package to his housekeeper.

NARR: … and on Friday, February 14, 1869, he sent the first two chapters of Volume 2 off to his publisher.

DMITRI MENDELEEV (to housekeeper)
Marina!

NARR: He was in a hurry to finish it, because he was struggling to make ends meet.

Photo of Mendeleev and his wife

BIOGRAPHER MICHAEL GORDIN, partly in VO
He hasn't yet gotten any royalties from the textbook, because it hasn't been written yet. He's got to keep his family fed and clothed. He has, at this point, two children and a wife. So he was always looking for more funds.

Montage of short Mendeleev scenes – packing his trunk, rubbing his eyes, playing cards.

NARR: To make a little extra money, Mendeleev planned to take a short break on Monday to do some consulting for a cheese-makers cooperative. But he had something on his mind: His publisher was expecting the next chapter of his textbook in two weeks, and he still hadn't settled on a way to organize the rest of his book.

Images of Vol. 1 contents, hydrogen and oxygen highlighted

NARR: Mendeleev had spent most of the first volume covering a few common elements like hydrogen and oxygen in great detail.

BIOGRAPHER MICHAEL GORDIN, partly in VO
You learn a huge amount of chemistry, but it's slow. Volume 1 contains just eight elements out of the 63 that were then known.

List of the remaining 55 elements he needs to deal with appears behind Scerri.

AUTHOR ERIC SCERRI, partly in VO
When it came to writing the second volume of his textbook, Mendeleev realized that he had better find an organizing principle fairly quickly, because he had to cover the remaining 55 elements.

DMITRI MENDELEEV

Since I'd set out to write a book called *Principles of Chemistry,* I felt I had to establish a system for classifying the elements – a system based not on chance, or guesswork, but on some sort of … *principle.*

Despondent Mendeleev refuses tea.

NARR: The problem gnawed at him all weekend.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He's trying to come up with a way of packing more elements in the same amount of space. He couldn't ramble the way he did in Volume 1, however useful that was.

Mendeleev works at his desk.

NARR: Mendeleev had already hit on the idea of focusing on whole families of elements, rather than treating one at a time.

Animation: Meet the Halogens

NARR: Chemists had long known that certain elements resemble each other in much the way family members do.

CHEMIST GREG PETSKO

You can often tell people are related because they have the same sort of face.

BIOGRAPHER MICHAEL GORDIN, partly in VO

They have the same nose. They have the same color eyes. There's something in common.

Animation: Three halogens bond with oxygen in the same way

BIOGRAPHER MICHAEL GORDIN VO

And that's something very similar in these chemical families. They tend to react similarly to the same kinds of substances.

Vol 1 Table of Contents – the halogens

NARR: Mendeleev had ended Volume 1 with two chapters on a well-known family, the halogens: chlorine, fluorine, bromine and iodine.

Vol 2 Table of Contents highlighting the alkali metals

NARR: He began Volume 2 in the same way, with chapters on sodium, potassium and lithium, a family called the alkali metals.

Mendeleev continues to work in his study.

BIOGRAPHER MICHAEL GORDIN VO

He realized that a family of elements is a good way of organizing so you can do more with less space.

Mendeleev looks up and ponders.

NARR: The problem was, there was no obvious family to turn to next. For insight into what other elements might be grouped together, Mendeleev looked more closely at the two families he already had.

Animation of floating families

BIOGRAPHER MICHAEL GORDIN, partly in VO

And in that process he figures out something rather extraordinary about the elements.

CU of Mendeleev writing. He writes the symbols for Li and Na on a piece of paper and notes the difference in their weights. Then he writes the symbols F and Cl on a separate piece of paper and notes the difference in their weights. He puts one piece alongside the other. The differences are almost the same: 16 and 16.5.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He looks at the atomic weights of sodium and lithium and looks at the difference between them. And then he does the same thing for fluorine to chlorine, and notices that those two differences are very close to each other.

Mendeleev stops to think, then grabs a piece of paper and starts writing. Pan along calligrapher's writing shows that for each pair of elements, the difference between the top row and the bottom is between 15 and 17.

NARR: Was this just a coincidence – or a clue? Excited, Mendeleev wrote down the lightest elements and their atomic weights. After seven elements, he broke off and started a new row, keeping elements with similar chemical properties in the same column. The numerical pattern continued to hold.

DMITRI MENDELEEV, partly in VO

The eye is immediately struck by a pattern – a regular change in the atomic weights of the elements within the horizontal rows and the vertical columns.

Animation. Focusing on three families, we show how the difference in weight within a family – 16 – is the same in all three families.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He notices that there's a regularity in the differences. That is, the changes that happen within a family happen regularly across families. And that's the fundamental insight that gets him thinking about how to organize all the other elements.

Reprise image of two rows of elements and their differences. Footage of Mendeleev at work.

AUTHOR ERIC SCERRI, partly in VO

Mendeleev had begun the weekend trying to solve the problem of what to do next in his textbook. But having reached this aha moment, he dropped everything else, and he poured all his energy into revealing an absolutely fundamental principle of nature.

Mendeleev is in the throes, scrawling letters and numbers on a piece of paper, then scratching them out.

BIOGRAPHER MICHAEL GORDIN, partly in VO

When he was taken by an idea, he was really taken by it. He starts putting together this system, and he's trying to figure out the hard spots, the things that don't quite make sense. Maybe I can scratch out this element here and put this element in its place. Should I change the atomic weights? Do I have to rethink their properties? And the problems of it, the intellectual puzzle, just grabs him.

Mendeleev plays solitaire.

NARR: The challenge Mendeleev faced was similar to one of his favorite diversions, the card game called Patience, in which the object is to arrange playing cards by both suit and number.

BIOGRAPHER MICHAEL GORDIN, partly in VO

That process of keeping several different variables in mind is kind of analogous to how Mendeleev was thinking. He started using *both* the regular, increasing order of atomic weights *and* the relationships of chemical properties with each other to build two dimensions.

Calligrapher leaves a blank.

NARR: Mendeleev didn't just lay out the known elements in order of rising atomic weight.

BIOGRAPHER MICHAEL GORDIN, partly in VO

When it looks like the next element doesn't have the properties it is supposed to have, he scooches it over and leaves a blank spot.

AUTHOR ERIC SCERRI

And has the audacity, has the daring to suggest that there might one day exist such an element that would fill that space.

Image of the fragment known as D2a/D2b. Mendeleev writes.

NARR: The few scraps of paper left from Mendeleev's struggle that weekend reveal that he sometimes arranged the chemical families in rows instead of columns.

Draft of table morphs into puzzle animation. The alkali metals, arranged horizontally, move to a different position in the lower table. The rest of the puzzle pieces take their positions, and the puzzle morphs back into his draft of the table.

NARR: Unhappy with this early attempt at a table, he moved the alkali metals to a new position in the next draft below… but kept them together.

AUTHOR ERIC SCERRI, partly in VO

Mendeleev is not moving elements individually. But he is moving them as a block. It is as if it's a composite piece of a jigsaw puzzle that he's moving all together.

Sleigh pulls up in front of Mendeleev's building.

NARR: On Monday morning, a driver arrived to take Mendeleev to the train station for his trip to the cheese cooperative.

Mendeleev dips a sugar cube into his tea.

NARR: He was well into his task but still struggling to make all the pieces fit.

Mendeleev lifts his cup, turns over the paper and begins to write.

NARR: We know this because one of the surviving fragments is a letter, delivered that morning, concerning arrangements for his trip to the cheese cooperative.

The back of the letter

AUTHOR ERIC SCERRI VO

And on the back of the letter, which still bears the stain of a cup, Mendeleev has sketched a few symbols and has carried out some very simple calculations. He is looking at differences in atomic weights.

NARR: So he was still working on the problem, even after wrestling with it all weekend.

Housekeeper enters to tell him driver is waiting. He shoos her away. Outside in the snow, the horse whinnies.

CU of an original Mendeleev document – a draft of the table littered with calculations, transpositions and cross-outs. Cut back occasionally to Mendeleev working on the table, puzzling, crossing out.

NARR: The drafts of Mendeleev's table show plainly the struggle he went through.

CHEMIST ROALD HOFFMANN, partly in VO

At the bottom of the page he lists the elements to be classified. As he fits them into the table on that page, he crosses out the elements. It's just what you and I would do. We can see the effort in that page. He's making mistakes. He's correcting them. It is full of crossings out. There are things that don't quite fit. This is a human being trying to understand this world.

Mendeleev paces. Outside, the driver is growing impatient, pacing to keep warm. Finally, he seizes the reins and drives off with a tinkling of sleigh bells.

NARR: Hour after hour, Mendeleev worked on the table, missing one train after another. Finally, he dismissed the coachman. The cheese-makers would have to wait.

We find Mendeleev lying on the sofa. When the housekeeper shows in a visitor, he jumps up, shakes hands and explains what's troubling him.

NARR: That afternoon, a visitor found him distraught, unable to capture the order he knew was there, just out of reach.

MENDELEEV TO HIS VISITOR (in Russian with subtitles)
I'm trying to finish my work. It's all formed in my head, but I just can't express it.

Mendeleev looks up something in a reference book.

NARR: Later that day, Mendeleev came to a choice that would crystallize his thinking. The elements involved were iodine and tellurium.

Mendeleev writes, then stops to think. As he looks up, we cut to an animation of the elements he's thinking about – iodine and tellurium – and their respective families.

BIOGRAPHER MICHAEL GORDIN, partly in VO
Iodine's a little lighter than tellurium so it should come first. But Mendeleev looks at that and says, "Well, if I put iodine first, it's in the wrong family. It is actually a halogen, which is the next row down."

CHEMIST GREGORY PETSKO, partly in VO
If he stuck to that weight rule, it would put an element outside of the family it obviously belonged in.

Iodine and tellurium switch places in the animation.

BIOGRAPHER MICHAEL GORDIN
So he decides tellurium, the heavier element, should go first.

Mendeleev writes Te=128?, then J=127. Continued animation showing the family resemblances Mendeleev has decided are more important

BIOGRAPHER MICHAEL GORDIN, partly in VO
It always bothered him the iodine was lighter than tellurium but came after. That breaks the order of atomic weights, but it preserves the family resemblances, which are more important than just the increase of atomic weights.

Mendeleev writes quickly.

NARR: With that principle established, Mendeleev hurried toward the end.

BIOGRAPHER MICHAEL GORDIN VO

And the more he worked on it, the better it looked.

Mendeleev copies over his completed table, then puts his pen down, satisfied.

NARR: Finally, that evening, Mendeleev completed his table.

The driver arrives again with his sleigh. We see Mendeleev inspecting his work. He looks pleased.

NARR: Before leaving the next day, he ordered 200 copies printed and sent to leading European chemists.

Mendeleev blows on the paper to dry the ink and places the table in a folder.

AUTHOR ERIC SCERRI, partly in VO

By the time he left for the cheese factory, Mendeleev knew that he was onto something extremely important. I think he realized that day that he had cracked it.

Mendeleev's handwritten fair copy is reset in type, rotated 90 degrees and flipped over. Finally, the alkali metals are moved to the opposite side of the table. When boxes are place around the elements, it closely resembles the familiar Periodic Table of the Elements.

NARR: With a few modifications, soon made by Mendeleev himself, his 1869 draft is easily recognized as the Periodic Table of the Elements – incomplete but unmistakable.

Zoom to empty spaces with question marks and proposed weights of the missing elements

NARR: In his published table, Mendeleev left blanks for some of the elements he thought were missing.

HISTORIAN ALAN ROCKE VO

Not only did he leave a blank space, but he suggested an approximate atomic weight for that future element.

BIOGRAPHER MICHAEL GORDIN, partly in VO

And the fact that Mendeleev, on that first weekend, is already thinking this way, that’s a sign that he believed that there’s something deeper going on here.

In the graphic of Mendeleev's table, the columns are highlighted one by one.

NARR: Mendeleev believed his table was more than a convenient way to arrange the elements. He was convinced he had discovered a Law of Nature: that the properties of the elements are determined by their atomic weights and vary in a regular, periodic way, across the table.

CHEMIST GREG PETSKO, partly in VO

It's periodic because the properties of the elements repeat in a regular fashion. When you wrap around from one row to the next and come back to where you were, the elements that are in the same column have similar properties.

AUTHOR OLIVER SACKS

He had an almost mystical feeling that this was there in nature and not so much a human invention as a discovery.

The camera pauses on the empty spot with question marks.

NARR: Given the remarkable regularity of his table, Mendeleev couldn't believe nature would have just left some spaces empty.

DMITRI MENDELEEV

Laws of nature do not permit exceptions.

AUTHOR ERIC SCERRI

There must be an element, which we have not yet discovered. Go look for that element.

AUTHOR OLIVER SACKS

And he was bold enough to not only to say an element is missing but to predict.

DMITRI MENDELEEV

The periodic law allows us not only to predict what new elements will be found but also to determine *in advance* their chemical and physical properties.

Image of Mendeleev's 1871 journal article in Annalen

NARR: In 1871, Mendeleev published an article making predictions about three of the missing elements, based on the properties of their neighbors in the table.

Graphic showing the specificity of Mendeleev's predictions

BIOGRAPHER MICHAEL GORDIN, partly in VO

Chemists really weren't used to making predictions of any kind, let alone ones to this degree of specificity. They are remarkably precise and quite daring for Mendeleev to print them.

Photos of Boisbaudran and a sample of gallium

NARR: Four years later, a French chemist found a new metal so soft it melted in his hand. He called it gallium.

Zoom to blank below aluminum in the PTE

NARR: It seemed to be a good fit for the empty spot below aluminum, but the density didn't match Mendeleev's prediction. He wrote the Frenchman, suggesting that he check his data.

Graphic contrasts Mendeleev's prediction with the measured density.

AUTHOR ERIC SCERRI, partly in VO

So you can just imagine this Frenchman, who actually has the element in his hands, hearing from this Siberian, who has never seen the element, daring to say to him that he's made a mistake**.**

Graphic: Gallium takes its place in the Periodic Table, replacing the question mark just below aluminum.

NARR: But sure enough, when the French scientist rechecked his measurements, Mendeleev was correct.

AUTHOR ERIC SCERRI, partly in VO

So not only had Mendeleev predicted the element, but he knew the properties of the element better than the discoverer of the element knew them.

BIOGRAPHER MICHAEL GORDIN

Within 15 years all three of the detailed predictions are discovered. And that catapults Mendeleev to chemical superstardom.

DMITRI MENDELEEV

I never thought I would live to see my ideas verified. [He pauses and smiles.] I was wrong.

Photo of William Ramsay and Lord Rayleigh

NARR: But in 1894, two British scientists made a discovery that threatened to bring Mendeleev's carefully crafted edifice crashing down. They found a new gas they called argon that didn't seem to fit into the table.

Letter from Ramsay to Rayleigh

HISTORIAN ALAN ROCKE, partly in VO

When Lord Rayleigh and William Ramsay discovered argon, it looked like a problem – a very serious challenge to the Periodic Table itself.

Photo of angry Mendeleev. Then animation of argon unable to bond with other elements, finding no place in the table.

BIOGRAPHER MICHAEL GORDIN, partly in VO

Mendeleev's first reaction to almost anything that was contradictory to the system was to be hostile to it and suspicious. And Mendeleev therefore decides it's not an element. There are lots of reasons to think that. First, it doesn't react with anything.

CHEMIST GREG PETSKO, partly in VO

Chemists couldn't get it to do anything. It was inert. It behaved like no other gas that anybody had ever encountered.

BIOGRAPHER MICHAEL GORDIN VO

And secondly, it has no place on the table. So how can it exist?

Photo of Ramsay, then animated helium wanders across the table in search of a spot.

NARR: Matters got worse when Ramsay announced he'd also isolated helium – 30 years after it was first detected in the sun. It was definitely an element, and it too had no place in the table.

Animation showing colored tubes of the three new gases

HISTORIAN ALAN ROCKE, partly in VO

And then just three years after that William Ramsay's research group discovered three new rare gases, krypton, xenon and neon.

BIOGRAPHER MICHAEL GORDIN, partly in VO

They display the same kind of properties. They are all inert gases. And they display the same increase of atomic weights as the other natural families do.

Atoms of four gases emerge from behind argon and move to the right side of the table.

HISTORIAN ALAN ROCKE, partly in VO

And that changed the situation dramatically. What began as a single anomaly, a single puzzle, now looked like a group of elements.

DMITRI MENDELEEV, partly in VO

Now we can see that helium, neon, argon, krypton and xenon are as closely united as any other group.

The noble gases take their place in the table.

BIOGRAPHER MICHAEL GORDIN

And so Mendeleev makes the single, biggest revision to the system he ever did. He puts in a new column. And that is the family of noble gases.

DMITRI MENDELEEV

My periodic system is in no way injured by these discoveries. In fact, they confirm and strengthen it.

Animation: the unruly garden is finally brought to order as the Periodic Table emerges from the weeds.

AUTHOR ERIC SCERRI, partly in VO

It turned out to be a vindication of the periodic system, and, if anything, made it even more profound a discovery.

NARR: Mendeleev's table had finally brought order to chemistry's unruly garden.

HISTORIAN ALAN ROCKE, partly in VO

After Mendeleev one could see that each element had a place. It was a grand design that worked.

Pan of the table

BIOGRAPHER MICHAEL GORDIN, partly in VO

Chemistry wasn't just one thing after another – random substances we've dug up from the earth. They are interlinked in a complicated and rich way.

DMITRI MENDELEEV, partly in VO

We are at the dawn of a new era in chemical science – approaching a new understanding of the still mysterious nature of the elements.

Host with the Periodic Table behind him

HOST

As the 19th century drew to a close, the Periodic Table's ability to corral the elements contributed to a growing sense that the work of science was just about complete. Most of nature's building blocks had been found, measured and cataloged. Chemists agreed these elements had been, and always would be, the same – forever fixed, unchanging. All that remained was to fill in the few remaining blanks.

Host steps forward to reveal a photo of our next character: Marie Curie.

HOST

Or so it seemed. In fact, this smug sense of satisfaction was about to be shattered by something – and someone – completely unexpected.

Marie uses wash bottle in the lab, then strolls down a "Paris" street.

NARR: She was the unlikeliest of revolutionaries – a graduate student … a *woman* … from *Poland* … who had left her homeland to pursue her passion for science in Paris.

Photo of Marie

NARR: Yet in four short years, her discoveries would transform our understanding of matter and make her one of the most famous women in the world.

Photo of Marie in the lab

CHEMIST DAGMAR RINGE, partly in VO

She worked on something that was relatively obscure and turned it into a blockbuster: new elements, new properties and a whole new way to look at the world.

Photos of young Marie and the Sklodowski family. Photo of square with ranks of Russian troops.

NARR: The world would know her as Marie Curie, but she was born Maria Sklodowska, into a family of Polish patriots, at a time when Warsaw was under Russian rule.

On a graphic map, Poland is swallowed up by three surrounding countries, and Warsaw becomes part of Russia.

NARR: Poland had been literally wiped off the map, its residents forbidden to speak their own language or teach their own history.

Photos of Marie's parents and their five children

NARR: But Maria's family secretly defied the czar, speaking Polish at home and reciting patriotic poetry to preserve their Polish heritage.

Photo of Warsaw with Russian obelisk

BIOGRAPHER SUSAN QUINN, partly in VO

She used to go by an obelisk erected in honor of the Russian people and spit on the obelisk on the way to school. So you can see Maria learned early to be a fighter and resister.

Photo of young Maria

NARR: The daughter of two teachers, Maria excelled in science and math.

Photo of down-trodden Poles

NARR: But in Russian-ruled Poland, women were not allowed to attend university, let alone become scientists.

HISTORIAN DAVID KAISER

Very, very few places in Europe, or elsewhere, had opportunities for young women to study science. So one of the few places that she could was, in fact, in Paris.

Photo of Wladyslaw Sklodowski and his three daughters

NARR: But because her family was too poor to send her, Maria would first have to work for six long years as a governess to support her older sister's studies.

Photo of Marie and her older sister

NARR: Only at age 24 did she finally get her chance.

BIOGRAPHER SUSAN QUINN

She waited her turn and she didn't give up. And when the turn came she took it.

Archival photos of Paris in the 1890s

MARIE CURIE, partly in VO

I was lost in the great city, but the feeling of living there alone – taking care of myself without any help – didn't depress me at all. I had been waiting for this opportunity for a long time.

Paris archival photos, emphasizing technology

NARR: Paris in the 1890s was like no other place on earth – a living showcase for the wonders of science and technology.

Streetcar photo

NARR: The city boasted such modern marvels as electric streetcars and telephone exchanges.

Photos of the Pasteur Institut

NARR: At the laboratories of Louis Pasteur, scientists were conquering diseases that had plagued humanity for centuries.

Lumiere brothers film footage

NARR: The Lumiere Brothers were thrilling crowds with their new invention: pictures that actually moved.

Pull back on photo to reveal the Eiffel Tower

NARR: And rising above it all was the brand new Eiffel Tower, which would remain the world's tallest structure for nearly half a century.

HISTORIAN DAVID KAISER

Here was Paris, the kind of intellectual, artistic, technological capital of the universe. This was where the modern age was born.

Photo of Paris night life

BIOGRAPHER SUSAN QUINN, partly in VO

She felt this precious sense of liberty. She could say whatever she wanted, go wherever she wanted. And she took it all in and loved it.

MARIE CURIE

Everything I saw and learned was a new delight to me. I had only one regret – the days were too short and went by too quickly.

Photos of Marie and the Sorbonne ca 1891

NARR: Adopting the French form of her name, "Marie," she enrolled at Paris' pre-eminent university, the Sorbonne, where she could study under the leading lights of French science.

Photo of Lippmann

NARR: One of them was Gabriel Lippmann, a future Nobel Prize winner.

Photos of Poincare, other Sorbonne teachers

BIOGRAPHER SUSAN QUINN VO

Another was Henri Poincare, who was one of the leading mathematicians of the 19th century. One of her math instructors was a mountain climber. Another was an aviator. These were exciting people, scientists who had exciting lives.

MARIE CURIE

It was like a new world open to me, the world of science, which I was at last permitted to know in all liberty.

Photos of Sorbonne classroom, Lippmann

NARR: Marie graduated first in her class in physics and, with Professor Lippmann's help, received a grant to do research on magnetism.

Photo of Pierre Curie in classroom

NARR: A friend suggested she seek out a French physicist who had studied the subject and might have some lab space for her. The meeting would change her life.

Photo of young Pierre Curie

MARIE CURIE, partly in VO

Pierre Curie seemed to me very young, though he was 35 at the time.

BIOGRAPHER SUSAN QUINN, PARTLY IN VO

I think it was pretty much electric from the beginning.

Photo of young Marie

PIERRE CURIE, partly in VO

With all my heart I thank you for your photograph. I showed it to my brother Jacques -- was I wrong? He finds you very fine but he also said, "She has a very decisive look, maybe even stubborn."

Photos of young Pierre Curie and the School of Industrial Physics and Chemistry, where he worked

NARR: Pierre Curie was a first-rate researcher, but he had never bothered to complete his dissertation and was content teaching at an industrial college.

Curie family photo

BIOGRAPHER SUSAN QUINN, partly in VO

He was diffident, modest and shy. He was very much an outsider. He had been homeschooled by his politically radical father, along with his brother Jacques.

MARIE CURIE VO

In a family photograph you see him with his brother. His head is resting on his hand. It's a pose of … dreaming, as if he is looking at some inner vision.

NARR: Pierre was a man of ideas, not action.

Photo of Marie

NARR: But he was galvanized by this young woman and pursued her as he had nothing else in his life.

Photo of Pierre and Marie in the lab

PIERRE CURIE, partly in VO

It would be a beautiful thing if we could spend our lives near each other, true to our dream – in science, where every discovery, no matter how small, lives on.

Photos of the Sorbonne and Marie's father

NARR: Pierre's proposal posed a dilemma for Marie. She had planned to get a first-rate scientific education in Paris and then return to her beloved Poland to teach and care for her aging father.

BIOGRAPHER SUSAN QUINN

Her mother had died of TB early on, and he was counting on Marie coming back.

Marie and Pierre walk along a "Paris" street.

NARR: Now this ardent young man was offering her an exciting life as a working scientist.

MARIE CURIE

It was a decision that would mean abandoning my family and my country.

BIOGRAPHER SUSAN QUINN

Marie had all those feelings of responsibility for her father, for her family, and then for Poland on top of that.

Photo of Marie and Pierre together, arms linked

NARR: In the end, their mutual devotion – to each other and to science – overcame Marie's resistance.

BIOGRAPHER SUSAN QUINN, partly in VO

She wrote one of her friends: "Fate has brought us together, and we simply can't bear to be apart."

Photo of the two of them with their bikes

NARR: The newlyweds left on a cycling honeymoon after a simple ceremony in 1895.

Photo of Marie and Pierre with young Irene

NARR: By 1897, even with a toddler to care for, Marie had set her sights on getting what no other woman had ever received in France: a doctorate in physics.

Selection of X-ray images

NARR: At the time, the world was abuzz with excitement over a new discovery: mysterious rays that had the power to "see through" solid objects.

X-ray of hand

PHYSICIST JIM GATES, partly in VO

You could by this process look at the bones inside of your living hand! It's as if you had a magical set of glasses that lets you see inside of living creatures. And that sparks the public imagination.

Archival images showing the potential medical applications

NARR: Doctors instantly recognized X-rays as an invaluable diagnostic tool.

Images of the scientific interest

HISTORIAN DAVID KAISER, partly in VO

There was a great rush of excitement from working scientists, as well. In that first year there were about a thousand scientific articles published, at a time when the entire physics community in the world was only a thousand members.

Photo of Marie and Pierre

NARR: But with so many others doing research on X-rays, Marie felt it would be hard to make an original contribution.

CHEMIST DAGMAR RINGE

And so she picked something that she could work on where there was less competition – in fact, no competition.

Photo of Henri Becquerel, Periodic Table with U highlighted.

NARR: Just a year earlier, a French physicist named Henri Becquerel had discovered a different kind of ray given off by the element uranium.

Photo of Becquerel's cross

NARR: These "uranic rays" were powerful enough to penetrate thick black paper and create an image on a photographic plate.

Becquerel's cross image slides over for comparison with a much sharper X-ray image.

NARR: But the images were not nearly as striking as those created by X-rays, and they seemed to have no practical value.

Animated montage of Becquerel's papers

NARR: So after writing a few papers about this scientific curiosity, Becquerel dropped the subject, thinking it had been "squeezed dry."

MATERIALS SCIENTIST AINISSA RAMIREZ

Marie just thought that this was a tremendous thing to work on, particularly as a graduate student.

MARIE CURIE

The subject was attractive to me because it was entirely new – little had been written about it.

Host stands at a bench with a battery, a wire and a small light bulb in front of him.

HOST

There was another reason Becquerel's uranic rays appealed to Marie:

CU of the electric bulb connected by wire to the battery. The bulb is lit. He cuts the wire and the light goes off.

HOST

She had spotted a clue that might reveal more about them.

He holds the two ends an inch apart.

HOST

As you can see, air is normally a poor conductor of electricity. The current can't jump this gap, so the bulb doesn't light. But Becquerel had noticed his uranic rays had the mysterious power to charge the air around them, allowing electricity to leak across.

CU: Bulb lights up as host touches the two ends of the wire together.

HOST

The amount of electricity was incredibly small – about a trillionth the amount needed to light this little bulb. No meter of the day could measure it. But Marie had a secret weapon Becquerel didn't.

Pierre shows Marie the equipment.

HISTORIAN DAVID KAISER VO

Right in Marie's own household was perhaps *the* world expert in how to measure tiny little electrical effects. The two of them, Pierre and Marie Curie, designed this really quite ingenious instrument to measure these very subtle electrical effects from her samples.

Pierre places a test substance on the bottom plate of the ionization chamber as Marie watches.

NARR: They placed a layer of uranium on a metal plate, then charged the plate with a battery.

Animation shows leaking of electricity from the bottom plate to the top.

NARR: As expected, electricity leaked across the gap to the plate above.

Pierre and Marie at the quartz generator

NARR: To measure this tiny current, the Curies would use this second device to create a matching amount of electricity.

Cutaway animation revealing crystal inside

NARR: Inside was a special crystal that could generate its own tiny charge, thanks to a phenomenon called piezoelectricity.

Old photo of Pierre at a lab bench with the quartz generator matching ours

NARR: More than 20 years earlier, Pierre and his brother Jacques had discovered that certain crystals give out electricity in response to pressure.

Animation shows how crystals give out electricity when squeezed or stretched.

HISTORIAN DAVID KAISER, partly in VO

The amount of electricity generated when you squeeze or stretch that crystal depends precisely on how hard you press on that crystal. And that means you have a way to make a very, very sensitive measurement of minute little electrical currents.

CU: Marie places a weight on the pan.

NARR: By placing a weight on the pan below ...

Animation showing the electrical connections among the three instruments and the passage of two currents to the electrometer

NARR: … Marie stretched the piezoelectric crystal inside the device. Then, by slowly *relieving* the tension – <u>un</u>stretching the crystal – she could generate a charge exactly offsetting the one coming from her uranium sample.

In lab footage, Pierre moves to the electrometer and calibrates the spot with Marie's help. We see a spot of light reflected onto the graduated scale Marie is watching. The spot is near 0.

NARR: She could tell the two charges were equal when the spot of light from this third instrument was at zero on the scale.

HISTORIAN DAVID KAISER, partly in VO

Though it didn't look very pretty, this sort of pulled together little contraption was exquisitely accurate and could allow them to make measurements like no one else in the world.

CU of starting the stop watch. Wide shot of Pierre instructing Marie how to use the instruments.

NARR: But *using* these instruments required extraordinary concentration and dexterity.

CU of Marie's fingers on the weight

NARR: Ever so gradually, Marie relieved the tension on the crystal …

CU of her eyes, then CU of what she's following: a beam of light that moves back and forth along a graduated scale, staying close to zero.

NARR: … while carefully watching the spot of light to keep the two charges in balance …

CU of Marie's face

NARR: … and timing how long it took to lift the weight entirely off the pan.

CU of hand on weight, two-shot of Marie and Pierre

NARR: The faster she had to remove the weight, the stronger the activity of her test sample.

Photo of Curie in her lab, holding a stop watch

BIOGRAPHER SUSAN QUINN, partly in VO

And that's why, when you see pictures of Marie Curie in this experiment, she is sitting there with a stop watch.

She lifts the weight from the tray, then stops the watch. "Tres bien" moment between Marie and Pierre.

MARIE CURIE, partly in VO

I never dreamt that I was about to embark on a new science that Pierre and I would follow for the rest of our days.

Marie continues her measurements, drinking tea to stay warm, adding new samples to the ionization chamber and repeating the process of measuring their effects.

NARR: Day after day, working in a cramped, unheated storeroom, Marie painstakingly carried out her measurements. She compiled data on uranium, then went on to test the other known elements to see if any of them could also electrify the air.

HISTORIAN DAVID KAISER, partly in VO

She was not expecting to make any sort of earth-shattering discoveries.

BIOGRAPHER SUSAN QUINN, partly in VO

She thought she would do some sort of diligent work on a whole lot of elements, and she would measure their power.

HISTORIAN DAVID KAISER VO

Exactly what you would expect for a perfectly legitimate PhD dissertation.

Marie continues her measurements.

NARR: And for a while, the results were predictably dull. No other elements showed this strange property.

Pierre works in the background.

BIOGRAPHER SUSAN QUINN, partly in VO

Things were going along pretty routinely until one day in February of 1898. And that was the day that everything changed.

Marie is puzzled, calls over Pierre.

NARR: In the course of a single week, Marie made two startling discoveries.

Zoom to thorium in the periodic table of the 1890s

NARR: She found that the element thorium could also make air a better conductor.

HISTORIAN DAVID KAISER, partly in VO

That was the first, real solid indication that this was not unique to uranium. This might be a property of matter, not a curiosity of one particular element.

MARIE CURIE, partly in **VO**

It was necessary to find a new term to define this new property of matter. I proposed the word "radioactivity."

Marie and Pierre puzzle over the results. CU of notebook shows pitchblende's readings are four times as high as uranium's. Marie and Pierre chatter in French.

NARR: The next surprise came when Marie tested pitchblende – the raw ore from which uranium is taken. Something was very wrong. Pitchblende seemed be four times as radioactive as uranium itself.

Marie watches as Pierre looks for the source of the strange reading. He removes the housing and brushes off the crystal inside.

CHEMIST DAGMAR RINGE, partly in VO
When I find a result like that, as a scientist my first reaction is, "I made a mistake," or, "The machine isn't working."

HISTORIAN DAVID KAISER, partly in VO
She did what every good scientist should do, which was doubt it, be extremely skeptical, and check every last step of that chain.

EVE CURIE VO
So my mother made her measurements over again …

EVE CURIE
– ten times, twenty times – until she was forced to accept the results.

Marie repeats her measurements again and again. The results keep coming out the same. Pierre joins her for the final confirmation. The stopwatch keeps coming up 20 seconds. Marie looks at Pierre: This is real.

NARR: In time, the Curies realized this was no mistake. The readings from pitchblende were real.

MATERIALS SCIENTIST AINISSA RAMIREZ
A light bulb went off, and they said, "Well, maybe there is something else in there."

Marie writes in her notebook.

BIOGRAPHER SUSAN QUINN, partly in VO
Very soon, they began to suspect that there was another element in pitchblende, which was producing this enormous radioactivity.

HISTORIAN DAVID KAISER
There must be some new thing under the sun, some new element that had never been seen before.

MARIE CURIE
And it must be intensely radioactive, since it was present in amounts so small that no one had ever detected it.

CU of Marie and Pierre working side by side at the instrument. Photo of Lippmann.

NARR: Since neither Marie nor Pierre was a member of the Academy of Sciences, they asked Marie's mentor, Gabriel Lippmann, to deliver the paper announcing this discovery.

Shot of the paper's title page: Rays Emitted by the Compounds of Uranium and Thorium, by Madame Sklodowska Curie.

CHEMIST GREG PESTSKO, partly in VO
This was one of the most important papers in the history of chemistry. And yet it was almost universally ignored.

Photo of Marie and Pierre. Footage of Marie being helped by younger male scientist.

HISTORIAN ALAN ROCKE, partly in VO
Who was this Marie Curie? She was a graduate student. She spoke French with a Polish accent. She was married to a teacher in an industrial school. And she was a woman.

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO
These are strikes that are definitely against you. And so her ideas just weren't embraced, because she was so different.

Marie and Pierre work in the chemistry lab.

NARR: But Marie knew she was onto something important.

BIOGRAPHER SUSAN QUINN VO
She had lit upon, almost by accident, an extremely exciting discovery. And as soon as he figured that out, Pierre abandoned his work on crystals and joined her.

NARR: To track down their mystery element, Marie and Pierre subjected pitchblende to a battery of chemical procedures.

CHEMIST DAGMAR RINGE, partly in VO
You break up your rock. You try to dissolve it. You treat it with all kinds of other chemicals.

NARR: The goal is to separate the ore into portions with different chemical properties, all the while tracking the radioactive signal.

CHEMIST GREG PETSKO, partly in VO
She then throws away everything that isn't radioactive. It's getting more and more concentrated as she goes through these steps.

NARR: The Curies soon discovered that two distinct parts of the pitchblende, with different chemical properties, were *both* radioactive. That meant not one but *two* new elements might be hidden in the ore.

EVE CURIE
By July 1898, they were able to announce the discovery of one of those substances with certainty.

Pierre approaches Marie with coffee pot in the lab. He pours. They talk.

PIERRE

Marie, you will have to name it.

EVE CURIE, partly in VO

The former Mademoiselle Sklodowska thought of her occupied native country, whose very name had been erased from the map of the world.

MARIE CURIE

Could we call it polonium?

BIOGRAPHER SUSAN QUINN, partly in VO

Poland, remember, was still not a country. This was one way of putting it on the map.

PIERRE CURIE

Eh bien, voila. Polonium it is.

Marie places another sample in the ionization chamber.

NARR: Marie next turned her attention to the second mystery element.

CU of Marie looking at results

HISTORIAN DAVID KAISER, partly in VO

She finds the activity is through the roof. It is nearly a thousand times more active than even her uranium sample had been.

In another laboratory, Eugene Demarçay tests her sample with a simple spectroscope while Marie and Pierre look on.

NARR: Marie's polonium sample had not been pure enough to yield a unique spectral line. Would this new, more powerful element pass the test?

HISTORIAN DAVID KAISER VO

By 1900 spectroscopy was often seen as the gold standard for identifying the materials you're working with. And if Marie Curie wanted to make some claim that she found in fact a whole new element, she was going to have to meet the chemists on their own terms. She'd need spectroscopic evidence.

Demarçay pulls back from the instrument and, in a book, points to the part of the spectrum where he's seen new lines.

EUGENE DEMARCAY

Regarde ici. Il ya une ligne …

He invites Marie to look. She sits and looks into the eyepiece.

NARR: Marie's sample showed the presence of the well-known element barium.

Cut to the spectrum of barium as she might have seen it, and above it the spectrum of a new element.

NARR: But it also revealed a pattern of spectral lines never seen before – strong evidence that she and Pierre had tracked down their mystery element.

Marie looks up and receives congratulations from the two men.

CHEMIST DAGMAR RINGE, partly in VO

She could tell that she had an element that hadn't been seen before, because the spectral lines she got were different.

Shot of the notebook page from Dec. 20, 1898: The word "Radium" is written in heavy ink at the top of the page.

BIOGRAPHER SUSAN QUINN, partly in VO

And in the notebook Pierre writes in very bold ink the name they decided to give the new element: Radium.

Spectroscopy scene continues.

HISTORIAN ALAN ROCKE, partly in VO

But in the 19th century there had been scores of claims of elements that later proved not to be elements at all. You needed to do more.

AUTHOR OLIVER SACKS, partly in VO

To satisfy the chemical community, a spectral line wasn't enough. They had to see the real stuff, which could be weighed, which could be measured.

BIOGRAPHER SUSAN QUINN

It was important, as you would with any other element, to isolate this element, to weigh it and to place it on the Periodic Table.

CHEMIST DAGMAR RINGE

So in order to be absolutely certain, she had to have pure material, and that is what she set out to do.

EVE CURIE

It was my mother who had no fear of throwing herself into that daunting task – without personnel, without money, without supplies.

Marie squeezes by Pierre in their cramped lab.

NARR: To isolate even a speck of radium, Marie would need to process huge quantities of pitchblende – a job too big for her tiny laboratory.

Photos of the crude shed where the radium isolation was carried out

NARR: The only space available for this work was a drafty old shed once used as a dissecting room for the school's medical students.

Movie poster for Madame Curie

NARR: As Greer Garson and Walter Pidgeon showed in the 1943 film *Madame Curie …*

Radium isolation scenes from the 1943 feature film Madame Curie. *Greer Garson as Marie Curie stirs a huge cauldron with a long rod.*

NARR: … the Curies worked tirelessly to separate the radium from tons of pitchblende residue they had shipped from a mine in Bohemia.

MARIE CURIE VO

Sometimes I had to spend the whole day mixing a boiling mass with a heavy iron rod nearly as big as I was. I would be broken with fatigue by the end of the day. And yet we spent the happiest days of our lives in this miserable old shed. An entirely new field was opening before us.

Movie isolation scenes continue.

NARR: Marie soon realized that radium was a smaller part of the pitchblende than she ever imagined – less than a millionth of one percent. Isolating it was going to be an enormous job.

BIOGRAPHER SUSAN QUINN, partly in VO

Marie's daughter said that, had it been up to Pierre, he might not have taken the next step.

Excerpt from movie – Pierre expresses frustration over how long it's taking.

WALTER PIDGEON AS PIERRE CURIE

The world has done without radium up to now. What does it matter if it isn't isolated for another hundred years?

GREER GARSON AS MARIE CURIE

I can't give it up.

AUTHOR OLIVER SACKS

There is a special passion which goes with the discovery of elements, and a line in the spectrum is not enough.

HISTORIAN DAVID KAISER

She was after an understanding of nature. And there was very, very little that would stand in her way.

Photo of resolute Marie. CU of pinch of table salt in a watch glass.

NARR: In 1902, after four years of arduous work, Marie finally succeeded in isolating one-tenth of a gram of radium chloride from *ten tons* of pitchblende residue.

MARIE CURIE

– four years to produce the kind of evidence that chemical science demands.

HISTORIAN DAVID KAISER, partly in VO

All of this effort so that she could actually convince the remaining chemists that this was a real, honest-to-goodness element.

CU of Curie notebook showing atomic weight calculation.

NARR: She measured radium's atomic weight at 225.9 – very close to the current value of 226.

Radium appears in the Periodic Table.

NARR: And she placed it correctly in the Periodic Table.

EVE CURIE, PARTLY IN VO

Radium officially existed. The incredulous chemists – and there were still a few – could now only bow before the facts, before the superhuman obstinacy of a woman.

Photo of Marie

HISTORIAN DAVID KAISER, partly in VO

Here she was, still basically a graduate student, and the whole world was beginning to talk about her discoveries. In just these four years, she has now discovered two brand new elements. Even more important, she has shown that this strange emanation, this radioactivity, is a feature of matter, not specific to one quirky little substance. And she's also developed a quite impressive technique for finding more.

BIOGRAPHER SUSAN QUINN

This was the beginning of identifying elements by their radioactive power.

Graphic: Actinium and radon take their places in the Periodic Table.

NARR: The same technique would soon be used by others to identify more new radioactive elements.

Shot of Marie's dissertation: "Radioactive Substances"

NARR: In 1903, Marie Sklodowska Curie became the first female scientist ever awarded a doctorate in France.

Photo of Marie

NARR: By then it was clear radioactivity was a pivotal scientific discovery, deserving of recognition.

HISTORIAN DAVID KAISER, partly in VO
There's no doubt that Marie Curie had done the lion's share of this work. And yet, when the time came to recognize this work, it very nearly went to other people.

Shot of the letter nominating Becquerel and Pierre Curie for the Nobel Prize. It gives credit to the two men.

BIOGRAPHER SUSAN QUINN, partly in VO
A number of prominent French scientists nominated Pierre Curie and Henri Becquerel for the Nobel Prize in 1903. And in this letter, they didn't mention Marie Curie at all.

Shot of Lippmann's signature, then photo of Lippmann

NARR: One of the nominators was Gabriel Lippmann.

BIOGRAPHER SUSAN QUINN, partly in VO
It's quite remarkable since Gabriel Lippmann was her teacher, her mentor. He actually presented her very first paper to the Academy. So he knew about her importance in this work and how central she was to these discoveries.

Composite photos of four "cabal" members who signed the letter

BIOGRAPHER SUSAN QUINN
And yet his cabal of Frenchmen just left her off the list. The idea that she could be an important scientist just didn't occur to them. She was totally invisible.

Pierre angrily writes a letter.

CHEMIST DAGMAR RINGE, partly in VO
Pierre – and we have to give him total credit for this – turned around and said, "I did not conceive of this idea. I helped with the work, but it was someone else's idea that made it possible, and that's Marie Curie."

BIOGRAPHER SUSAN QUINN, partly in VO
Pierre was adamant that Marie needed to be included. He immediately wrote back and said, "Wouldn't it be better, from an artistic point of view, to award the prize to Marie Curie and to me?"

Images of Marie's two Nobel Prizes

NARR: In the end, Marie did share in the Nobel with Pierre and Henri Becquerel. She would go on to win a second all her own.

Page from Le Radium with picture of Curies in the lab

NARR: But the real prize was the magical substance for which she would always be known. Some nights the Curies would stop by the laboratory to admire the element Marie called "my child."

Cut to door of darkened laboratory being opened with a squeak

EVE CURIE, partly in VO
They arrived in the Rue Lhomond. Pierre put the key in the lock. The door squeaked and admitted them to their world.

Marie and Pierre enter and see the (fake) radium samples glowing on the shelves.

AUTHOR OLIVER SACKS VO
Eve Curie in her biography of her mother …

MARIE CURIE TO PIERRE
Don't light the lamps! Look!

AUTHOR OLIVER SACKS, partly in VO
… describes the wonder of the Curies as they went into their lab one night and saw these glowing vials.

MARIE CURIE VO
From all sides, we could see gleamings suspended in darkness, like faint fairy lights.

MARIE CURIE TO PIERRE
Do you remember the day you said to me, "I would like radium to be a beautiful color?"

EVE CURIE, partly in VO
Radium had something better than a beautiful color. It was spontaneously luminous.

Footage of the glowing samples

CHEMIST GREG PETSKO, partly in VO
The fact that radium glowed in the dark seemed magical. But it was also troubling, because it almost seemed to violate some kind of fundamental, physical law.

PHYSICIST JIM GATES, partly in VO
Scientists had known for some time that light is a form of energy, so if you distill something and it suddenly glows in the dark, you have to ask the question: Where does that energy come from?

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO
It's not changing shape. It's not interacting with the environment to get this energy. But it is just glowing, infinitely, and we had no idea why it did that.

Animation of atoms breaking down and changing identities

NARR: It was Marie who had the flash of insight: Perhaps some kinds of matter were changing from one kind to another, their atoms splitting apart and releasing energy in the process.

MARIE CURIE

This theory of the source of the energy is very seductive; it explains radioactivity very well.

Photo of doubtful Russian chemists, arms crossed, Mendeleev in the corner

NARR: But it was an idea many chemists refused to accept.

DMITRI MENDELEEV

Tell me, please, how much radium salt is there in the entire earth? A few grams! On this shaky foundation they want to overturn our understanding of the nature of matter!

Photo of the Curies

NARR: Even the Curies were reluctant to accept it.

PHYSICIST JIM GATES, partly in VO

The Curies themselves, they wanted to think of elements as immutable, unchangeable parts of nature.

Image of the Curies over glowing vessel

AUTHOR OLIVER SACKS, partly in VO

The idea that one could have transmutation from one element to another was very disturbing, even to her, at first.

Photo of Marie, head down, surrounded by men at a Solvay conference. Tilt up and widen out to reveal Rutherford and Einstein standing behind her.

NARR: But the Curies' discoveries inspired others around the world to pursue this daring theory.

Animation of the atom breaking apart – emphasis on fragments coming out.

HISTORIAN DAVID KAISER, partly in VO

The idea that finally got pieced together was that the energy was, in fact, coming from the disintegration of these atoms themselves. Radioactivity was a sign that the atom itself was unstable. It could break apart.

Host picks up an animated round ball labeled U, for uranium.

HOST

This discovery implied something even more profound. Up to then, most scientists had believed atoms were the smallest units of matter – “solid, unsplittable lumps."

Now the ball begins throwing off animated heat, light and other products of radioactivity.

HOST

But if radioactivity was atoms falling apart, there must be even smaller pieces inside, still awaiting discovery.

Host walks forward to reveal photo of Curie with her two daughters

HOST

Thanks to this Polish expatriate … this graduate student … this young mother … scientists hoping to solve the mystery of matter now had a pressing new question to answer: What’s inside the atom?

VO: Next time on *The Mystery of Matter ...*

Harry Moseley (identified on screen) at his x-ray machine.

HARRY MOSELEY VO

There’s a fundamental quantity in the atom which increases by regular steps as we pass from one element to the next.

PHYSICIST JUSTIN WARK VO

I think he must have been astonished.

Physicist Luis Alvarez bursts into the UC Berkeley cyclotron control room and shouts to his graduate student, Phil Abelson, who is seated at the console.

PHYSICIST LUIS ALVAREZ

Phil, the Germans have split the uranium atom!

Glenn Seaborg (identified on screen) raises a narrow centrifuge tube and studies the small sample of plutonium in its pointed bottom.

PHYSICIST JIM GATES, partly in VO

Seaborg figured out how to turn it into a new element, plutonium.

Seaborg and graduate student Arthur Wahl perform a chemical test on plutonium. A mushroom cloud appears inside the flask as Seaborg mentions the changing world.

GLENN SEABORG, partly in VO

No matter what you do with the rest of your life, nothing will be as important as your work on this project. It will change the world.

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Banner: More from The Mystery of Matter

Photo of Marie Curie

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO

For me, Marie Curie is a story of perseverance. She just said, "Hey! You don't like what I'm doing, I'm just going to work harder and prove you wrong.

Marie and Pierre in the lab. Photo of Marie as a young girl.

BIOGRAPHER SUSAN QUINN, partly in VO

There is just so much about her and her stick-to-it-tiveness from the beginning. It's so moving and so wonderful. Her courage throughout her life is an enormous inspiration to everyone, but especially to women.

Images and footage of Marie, including Pierre and kids

CHEMIST DAGMAR RINGE, partly in VO

She was certainly an inspiration to me. I come from a generation when it was also, not quite yet fashionable to be a scientist. And here was a woman who had achieved it – to not only be a scientist but to be a wife, a mother, a part of a community. Those are very hard to do all at once. She was able to do that. And as women came along, they could look at that and say, "Well, maybe I can do it, too."

Footage of Marie in the lab

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO

If you look a little different, if you are a different gender, a different race, there are many barriers to overcome. But you do what Marie did, which is, you put your head down and you work harder. Footage of Marie

HISTORIAN DAVID KAISER, partly in VO

Curie's legacy is a many-fold. She changed cherished truths or notions about how the world seems to work, what's the universe made out of? She challenged equally steadfast notion of who should be contributing – who could play the game of science? She showed by example that there could be all kinds of people doing really, breathtakingly important science, all kinds of people could have a hand in pursuing the mystery of matter.