3.2

CHEMISTRY: PERIODIC TABLE OF ELEMENTS

0:00–0:34

PERIODIC TABLE OF THE ELEMENTS

Hello, I'm Hank Green, welcome to Crash Course Chemistry. Today we're talking about the most important table ever. Not the table where they signed the Declaration of Independence, nor any table of contents, nor this table right here, nor the stone table of Aslan.

Nay, it is the periodic table of elements — a concise, information-dense catalogue of all of the different sorts of atoms in the Universe.

Today I want to talk a bit about the creation of this table, which is, to be clear, one of the crowning achievements of human thought.

0:34–1:41

LET'S PRETEND

To start out though, let's close our eyes and pretend. Imagine you're in Siberia and you're a 13-year-old boy, and your father, who was a professor but had gone blind, leaving your family of more than ten brothers and sisters destitute, has just died. I know, downer. Your mom, to support the family has reopened an abandoned glass making factory in the small town where you live largely because she wants to make enough money to send you to school some day. A year passes, the factory burns down.

But your mom, she sees your potential, she knows that you have a keen scientific mind and will not see that squandered. So with your siblings out of the house and on their own, she packs up your belongings, straps them to a horse, and with you in tow, rides 1,200 miles through the Ural Mountains on horseback to a university in Moscow. There, on your behalf, she pleads earnestly and effectively and they reject you.

1:42–2:32

DMITRI MENDELEEV

So together, you ride another 400 miles to St. Petersburg, to the school where your father graduated as a scientist, and as luck or extreme insane, undeniably Russian persistence would have it, they accept you and your saddle-worn butt as a pupil. Your mother, having completed her mission, promptly dies.

If you're doing your imagining as I've told you, you might feel a tremendous debt to your mother and a very deep desire to ensure that you achieve something on par with the sacrifices she made for you. And maybe that's one reason why Dmitri Ivanovich Mendeleev became the crown jewel of Russian science and a theorist who revolutionized how we see the world.

Mendeleev spent a great deal of time in laboratories as a student studying the burgeoning new field of chemistry. He worked with all the elements that you could work with at the time and his knowledge gave him unique insights into their properties. Those insights would come in handy.

2:33–3:10

ATOMIC WEIGHTS

Let's all imagine we're Mendeleev again — I like doing that — and that we know a bunch of stuff about chemistry, which you know, you don't yet — yet! But we're imagining.

So it's the 1860s and about 60 elements are known to mankind and their atomic weights are mostly known as well. So the simplest thing was just to sort them in order of their atomic weights.

But interestingly, you, because you're a clever pants, realize that the most significant relationship seemed to have nothing to do with the atomic weight. Lithium, sodium, potassium and rubidium were all extremely prone to reacting with chlorine, fluorine, iodine, and bromine. Beryllium, magnesium, calcium and strontium were all similar, but less reactive.

3:11–3:45

PERIODIC RELATIONSHIPS

But with a quick inspection, you — and to be fair, a number of other chemists — realize that there was a relationship between atomic weights, but it's periodic. At the beginning of the list of elements, characteristics repeat every seven elements.

An aside here, we now know that it's every eight elements, but in the 1860s, elements were studied based on their reactivity, so the non-reactive noble gases had not yet been discovered. So the period occurred every seven elements.

As the mass of the elements increases, the repetition starts to look a little less periodic, though it's certainly still there. It just isn't perfect. Some of your colleagues, they're saying, "Well, such is life. "It was perfect repetition early on, but later in the list it gets a little fuzzier."

3:46–4:48

UNDISCOVERED ELEMENTS

But not you. You become obsessed. Obsessed with the perfection of the periodicity. You write out the names and weights and properties of elements on cards, you laid them across your desk, shuffled them, tear them to pieces in frustration until one day you realize that you're simply missing cards.

The numbers aren't working not because there's something wrong with your ideas, but because some elements simply haven't been discovered yet.

Armed with this insight, you insert gaps into the table and things suddenly fall perfectly into place. Seven element periods for the first two rows with hydrogen in its own category. 18-element periods for the next two rows. You're so certain, that you predict the properties of these missing elements. And when a French scientist comes along and says that he has, in fact, discovered one of them, you argue with him, saying that you discovered it first in your mind. And when you see his data and it doesn't match yours, you publish a paper saying his data for the new element he discovered is wrong.

4:49–5:37

ALKALI METALS

That's how certain you are of yourself and this beautiful new theoretical framework you've created.

And you know what the really crazy thing is? You're right. That French guy's data was wrong. You, never having examined the element he discovered, knew more about it than he did. Because you are Mendeleev, master of the elements.

Okay, we're done imagining for the episode. That was fun though. The different groups Mendeleev had identified are a lot of the same groups that we study today. Starting at the left we have the soft, shiny, extremely reactive alkali metals. So reactive, in fact, that they have to be stored in inert gases or oil to prevent them from reacting with the atmosphere.

Alkali metals want nothing more than to dump off an electron and form a positive ion or cation. And they're always jonesing to hook up with a hottie from the other side of the table. So, of course, seeing as they're so reactive, you don't find hunks of them lying around in nature.Instead, chemists must extract them from compounds containing them.

5:38–6:19

ALKALINE EARTH METALS

Next you have the alkaline earth metals. Reactive metals, but not as reactive as the alkali metals, forming cations with two positive charges instead of just one. Calcium, shown here undergoes a very similar reaction to sodium in water, just a little more slowly, producing a little less heat.

The middle body area of the table is made up of a nice solid rectangle of transition metals. These are the metals you think of as metals with iron, and nickel, and gold, and platinum. The majority of elements are metals — they're fairly unreactive, great conductors of heat, but more importantly for us, good conductors of electricity. They're malleable and can be bent, and formed, and hammered into sheets. And they're extremely important in chemistry, but overall surprisingly similar to each other.

6:20–6:50

HALOGENS

On the far right, just over from the noble gases, the halogens make up a set of extremely reactive gases that form negative ions or anions with one negative charge and love to react with the alkali and alkaline earth metals.

The rectangle between the halogens and the transition metals contain a peculiar scatter shot of metals, metalloids, gases and nonmetals. These guys don't end up as ions unless you take extreme action and start shooting other ions at them. So generally, a bit boring over here, though lots of interesting covalent organic chemistry, we'll get to that.

6:51–7:30

LATHANIDES AND NOBLE GASES

Down below in their own little island are the lanthanides and actinides — metals that were largely undiscovered in Mendeleev's day because they're so similar that it's next to impossible to separate them from each other.

And finally, on the far, far right, also undiscovered when Mendeleev built his chart, the completely unreactive noble gases.

Like a lot of other obsessive scientists, Mendeleev never thought he was done with his table. So he held it back for quite a while, only publishing it as part of a new chemistry textbook he was working on as a way to make some quick cash that he needed.

And as with many other scientific revelations, they were a number of other people hot on this discovery's trail. As many as six people published on the periodicity of elements at roughly the same time as Mendeleev. But a few things set him apart.

7:30–8:27

MENDELEEV IS DIFFERENT

One: he was obsessive. He knew the data better than anyone else, and had spent a ton of time working on a theory that many people thought was just an interesting little quirk.

And two: he realized in a way no one else did, that the idea of periodicity had far-reaching consequences. It seems as if he had a deep belief in the cosmic importance of what he was doing, almost a religious fascination.

Mendeleev believed in God, but also he believed that organized religions were a false path to the unknowable nature of God. I like to believe that he thought he saw some divine pattern in his tables and Mendeleev felt as if he was coming to know God in a way that no other man ever had.

To be clear, this is pure conjecture.

And as we now know the periodicity of elements is a physical phenomenon. It's a function of electrons, which are, in some ways, pretty dang peculiar, but certainly not at all mystical. But we'll get to that peculiar physical reality in the next episode.

8:28–9:22

THE FORMS OF THE TABLE

The periodic table that we know and love — I love it anyway — is a representation of reality, a way of understanding and sorting the Universe as it exists.

But that form of the table is not by any means set in stone. Indeed, a contemporary of Mendeleev envisioned the table sat onto a screw or a cylinder with the elements wrapping around from one side to another. While Mendeleev's table looks more like a map up on a wall, de Chancourtois, a geologist, envisioned more of a globe. Unfortunately for de Chancourtois, no publisher could figure out how to print his cylindrical, three-dimensional table. And so he published his paper without a graphical representation of his periodic cylinder of the elements. And it was largely ignored.

I guess they didn't have paper craft back then. I am a huge fan of this cut and tape model of the periodic table. You can make your own, there's a link in the description, and there are also a ton of other designs for periodic tables that have various advantages over the one that we're all familiar with.

9:25–9:44

LANTHANIDES AND ACTINIDES

Our periodic table as it stands is really a little bit unhappy with itself, frankly. The lanthanides and actinides really should be part of the table, but we separate them out because it's hard to fit that on a piece of paper.

Really, this is what it should look like.

And really, it would be best if it wrapped around into a circle so that fluorine and neon and sodium were all next to each other instead of being on the opposite sides of the map because they're just one proton away.

9:45–9:56

MENDELEEV'S CONTRIBUTION

Mendeleev's contribution, nonetheless, is more powerful than at first it seemed. He ended up forming a guide to help future chemists understand things that wouldn't be discovered for 25, 50, even 100 years.

9:57–10:30

ELECTRONS

Indeed, after Mendeleev's theories were published and accepted, the overwhelming cry from the scientific community was, "Why? "Why? Why?" And though Mendeleev was not himself concerned with this stuff, he actually denied the existence of atoms, or indeed anything he couldn't see with his own eyes. It turned out that the answer to the first why was the electron.

That sneaky, little electron. Mendeleev, if he'd been around to see their discovery, he would have hated them. But you, you will have a healthy respect for them. After you learn all about them on the next episode of Crash Course Chemistry.

10:31–11:21

CONCLUSION

Thank you for watching this episode of Crash Course Chemistry. If you were paying attention, you now know the terrible, beautiful and wonderful story of Dmitri Mendeleev, how he organized the elements into the periodic table, some of the basics of the relationships on that table, why Mendeleev stood out from his colleagues, and how the table as we know it today could stand some improvement.

This episode of Crash Course Chemistry was written by myself, filmed and directed by Caitlin Hoffmeister, and edited by Nick Jenkins. The script was edited by Blake de Pastino and Dr. Heiko Langner. Our sound designer is Michael Aronda, and Thought Cafe is our graphics team. If you have any questions, please ask them in the comments below.

Thank you for learning with us here at Crash Course Chemistry.