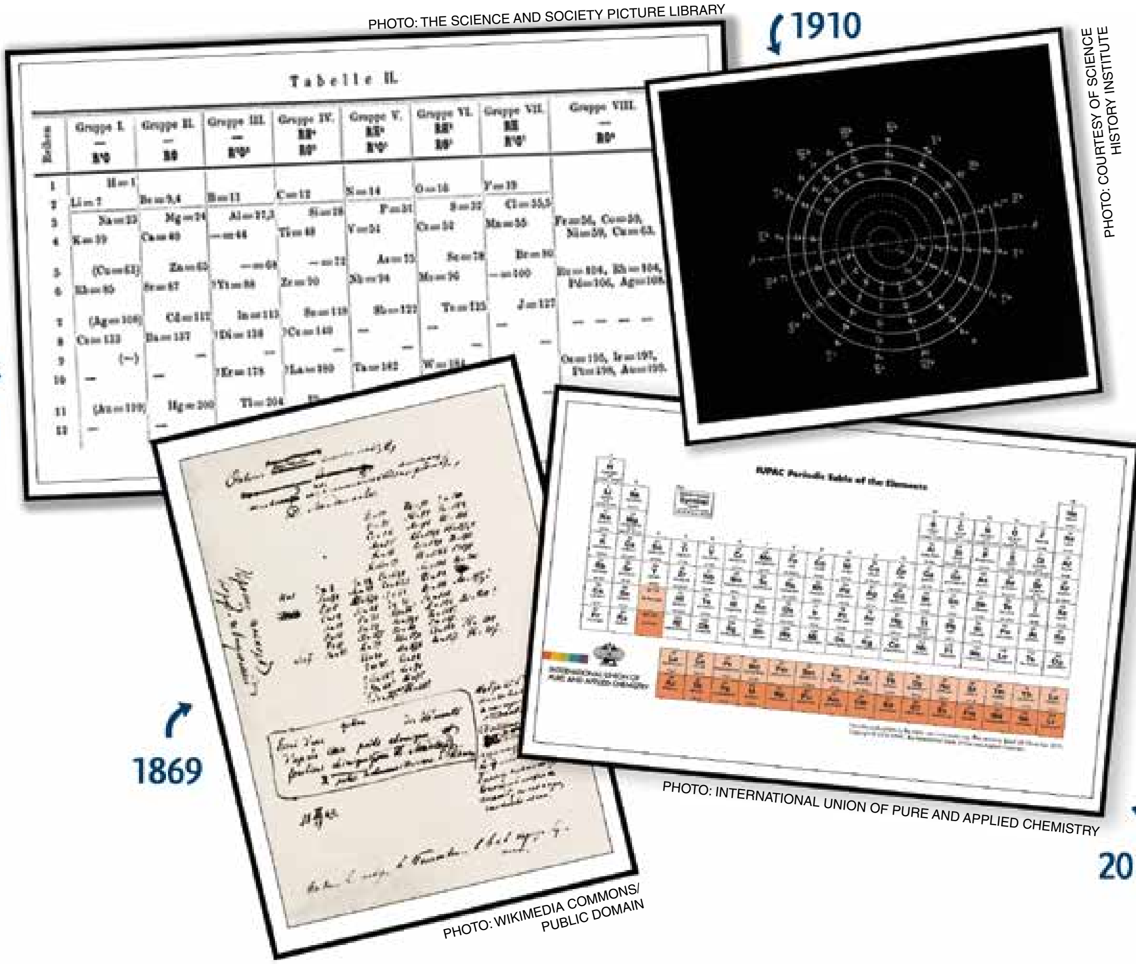

1871

1869

1910

2019

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The Periodic Table turns 150

Is the best yet to come?

By David Warmflash

The periodic table of elements is one of the most recognizable icons of science. You probably have one hanging on your chemistry classroom wall. If you google it, you'll see versions in rainbow colors, or with tiny photos in every box representing each element. There's even a periodic table of moles!

You could almost call the table mundane, except really, it's anything but. The periodic table has been perhaps as foundational to chemistry as the discovery of DNA has been to biology. It is 150 years old this year and is holding up well under the test of time—and science.

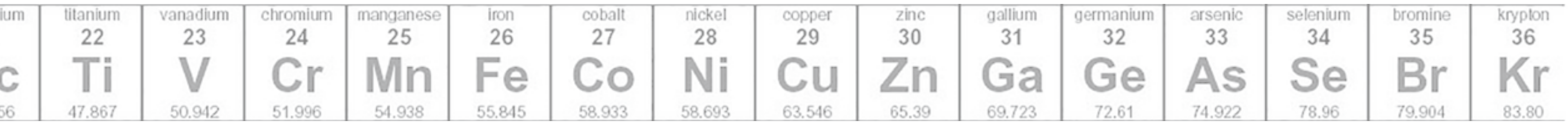

PHOTO: THINKSTOCK

In celebration of the table, the United Nations proclaimed 2019 as the International Year of the Periodic Table of Chemical Elements. Time to break out the helium balloons, iron-based sparklers, and calcium-rich ice cream!

And whom do we have to thank for the exquisite arrangement of elements? While many scientists contributed to the formation of the table, Russian chemist Dmitri Mendeleev is most often credited for the periodic table's creation. He found that there was a periodicity to their organization, a repetition of particular chemical properties at regular intervals as atomic weight increased.

In 1869, Mendeleev published his vision in an early form of the periodic table. It included the 63 elements that were known at the time, with holes to account for elements that hadn't yet been discovered. And while the table has been fleshed out over the past century and a half—including the addition of four new elements in 2016—the essence of Mendeleev's original idea remains. But who knows, future discoveries could lead to materials that even Mendeleev couldn't have dreamed of.

Getting organized

To understand how Mendeleev created the table in the first place, you have to go back in time and erase what you've learned about the table. Imagine for a moment that the distinctive shape of the present-day periodic table with its neat columns and rows doesn't exist. You don't yet know about protons and therefore atomic numbers, which, for the most part, conveniently run in order from one to 118 from left to right and top to bottom of the table.

All you know about the elements identified at the time is how they interact with each other, their physical properties, and their relative atomic weights. And you want to categorize them.

Before Mendeleev came along with his approach, other scientists were attempting to organize the elements. As early as 1789, French chemist Antoine Lavoisier had categorized elements into metals, nonmetals, "earths," and gases, based on their physical and chemical characteristics. By 1829, German chemist Johann Döbereiner had noticed patterns among triplets of elements. In 1865, British chemist John Newlands noticed the periodicity of chemical properties and likened the phenomenon to musical octaves, in which the same tone repeats after an increase or decrease of eight notes. In Germany, chemist Julius Lothar Meyer was developing his own periodic table that was published in 1870. But Mendeleev beat Meyer to the punch a year earlier.

What sort of chemical properties did Mendeleev have in mind when he developed his table? To get a better idea of the patterns he noticed, let's start with the metal lithium (Li). Mendeleev knew the hydride—a compound of hydrogen with another element—that Li formed had the formula LiH.

$$2\,Li(s) + H_2(g) \rightarrow 2\,LiH(s)$$

In contrast, the next element by weight, beryllium (Be), formed the hydride BeH_2.

$$Be(s) + H_2(g) \rightarrow BeH_2(s)$$

Each successively heavier element formed different kinds of hydrides until he got to sodium (Na). Sodium behaved like lithium in its reactions with hydrogen, forming NaH.

$$2\,Na(s) + H_2(g) \rightarrow 2\,NaH(s)$$

Thus, a pattern started to emerge.

But Mendeleev's most insightful decision was to let properties sometimes trump atomic weight when he placed elements. For example, if you look at the periodic table, you'll notice that nickel follows cobalt in the fourth row

THE PERIODIC TABLE TIMELINE: SCIENTISTS' CONTRIBUTIONS

1789 French chemist Antoine Lavoisier categorized elements into metals, nonmetals, "earths," and gases.

1829 German chemist Johann Döbereiner noticed that triplets of elements shared chemical behaviors.

1865 British chemist John Newlands likened the periodicity of chemical properties to musical octaves.

PHOTO: THINKSTOCK

scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	kry
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	3
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	K
44.956	47.867	50.942	51.996	54.938	55.845	58.933	58.693	63.546	65.39	69.723	72.61	74.922	78.96	79.904	83

even though nickel is lighter. Mendeleev placed them this way because nickel's properties aligned with palladium's (on the next row, same column) and cobalt's with rhodium.

This approach allowed him to skip slots in the table that corresponded to chemical properties and atomic mass ranges that did not match any elements known at the time. For each open slot, Mendeleev predicted the existence of a yet-to-be discovered element.

He turned out to be right most of the time. For example, Mendeleev had left spaces for yet-to-be discovered elements that he called eka-aluminum, eka-manganese, and eka-silicon—eka is the Sanskrit word for "one." These spots were ultimately taken by gallium, technetium, and germanium.

That's not to say Mendeleev's table was perfect from the beginning, or even the only way to organize elements. He himself revised it within two years of introducing it. Mendeleev's 1869 periodic table had the elements with increasing mass moving down in columns, while elements with similar chemical properties lined up horizontally in rows. In 1871, however, he reversed this idea. He lined up elements with similar properties vertically, and the periods appeared in horizontal rows.

The discovery of protons

It wasn't until more than 40 years later in 1913 that British physicist Henry Moseley used a technique called X-ray spectroscopy to count the numbers of positive charges in the atomic nucleus. Moseley then developed the first modern periodic table, basing the element sequence directly on these charges. In 1920, New Zealand-born British physicist Ernest identified the charge as the atomic number, or the proton number. Remarkably, organizing the table this way validated Mendeleev's original approach

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THE HYDROGEN PUZZLE

We often see hydrogen atop group 1 although hydrogen is very different from the other elements in the column. Unlike group 1 elements, hydrogen is not a metal, it's a gas at room temperature, and it bonds covalently most of the time. Group 1 elements are metals, solid at room temperature, and form only ionic bonds.

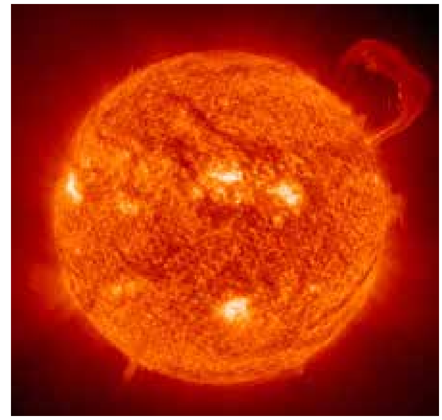
So, why is hydrogen grouped with these metals?

Today, we know that hydrogen has a single electron in its **electron shell**, defined as a set of electrons with similar energies in an atom. This shell contains one **subshell**, which consists of one **orbital**. An orbital is a region of high probability of finding an electron. Each orbital can hold up to two electrons.

Since hydrogen has only one electron total, its electron is in the outermost—or **valence**—shell. Valence shell electrons account for how an element reacts chemically. Other group 1 elements have more than one electron, but like hydrogen, they have only a single electron in their valence shells.

PHOTOS: COURTESY OF NASA

On Earth, hydrogen is mainly found in water.



The sun is more than 70% hydrogen by mass.

Because of this shared trait, hydrogen forms some compounds in ways that are similar to how alkali metals form compounds. Reactions between hydrogen and chlorine, and between sodium and chlorine provide an example of this:

$$H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$$

$$2\,Na(s) + Cl_2(g) \rightarrow 2\,NaCl(s)$$

But in other ways, hydrogen resembles elements in group 17, the halogens, which are nonmetals like hydrogen. Halogens' valence shells have seven electrons, and need just one more for these shells to be full. Hydrogen's valence shell also needs just one more electron to fill its valence shell and form an anion.

$$H(g) + e^- \rightarrow H^-(g)$$

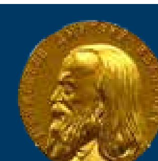
$$F(g) + e^- \rightarrow F^-(g)$$

After 150 years, some scientists still debate where this unique element fits best.

1869 Russian chemist Dmitri Mendeleev published an early form of what would become the modern periodic table.

1870 German chemist Julius Lothar Meyer published a different version of the periodic table.

1871 Mendeleev revised his table.



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ium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	krypton
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
c	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
56	47.867	50.942	51.996	54.938	55.845	58.933	58.693	63.546	65.39	69.723	72.61	74.922	78.96	79.904	83.80

Additional findings further fleshed out the table. By this point, for instance, noble gases had been discovered. Initially, they were placed to the left of group 1 metals. But further study justified moving them to the far-right side of the table where they reside now.

Also, beginning with period 4, which starts with potassium (K), the table expanded like an accordion to hold 10 additional groups. The addition of these transition elements gave the table a shape more like you see in today's version.

And what about the two rows that sit below the main table? These are the lanthanide and actinide series. The first elements in these rows were discovered as early as the 1700s, but they weren't organized in their own section until the 1900s. Although they look separate from the rest of the table, they really belong to periods 6 and 7, respectively, and in between groups 2 and 3.

Filling in the blanks

Changes to the periodic table continue to this day and will likely keep surprising us in the future. As recently as 2016, the four final gaps in period 7—elements 113, 115, 117, and 118—were officially filled. In order of increasing atomic number, these elements are named nihonium, moscovium, tennessine, and oganesson.

So, it would seem that the periodic table is complete with period 7 filled in. Now what?

The Race to Invent the Periodic Table

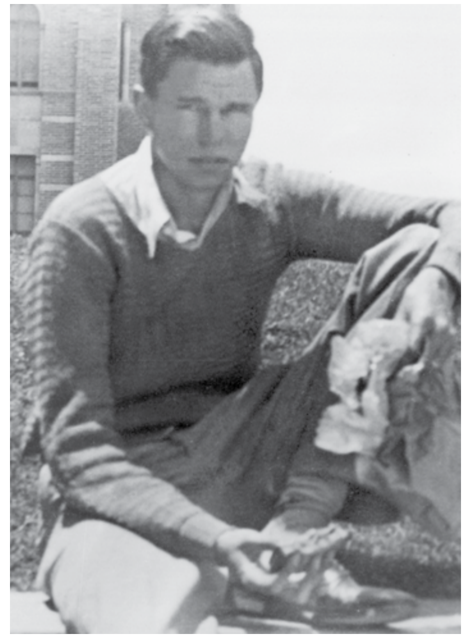
https://youtu.be/-ojcm3llf98

Some scientists have hypothesized that period 7 might not be the last one in the table. A proposed *superactinide series* could get us to element 157!

How is that possible? Well, during the 1950s, chemists had developed a model of the nucleus in which protons and neutrons are not simply clumped together, but rather arranged in rings. Based on the idea that each nuclear ring could become full, U.S. chemist and Nobel Laureate Glenn Seaborg proposed something called an "island of stability." He suggested that when a ring becomes full with a particular number of protons and neutrons, a super-heavy element would be stable for long periods of time.

Take flerovium (Fl) as an example. It's a super-heavy element that was first discovered in 1998 and is only stable for about 2.6 seconds. The island of stability theory predicts that if Fl could be created with 184 neutrons, it would be stable. So far, it has only been observed with a maximum of 176 neutrons.

Moving to even heavier elements, the next island of stability in Seaborg's hypothesis is the yet-to-be created element 120, which would be in period 8 on an extended periodic table, along with element 126. Both these elements would belong to Seaborg's *superactinide* series, but only a particular number of neutrons would allow them to stick around.



PHOTOS: LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. chemist and Nobel Laureate Glenn Seaborg

If such stable elements could be created at some point in the future, there would be more at stake than just creating and filling period 8, because stability is the key to practicality. Such elements could be used to make special materials with properties that we cannot even begin to imagine. Or maybe we can. Vibranium, anyone?

David Warmflash is a science writer based in Portland, Oregon.

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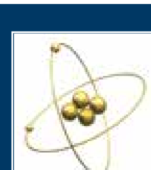
THE PERIODIC TABLE TIMELINE: SCIENTISTS' CONTRIBUTIONS

1913 British physicist Henry Moseley developed the modern periodic table, basing the sequence of elements on atomic number.

1919 New Zealand-born British physicist Ernest Rutherford discovered protons.



2016 The official addition of four new elements completed the seventh row of the periodic table.