



**Tools and Resources**

***“The Periodic Table Turns 150: Is the Best Yet to Come?”***

February/March 2019

<http://www.acs.org/chemmatters>

**Teacher’s Guide:**



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**Tools and Resources**

***“The Periodic Table Turns 150: Is the Best Yet to Come?”***

**February/March 2019**

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# Connections to Chemistry Concepts

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| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **History of the periodic table** | The article provides students with the historical context for the look and function of the current periodic table. |
| **Periodic law** | The concept of periodicity, and the roles of protons in differentiating the elements and of electrons in determining elemental properties, may help students understand why individual elements are different and how the properties of these different elements seem to repeat. |
| **Electron orbitals** | The role of electrons in the organization of the periodic table allows the teacher to reinforce the importance of electrons in the properties of the elements. |
| **Chemical properties** | The article explains how scientists often used chemical properties of the elements and their compounds to understand and develop organizational patterns which led to the periodic table. |
| **Protons** | The importance of Rutherford’s work with the proton number and Henry Moseley’s work with x-ray spectroscopy described in the article provides justification for arranging elements in the periodic table by increasing positive nuclear charges (protons), rather than by increasing mass as was done in Mendeleev’s original table. |
| **Superactinides** | The predicted existence of these elements by Seaborg and the islands of stability due to completed nuclear rings helps the teacher to explain scientific opportunities for the discovery of future elements and their placement in the periodic table. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:
	+ **ELA-Literacy.RST.9-10.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
	+ **ELA-Literacy.RST.9-10.5:** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
	+ **ELA-Literacy.RST.11-12.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
	+ **ELA-Literacy.RST.11-12.4:** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
	+ **ELA-Literacy.WHST.9-10.2F:** Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
	+ **ELA-Literacy.WHST.11-12.1E:** Provide a concluding statement or section that follows from or supports the argument presented.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in the February/March 2019 issue:

Mixtures

Structural formulas

Environmental impacts of personal and societal decisions

Nanoparticles

Periodic properties

Phase changes

Green chemistry

* Consider asking students to read “Open for Discussion: Unpacking the Paleo Diet” on page 4 before they read “Making Sense of Milk” to learn why some people might choose not to consume dairy products.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* Encourage students to watch the videos and try the simulations suggested in some of the articles.

# Possible Student Misconceptions

1. **“The periodic table is constructed in order of increasing mass.”** Dmitri Mendeleev’s original 1869 periodic table was designed on increasing atomic mass. This was a logical way to sequence the known elements. However, there were sequencing problems with the chemical and physical properties of a few elements (e.g., Co and Ni) when arranged by increasing mass: they appeared out of place according to their properties. In some cases, there wasn’t a known element that would logically fill into a specific space. Mendeleev did not have an explanation for the incorrect properties when sequenced by increasing mass, and the reason for the incorrect sequencing was not totally understood until the proton was discovered by Rutherford in 1920. For most elements, as the number of protons, or atomic number, increased, their atomic masses increased correspondingly. In 1913, Moseley’s experiment with x-ray spectroscopy allowed him to count the number of positive charges in the nucleus of many elements. This information allowed him to explain why cobalt and nickel (as well as some other elements) were seemingly out of place in Mendeleev’s periodic table based on increasing mass. Moseley’s work identified cobalt with a mass of 58.93 amus contained 27 positive nuclear charges, while the lighter nickel with a mass of 58.69 amus had 28 positive nuclear charges. Based on this work, Moseley revised the periodic table to sequence the elements in order of increasing positive nuclear charge, which corrected problems with Mendeleev’s table. Increasing atomic number (protons) is the basis for the current periodic table.
2. **“The first 92 elements all occur naturally and are not radioactive.”** Some people may believe that the first 92 elements (hydrogen through uranium) are naturally occurring and not radioactive, but this is not entirely true. Most people certainly know about atomic bombs and nuclear power plants that rely upon uranium’s (element 92) radioactivity. While the common forms of elements 1–83 are not radioactive, all elements with atomic numbers greater than 83 (bismuth) are radioactive, and most elements with atomic numbers 1–83 have at least one radioactive isotopic form. For example, carbon (which exists as graphite, charcoal, diamond, and buckminsterfullerene) is not radioactive as the common carbon-12 isotope but is radioactive in its carbon-14 form. The discovery of technetium (element 43) was not confirmed until 1937, and it was the first man-made element. Since its discovery, extremely small quantities of technetium have been located in the Earth, but the quantities are so minute that it is synthesized rather than mined. So, technically, all of the elements
1–92 occur naturally in some quantity in the Earth, but most are radioactive in at least one isotopic form.
3. **“Dmitri Mendeleev invented the current periodic table.”** Dmitri Mendeleev is usually credited with designing the original periodic table we use today in a modified form, but many people have been involved with classifying and organizing the known elements. Mendeleev’s original 1869 periodic table has been modified by Mendeleev himself in 1871, Moseley in 1913, and Seaborg in 1944 to arrive at the common periodic table that is used today.
4. **“So, now that row seven of the periodic table is complete, there are no new elements to be discovered or places to put them in the periodic table.”** While that might seem logical, it is not correct. The completion of row seven in the periodic table does provide symmetry and a sense of completion, but the article states that more elements may be out there awaiting discovery, and Seaborg suggested the possibility of a superactinide series of elements that may increase the number of elements on the periodic table to 157. The placement of these new elements in the table would likely follow their outer electron configuration arrangements just as the previous elements have done.
5. **“Mendeleev must have known there was some other as-of-yet undiscovered particle (i.e., the proton) when he arranged elements like cobalt and nickel on his table, seemingly in the wrong order based on their atomic masses.”** Not really. He only knew that the physical and chemical properties dictated his placing them where he did.
6. **“The number of neutrons in the nucleus doesn’t have much influence on an element’s properties, because the number of protons determines the specific element and the number and arrangement of outer electrons determine the reactivity.”** Actually, the number of neutrons in the nucleus of an atom has an important influence on the element and its properties. The stability of an element is partly a function of the ratio between protons and neutrons in the nucleus of the atom. If that ratio is too far out of balance, the nucleus becomes unstable and radioactive, in an attempt to achieve greater stability. So, neutrons influence whether an isotope of an element will be radioactive. Also, the article explains that the number of neutrons in the nuclear ring plays a role in the half-life of an isotope of the super-heavy elements and may allow some of these elements to last longer than mere seconds.
7. **“I heard that Mendeleev accurately predicted the missing elements and their properties when he organized his original 1869 periodic table.”** It’s true that in 1869, when he was placing the 63 then-known elements into his periodic table, Mendeleev left spaces for undiscovered elements and made predictions about their properties. However, the accuracy of his predictions varied. Mendeleev’s most successful predictions involved the element he called eka-silicon (meaning one down from silicon), which we now know as germanium. He also had relatively accurate predictions for eka-boron (now scandium), eka-aluminum (now gallium), and eka-manganese (now technetium). Other predictions (some later than 1869) such as for protactinium (then eka-tantalum) were wrong in location. Mendeleev also predicted a heavier element similar to titanium and zirconium, but he incorrectly placed lanthanum below them. Amazingly, Mendeleev was often correct in his predictions, but not perfect.

*(*[*https://en.wikipedia.org/wiki/Mendeleev%27s\_predicted\_elements*](https://en.wikipedia.org/wiki/Mendeleev%27s_predicted_elements)*)*

# Anticipating Student Questions

1. **“Are there additional forms of the periodic table, besides the one in my textbook or the poster on the wall?”** Yes! There are possibly hundreds of different forms of the periodic table of the elements, each with a unique way of showing the periodic nature and properties of the elements. The traditional, or condensed, form of the periodic table shows elements 1–118 in a castle-like shape with two long rows underneath the main structure. Other forms include a galaxy shape, a pyramid, a circle, a spiral, 3-dimensional, and many others. (<https://www.meta-synthesis.com/webbook/35_pt/pt_database.php>)
2. **“Why are there two rows of elements (lanthanides and actinides) separated at the bottom of the periodic table?”** The most common form of the periodic table separates the lanthanide and actinide elements from the main body of the table. There are two reasons offered for this separation. First, by placing the lanthanide and actinide elements separately below the main table, the physical size of the table is reduced in length. This allows the table to be printed on standard 8.5” x 11” printer paper in a size that can easily be read by most people. It also avoids having to have a troublesome fold-out page in a textbook or the extreme cost associated with producing a very long wall chart. The second reason is that chemically the lanthanide and actinide elements have some similar properties due to their
f-block electrons buried deeply within the atoms. Because of their similar properties, the lanthanide and actinide elements were originally difficult to separate and identify as individual elements.
3. **“How are new elements discovered and verified?”** Each element has a unique number of protons, or its atomic number. So, simplistically, all that is required to form a new element is to add another proton to the nucleus of the previous largest element. In a sense, it would be like finding the largest number—all one has to do is take the previous number and add one more to it. This process worked for elements 95–100. But, in reality, it is not that easy because all elements past number 83 are radioactive, and some exist only for seconds before decaying into a different element. So adding another proton, isolating, and identifying the new element prior to its decay is exceedingly difficult. In practice, scientists fire smaller elements (hydrogen through zinc) at larger, relatively stable nuclei to form super-heavy elements. However, the difficulty is that, as the smaller element projectiles get larger in mass, it takes greater energy to smash them into the target atoms. This energy, the time, and the cost are current limits to producing new elements—but the search won’t stop. Once synthesized by one laboratory, another laboratory must halt its work on synthesizing a new element to duplicate and verify the results of the reported discovery. Currently, there are only a few facilities in the world conducting research on the synthesis and verification of new elements, including the Riken Institute in Japan, the Joint Institute for Nuclear Research in Russia, the Lawrence Livermore National Laboratory in California, the Oak Ridge National Laboratory in Tennessee, and GSI in Germany.
4. **“Are there any practical uses for the transuranium elements?”** There are a number of uses for several of the transuranium elements. Plutonium (element 94) is used as a fuel in fast-breeder reactors, in nuclear weapons, and as a compact energy source for spacecraft, etc. Americium (element 95) is an alpha-particle emitter for smoke alarms. Both americium and californium (element 98) have isotopes used in medicine (cancer treatments) and in industry (well logging). The costs of producing these transuranic elements (from $4,000/gram for plutonium to $60,000,000/gram for californium) limits their potential uses. Elements past californium have essentially no industrial applications due to costs, limited supply, and very short lives.
5. **“Do any elements exist between the ones currently on the periodic table?”** If you mean, “Is there a possible element between, for example, iron (element 26) and cobalt (element 27)?”—the answer is no. Because elements are arranged in the periodic table by increasing atomic number (protons), there is not an element with a fractional number of protons like an atomic number of 26.5 that could occur between iron and cobalt. However, there have been times when there were gaps in the periodic table where the missing element contained a whole number of protons but hadn’t been isolated yet. An example from several years ago was when current element 117 (tennessine) was undiscovered, while numbers 116 and 118 had been synthesized, leaving a gap between them, until 2010 when tennessine was announced.
6. **“Why do elements in columns or families in the periodic table have similar properties?”** The properties of individual elements are largely determined by their electron configurations—especially the number and arrangement of their outer-energy-level electrons. Because of the periodic table’s arrangement into columns with similar outer electron configurations—and those outer electron configurations influencing properties—the elements in each column will have similar (but not identical) properties.
7. **“Why do some periodic tables (like the one hanging in my classroom?) have strange letters like Uut, Uup, Uus, and Uuo for some of the newer elements?”** That’s a great question! Once a new element has been announced and verified by a research group, it is assigned a placeholder name until the International Union of Pure and Applied Chemistry (IUPAC) determines who has the honor of naming the new element and officially accepting the name that is proposed. This process can take many years. In the meanwhile, the new element is assigned a working name and symbol composed of the Latin names for the digits in its atomic number. So, Uut was ununtrium, spelling out the numbers 1, 1, and 3 for element 113; likewise, Uup was ununpentium, for 115; Uus was the symbol for ununseptium, spelling out 117; and Uuo was the symbol for ununoctium, number 118.

# Activities

**Labs and demos**

**“Electron Configuration and the Periodic Table” lab:** Students write electron configurations for selected elements, predict electron configurations for other atoms, and predict reactivity based upon an atom’s electron configuration and position in the periodic table. (Access is restricted to AACT members, but the article will be available for free until April 1, 2019, at <https://teachchemistry.org/classroom-resources/electron-configuration-and-the-periodic-table>.)

**“Periodic Pasta Table” lab:** Students use a cardboard base and spaghetti noodles to create a three-dimensional model of a periodic property for the periodic table. The lab activity includes photographs, student and teacher hints, extensions, and directions. (<https://www.exploratorium.edu/snacks/periodic-pasta-table>)

**Simulations**

“**Alien Periodic Table”:** This activity simulates the organization of the periodic table into groups and periods, allowing students to find patterns and visualize the Periodic Law using cartoon drawings of “aliens”. (<https://www.gulfcoast.edu/current-students/academic-divisions/natural-sciences/biology-project/chemistry-1/documents/alien-periodic-table.pdf>)

**Media**

**“The Periodic Table – Classification of Elements” (8:55):** This Khan Academy video names the chemical families, defines groups and periods, and explains how metals, metalloids, and non-metals can be identified by their locations in the table; it also discusses the elements’ reactivities. (<https://www.youtube.com/watch?v=t_f8bB1kf6M>)

**“Periodic Videos”, (times vary):** Select an element and this interactive periodic table links to a video (of varying length) about each element numbers 1–118 providing information including visuals, history, uses, and interesting facts. (<http://periodicvideos.com/>)

**Lessons and lesson plans**

**“The Periodic Table Unit Plan” lesson unit:** this guide provides 7-10 days of resources and a dozen activities for supporting students’ learning of the periodic table, properties, and trends with links to all resources. (Access is restricted to AACT members, but the article will be available for free until April 1, 2019, at <https://teachchemistry.org/classroom-resources/the-periodic-table-unit-plan>.)

**“The Periodic Table of the Elements” lesson:** This site provides a lesson overview with links to activities including multimedia and print materials, looking at the origin of the periodic table and the anatomy of the periodic table. (<https://www.pbslearningmedia.org/resource/phy03.sci.phys.matter.lp_pertable/the-periodic-table-of-the-elements/>)

**Projects and extension activities**

**“Group and Periodic Properties Lab” extension lab:** Students perform experiments with sodium, potassium, calcium, magnesium, sulfur, and phosphorous to observe reactions and form conclusions about trends down groups and across periods. The teacher will need to determine if these activities can be safely performed by students, due to the limited instructions and teacher supports, or if they should be used only as teacher demonstrations, due to safety and laboratory equipment issues; some can be done either way. (<https://serc.carleton.edu/sp/mnstep/activities/26404.html>)

**“A Research Paper on the Elements, in 3-D” project:** Students research an element, construct a paper icosahedron, and display information about the element on the faces of their icosahedron. Although the abstract states the audience for this project is elementary and middle school students, it is also successful with high school students. (<https://pubs.acs.org/doi/pdf/10.1021/ed086p1142>. Note that this link takes you to a brief abstract only; the full article is only available to American Chemical Society members or subscribers to the journal.)

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***

“The New Alchemy” describes the stars as the source of all elements on Earth, the formation of new elements through transmutation, and the revision of the periodic table through the work of Seaborg and McMillan. (McClure, M. The New Alchemy. *ChemMatters*. 2006, *24* (3), pp 15–17)

In “What Uuought to Know about Elements 112–118”, readers will learn about the process of making and discovering super-heavy elements using projectiles and element targets. (Brownlee, C. What Uuought to Know About Elements 112–118. *ChemMatters*. 2008, *26* (3), pp 9–10)

“The Many Looks of the Periodic Table” displays and discusses the traditional format of the periodic table, along with variations that include a spiral, a galaxy, a circle, and a three-dimensional table. (Katz, G. The Many Looks of the Periodic Table. *ChemMatters*. 2008, *26* (3), pp 12–14)

“Where Do Chemical Elements Come From?” describes the nucleosynthesis of the elements in the stars, starting with hydrogen and the formation of helium through iron in younger stars, to the formation of heavier elements in supernovas. (Ruth, C. Where Do Chemical Elements Come From? *ChemMatters*. 2009, *27* (3), pp 6–8)

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The majority of the September 8, 2003 issue of *Chemical and Engineering News* was devoted to the celebration of the magazine's 80th anniversary, by looking at the periodic table. Color graphics and 89 varied essays provide perspective on the periodic table and the elements. (Chem. Eng. News, 2003, *81* (36)

This 2018 article describes how the authors arranged students into a representation of the “s” and “p” elements of the periodic table, with each student portraying a specific element. The instructor directed students to evaluate statements of peers and analyze periodic trends, while answering questions to learn about the periodic table’s predictive powers. (Hoffman, A.; Hennessy, M. The People Periodic Table: A Framework for Engaging Introductory Chemistry Students. *J. Chem. Educ.*, 2018, *95* (2), p 281–285; <https://pubs.acs.org/doi/10.1021/acs.jchemed.7b00226>. Note that this link takes you to a brief abstract only; the full article is only available to American Chemical Society members or subscribers to the journal.)

# Web Resources for More Information

**History of the periodic table**

This site explains the development of the periodic table from Aristotle through Seaborg.

(<http://www.newworldencyclopedia.org/entry/History_of_the_periodic_table>)

This Wikipedia site is a timeline for information on the discovery of each element.

(<https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries>)

**Dmitri Mendeleev’s and Julius Lothar Meyer’s similar periodic tables**

This resource provides biographical material and information on Mendeleev’s work to develop the periodic table.

(<https://www.khanacademy.org/partner-content/big-history-project/stars-and-elements/knowing-stars-elements/a/dmitri-mendeleev>)

Meyer developed a periodic table similar to Mendeleev, and this site looks at the work of both Meyer and Mendeleev and the contributions of each man.

(<https://www.sciencehistory.org/historical-profile/julius-lothar-meyer-and-dmitri-ivanovich-mendeleev>)

**Johann Döbereiner’s and John Newlands’ early classification attempts**

John Newland’s work on the Law of Octaves for organizing the elements is explained at this site, along with diagrams to help readers.

(<https://www.wonderwikikids.com/conceptmaps/Newlands_Law.html>)

This site is a brief biography for Döbereiner and his work in chemistry, including his organization of elements into triads.

([http://www.eoht.info/page/Johann+Dobereiner](http://www.eoht.info/page/Johann%2BDobereiner))

**Henry Moseley’s and Glenn Seaborg’s contributions to the modern periodic table**

Moseley’s contributions to improving the periodic table by ordering elements in increasing atomic number are explained in this biography, along with his other scientific contributions.

(<http://www.chemistryexplained.com/knowledge/Henry_Moseley.html>)

Glenn Seaborg’s life and contributions to science, including his discovery of elements and major revision to the periodic table, are described in this reference.

(<https://www.famousscientists.org/glenn-seaborg/>)

**Periodic tables**

“The Internet Database of Periodic Tables” is a vast and comprehensive source of all things related to periodic tables.

(<https://www.meta-synthesis.com/webbook/35_pt/pt_database.php>)

**Electron energy levels and the periodic table**

This is a clear description of how electrons are organized in atoms and how this organization is the basis for the periodic table.

(<https://www.khanacademy.org/science/biology/chemistry--of-life/electron-shells-and-orbitals/a/the-periodic-table-electron-shells-and-orbitals-article>)

**Periodic properties and trends**

The periodic properties of elements, including atomic radius, ionization energy, electron affinity, electronegativity, metallic character, and others, are explained and illustrated in this resource.

([https://chem.libretexts.org/Textbook\_Maps/Inorganic\_Chemistry/Supplemental\_Modules\_(Inorganic\_Chemistry)/Descriptive\_Chemistry/Periodic\_Trends\_of\_Elemental\_Properties/Periodic\_Properties\_of\_the\_Elements](https://chem.libretexts.org/Textbook_Maps/Inorganic_Chemistry/Supplemental_Modules_%28Inorganic_Chemistry%29/Descriptive_Chemistry/Periodic_Trends_of_Elemental_Properties/Periodic_Properties_of_the_Elements))

**Nuclear structure, shells, and the island of stability**

This technical article provides in-depth information on the nucleus, the nuclear shell model, and super-heavy elements.

(<https://www.nap.edu/read/6288/chapter/5#61>)

Neil DeGrasse Tyson narrates this NOVA video (13:10) explaining the island of stability.

(<https://www.youtube.com/watch?v=pkV63_Y6Klw>)

**Interactive periodic table**

Click on any element in this interactive periodic table to explore facts, uses, properties, history, atomic data, oxidation states, and isotopes. In addition, podcasts, videos, resources, references, and more are available for most of the elements.

(<http://www.rsc.org/periodic-table>)

**Discovering new elements**

This site emphasizes that many more elements remain to be discovered and discusses the research process and the rivalry among research teams; the site includes colorful graphics.

(<http://www.bbc.com/earth/story/20160115-how-many-more-chemical-elements-are-there-for-us-to-find>)

**Even more resources**

The ACS ChemClub site provides over a dozen Web sites, puzzles, videos, and other activities for possible projects or lesson extensions. (<https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/periodic-table.html>)

A search of the “Compound Interest” Web site for “element infographics” brings up infographics of groups 1–8, plus the transition elements, lanthanides, actinides, and transactinides.

(<https://www.compoundchem.com/>)