



**Tools and Resources**

***“The Periodic Table’s
Final Four”***

April/May 2019

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

**Teacher’s Guide:**



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**Tools and Resources**

***“The Periodic Table’s Final Four”***

**April/May 2019**

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# Connections to Chemistry Concepts

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| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Chemical nomenclature** | While teaching a unit on chemical nomenclature, the information in the article about the role of IUPAC and its governance in naming compounds can give insight into how new elements get their names. |
| **Periodic table** | The story of the completion of the last row on the periodic table shows the usefulness and value of the table as a critical organizational tool for chemists. |
| **Elements** | The information about a list of the earliest elements used in Lavoisier’s chemistry book, as well as the creation of the latest elements, can be used to enhance a lesson on elements and what constitutes an element. |
| **Nuclear chemistry** | The stories in the article of making new elements from pairs of a heavy element and a lighter element in a cyclotron can be used during a unit on nuclear chemistry. |
| **Nuclear reactions** | The discussion of the production of curium from alpha particles and plutonium is illustrated with an equation that can be used as an example of how nuclear reactions are written. |
| **Atomic number** | The information about atomic number determining the identity of an element supports what students learn in the curriculum about the composition of atoms. |
| **Radioactivity** | The sidebar discussing radioisotopes and their uses in medicine can be used as an example of the beneficial application of new discoveries. |
| **Scientific discovery** | The process involved in claiming new elements provides an example of the rigors of, and the competition and rivalries often involved in, scientific discovery.  |

# 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 this issue:
	+ Structural formulas
	+ Proteins
	+ Hydrogen bonding
	+ Environmental impacts of personal and societal decisions
	+ Periodic properties
	+ Nuclear chemistry
	+ Equilibrium
	+ Green chemistry
* Consider asking students to read “Open for Discussion: Paper vs. Pixel” on page 4 before or after they read “Celebrating Paper!” to help them understand the complexity of making decisions about whether to use paper or electronic versions of paper products such as e-textbooks.
* The theme of Chemists Celebrate Earth Week (CCEW) this year is “The Chemistry of Paper,” so you and your students can check out some of the activities that can be found at the website found on the back cover.
* The engaging video “Is it OK to pee in the pool?” (see p. 18), produced by ACS, has excellent chemistry information.
* 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.

# Possible Student Misconceptions

1. **“There are exactly 92 naturally-occurring elements.”** Ninety-two is the number that has been found in textbooks for many years as the number of naturally-occurring elements. Sometimes, the number of naturally-occurring elements was reported as 91 because element 43, technetium, didn’t have any stable isotopes and was made by bombarding molybdenum with neutrons. When traces of technetium were detected in uranium as a fission product of U-235 or U-238, the number of naturally-occurring elements was increased to 92. Elements 93–98 were all first produced artificially at the University of California, Berkeley, and scientists believed they did not occur naturally. After detection of neptunium and plutonium in pitchblende, the number was increased to 94. Due to further experimentation with pitchblende, the ore Marie Curie used to extract radium and polonium, the elements 93–98 were observed in trace amounts as products of other nuclear processes of naturally-occurring elements in pitchblende. This brings the number of naturally-occurring elements up to 98. Elements 99–118 have only been found as products of particle accelerator experiments. Some still hold onto 94 as the number of naturally-occurring elements, stating that elements larger than these have half-lives too short to be considered as occurring naturally. (<https://www.thoughtco.com/how-many-elements-found-naturally-606636>)
2. **“The person who discovers an element can name it whatever they want.”** This may have been true prior to 1969, but then IUPAC set forth the guidelines and rules that govern how an element can be named. So now, IUPAC states that once the discoverer of an element has been confirmed, the discoverers must adhere to the following rules:
3. The name must differ as little as possible in different languages.
4. The element can be named after any of the following:
* a mythological concept or character, including astrological bodies, like planets
* a mineral
* a geographical location or place
* a property of the element
* a scientist
1. The element must use the suffix *ium—*unless it is in group 17, where it will end in *ine,* or in group 18, where it will end in *on*.
2. When a name has been used unofficially for an element, but a different name is eventually chosen for that element, the unofficial name can never be used again for any future elements to avoid confusion in the literature.

The last rule has an interesting story behind it that students might appreciate. The United States chose the name *rutherfordium* in honor of Ernest Rutherford for element 104 and *hahnium* for element 105 in honor of Otto Hahn. Russian scientists chose the name *kurchatovium* in honor of Igor Kurchatov, “the father of the Russian atomic bomb,” for element 104, and *neilsbohrium* for element 105. Both names and symbols were in use on periodic tables and present in the literature. IUPAC felt the name kurchatovium was chosen to anger the Americans, so it awarded naming rights for 104 to the US and chose the name *dubnium* for element 105 in honor of the location of the Russian particle research lab. The name hahnium can never be proposed again for the name of an element. Otto Hahn received a Nobel Prize for his work in discovering nuclear fission while trying to create larger elements than uranium. Although Hahn conducted the actual experiments, it was Lise Meitner, his colleague of many years, who figured out what had happened and wrote the explanation. When Hahn, a German, published the work, he did not include Meitner’s name because she was Jewish and it is thought he did not want to be accused of collaborating with a Jew during Nazi rule. However, after the war, he still did not give her credit. It is perhaps karma that he is not immortalized on the periodic table while Lise Meitner was finally recognized for her part in the discovery and is memorialized on the periodic table with element 109, meitnerium.

1. **“Most elements have been discovered in the United States.”** Actually, more elements have been discovered in the United Kingdom than any other country. Twenty-four elements have been discovered in the UK, followed closely by the US with 21 elements and Sweden with 20. German scientists are credited with the discovery of 19 elements, while 17 have been discovered in France. However, with respect to the 26 transuranium elements, U.S. scientists have discovered 20. Of those 20 elements, the discoveries of eight of them are shared with Russians who, with those eight, have discovered or co-discovered a total of nine. German scientists have discovered five of the new elements, 108–112. (<https://www.businessinsider.com/this-brilliant-graphic-shows-you-which-country-discovered-every-element-in-the-periodic-table-2014-4>)
2. **“The order of the elements on the periodic table is determined by their atomic mass.”** Even though it is presented in every lesson on the periodic table that the current periodic table is arranged according to the number of protons in the nucleus of an element, many students still cling to the idea that the periodic table is arranged according to atomic weight. Perhaps it is because, for the majority of the elements, that appears to be the case. While Dmitri Mendeleev did, in fact, arrange the precursor to today’s periodic table using atomic weight and chemical properties, the proton had not yet been discovered. When the table is arranged strictly by weight today, a few discrepancies in the order of the elements occur. These discrepancies, such as the order of cobalt and nickel (nickel would come before cobalt if weight is used) and argon and potassium, were not an issue when Mendeleev was building his table because the atomic weights he used for cobalt and nickel were identical at the time and argon had not yet been discovered.

When Henry Moseley conducted experiments in 1913 that involved bombarding the elements with high energy electrons and measuring the resulting X-ray frequencies, he found that each element produced a unique frequency. When the elements were ordered according to this frequency, to which he had assigned a unique sequential whole number, the order of the elements was confirmed and those anomalies that had surfaced from solely considering atomic weight were resolved. This number was correctly identified as the number of positive charges, protons, in the nucleus and matches the number of electrons in the atom. Having a simple whole number for each element allowed for easier detection of the “holes” in the periodic table, which led to the discovery of other yet-unknown elements. Moseley’s sequential arrangement exposed the missing elements 43, 61, 72, and 75. Moseley was only 26 at the time of his discovery and left his research to volunteer with the Royal Engineers during World War I. He was killed in action in 1915 at the age of 27. Had he not been killed, it is likely he would have received a Nobel Prize for his work. Nobel Prize-winning physicist Robert Millikan wrote of Moseley’s passing, "In a research which is destined to rank as one of the dozen most brilliant in conception, skillful in execution, and illuminating in results in the history of science, a young man twenty-six years old threw open the windows through which we can glimpse the sub-atomic world with a definiteness and certainty never dreamed of before. Had the European War had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history.” Following Moseley’s death, Ernest Rutherford lobbied the British government to no longer allow its prominent and promising scientists to enlist for combat duty. (<https://en.wikipedia.org/wiki/Henry_Moseley>)

1. **“With the completion of the 7th row of the periodic table, the table is now complete, there are no more elements to be added.”** While the completion of the 7th row of the periodic table makes the table look complete, there are probably more elements that will be made in the same manner as the last four and will fit on row eight. Exactly how many more elements can be made is up for debate. Some scientists feel that the atoms have a certain stability depending on the number of protons and neutrons in the nucleus. Some isotopes of element 114 may exhibit more stability than the other elements surrounding it. The discovery of new elements may not proceed sequentially due to the stability of certain proton-neutron arrangements in the nucleus. Richard Feynman predicted that the largest element possible will be element 137, while others have proposed elements up to 173. With the 8th period of elements, scientists project *g* orbitals for the additional electrons.
2. **“There’s only one way to organize the periodic table.”** There are many ways to organize the elements other than the order seen in the periodic table that you find in your textbook. The current arrangement of the elements has evolved over time and continues to be challenged with new ideas about the elements. Some scientists propose placing hydrogen above carbon on the periodic table since, like “hybridized” carbon, it has a half-filled shell of electrons. Other tables use different shapes like spirals or helixes, while still others are arranged in 3-D. A plethora of different periodic tables can be found at this site:

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

1. **“It’s easy to make new elements—just fire a lighter atom at a heavier atom.”** It is not easy to make new elements. Finding a suitable ion source material and a relatively stable heavier element, whose fusion with the ion source results in the desired element, is challenging. It can also be expensive. The calcium-48 isotope that was used in the creation of three of the final four elements costs over $250,000 per gm. Then there are the instrument parameters. Incoming atoms need to be fired with enough speed to overcome nuclear repulsion but not so fast that they would cause fission of the target element. The ion source beam fires at a rate of 6 trillion atoms per second at a thin metal foil target that may only contain a few atoms of the heavier element with the hopes that one nucleus of the ion source will overcome the repulsion of the positively charged nuclei to become fused as one nucleus without causing the fission of the larger atom. Element 113 took scientists at the RIKEN research lab in Japan nine years to produce three atoms. The first atom was produced in 2004 and a second was produced in 2005. However, it took seven more years before they succeeded in producing a third atom and could claim naming rights to the element.

# Anticipating Student Questions

1. **“What elements, besides carbon, copper, gold, and mercury, were used by early civilizations?”** In addition to those above, the other elements that were used in the earliest civilizations were silver, tin, lead, meteoric iron, and sulfur. Copper, silver, gold, and carbon are considered native elements because they can be found in pure form (uncombined).
2. **“If the number of protons determines the element, what significance do the neutrons have?”** The neutrons are responsible for the stability of the nucleus. The protons are positively charged and, like all positively-charged particles, repel each other. The neutrons are not charged and, in occupying the same space as the protons, shield the positive protons from each other, while the strong force of the nucleus holds all the particles in the nucleus together. Nuclei with neutron: proton ratios of 1:1 to 1.5:1 are stable. Nuclei with neutron: proton ratios greater than 1.5:1 become unstable and exhibit beta decay, essentially turning a neutron into a proton, while those with ratios lower than 1:1 are also unstable and exhibit radioactive decay by electron capture, which turns a proton into a neutron.
3. **“Why are the atomic weights of all the transuranium elements in brackets?”** The atomic weight shown on the periodic table is a weighted average of the masses of all the known isotopes of that element. With the man-made elements, the isotope produced depends on the way the element was synthesized, so natural isotopic abundance has no meaning for these elements. Therefore, the total nucleon count—protons + neutrons—of the most stable isotope (the one with the longest half-life) is placed in brackets on the periodic table to distinguish it from the average atomic weights used for all the other elements.
4. **“What happens to the neutrons that are released when scientists smash atoms together? Are they dangerous?”** The neutrons that “smash” atoms are contained within the particle accelerators. Neutrons are not stable outside the nucleus and decay into a proton and an electron within 14 minutes. Neutrons can travel farther and penetrate more types of material than any other type of radiation. They can penetrate thick lead or steel walls, but they can be stopped if blocked by hydrogen-rich materials like concrete or water. Because neutrons are not charged, they are not repelled by either protons or electrons and can penetrate the nucleus of an atom, often causing it to become unstable and radioactive. They can alter a cell’s DNA and interfere with normal cellular function. They are rarely encountered in the environment, due to their short life. The only time large numbers of neutrons can escape into the environment is during a critical nuclear reactor accident or detonation of a nuclear bomb.
5. **“Where is IUPAC’s headquarters? What do they do there?”** IUPAC’s headquarters is located in Zurich, Switzerland. The organization is recognized as the international authority on chemical nomenclature, symbols, and terminology, and for the standardization of atomic weights and units. They provide information that aids in drafting regulations related to chemical manufacturing, international commerce, and matters related to food, health, and the environment. The administrative branch of IUPAC is referred to as the Secretariat and is located in Research Triangle Park, North Carolina.
6. **“The article says there were more names for element 102. What were they?”** Element 102 provided IUPAC with lots of controversy. First, the discovery was claimed by Swedish scientists who chose the name ***nobelium*** after Alfred Nobel and the Nobel Institute. When their claims could not be duplicated and confirmed by work done by Glenn Seaborg’s research team in the U.S., they withdrew their claim. The U.S. team claimed they had made the element and continued to refer to it as *nobelium*. But Russian scientists found flaws in Seaborg’s work and presented their own claim for the discovery, in 1969. They chose the name ***joliotium*** in honor of Irene Joliot-Curie. After IUPAC scientists reviewed all three experiments, they concluded that the Russians had first created element 102. In 1994, IUPAC ratified names for elements 101–109. The name *nobelium* was ratified for element 102, despite the wishes of its discoverers. In 1995, after much protest to the recently ratified names, IUPAC changed the name of element 102 to ***flerovium***, in an attempt to appease Georgy Flyorov and the Flerov Laboratory of Nuclear Reactions. This name also was rejected, so, in 1997, IUPAC changed the name back to *nobelium*, stating that after 30 years the name had become entrenched in the literature and Alfred Nobel was worthy of the honor. It is interesting that the name *flerovium* was eventually used for element 114, despite IUPAC’s own rule disallowing previously-nominated names ever to be used again.
7. **“If only a few atoms of an element are made, how can they determine its properties?** Because of modern equipment like electron microscopes, scientists can work with incredibly small samples, even those that are only one atom. One atom can be reacted in a small capsule and the results analyzed to determine the chemical properties of the new element. A small sample size is challenging, but it does not prevent testing. The incredibly short, fraction-of-a-second half-lives of the newer elements, however, prevents any chemical testing, even with one atom.
8. **“What purpose do the man-made elements serve?”** Most of the synthetic elements are used only in nuclear research. They provide scientists insight and clues on how the neutrons and protons are organized in the nucleus. The elements beyond element 99 serve purely research purposes, but elements 93–99 and 43 (technetium) have a variety of uses.

|  |  |  |
| --- | --- | --- |
| Atomic No. | Name | Use |
| 43 | Technetium | Diagnostic purposes in medical applications, corrosion inhibitors in steel used for enclosed systems |
| 93 | Neptunium | Research, used as the precursor material for the production of plutonium, used in neutron detection equipment |
| 94 | Plutonium | Used in atomic bombs and to power nuclear reactors for generation of electricity |
| 95 | Americium | Used in smoke detectors |
| 96 | Curium | Used to produce heavier elements and provides an alpha source in x-ray spectrometers |
| 97 | Berkelium | Research uses only |
| 98 | Californium | Strong neutron emitter in fuel rod scanners in nuclear reactors, moisture gauges to find water and petroleum in oil wells, and in some treatments of cervical and brain cancer  |
| 99 | Einsteinium | Used to calibrate the chemical analysis spectrometer on the Surveyor 5 lunar probe and to make heavier elements |

# Activities

**Labs and demos**

**“Frosty the Snowman Meets His Demise: An Analogy to Carbon Dating” lab:** Students use graduated cylinders to measure the volume of water that is produced from ice or snow melting in a funnel at their lab stations and record the time that corresponds to each measurement. They can use their data to work backwards to determine when Frosty was brought inside. (<http://sciencenetlinks.com/lessons/frosty-the-snowman-meets-his-demise/>)

**“Particle accelerator concept using a ping pong ball” demo:** This videotaped (1:34) demonstration uses a glass bowl containing electric fields, and a coated ping pong ball to demonstrate how a particle accelerator works. (<https://www.youtube.com/watch?v=EKxzXAQJvB8&eurl=http%3A%2F%2Fvideo.google.com%2Fvideosearch%3Fhl%3Den%26source%3Dhp%26q%3Dparticle%2Baccelerator%2Bexperiment%26um%3D1%26ie%3DUTF-8%26ei%3D21uRSu-9HImZlAfu0pG1DA%26sa&feature=player_embedded>)

This video (10:53) shows you how to make a salad bowl particle accelerator similar to the one above: <https://www.youtube.com/watch?v=1x5hupUifBk>. (Note that the project doesn’t produce spectacular results—rather disappointing, actually, but it can work.)

**Simulations**

 **“A Cyclotron”:** Students observe particle behavior at the instrument’s original settings and then can double the electric field or the magnetic field to observe the effects these two fields have on particle behavior in a cyclotron.

(<http://physics.bu.edu/~duffy/HTML5/cyclotron.html>)

**Media**

**“Have we found all the elements?” video (5:19):** The narrator seeks to answer this question after presenting the four latest elements to be added to the periodic table (the same four as in the Dingle “The Final Four” article) and discussing how they were made. He mentions the problems found in attempts to create elements larger than these and also mentions which as-yet-to-be-discovered elements might be found to be stable. (<https://www.youtube.com/watch?v=rwC9BBHkaAI>)

**“Lise Meitner” video (4:50):** In this history of the earliest attempts to make new elements by bombarding heavy elements with neutrons, the experiments of Otto Hahn and interpretations of those experiments by Lise Meitner provide insight into the plight of early women scientists. (Free access to video at <https://teachchemistry.org/classroom-resources/lise-meitner-video>) Teacher materials and guided questions for the students to answer after/while viewing the video are available on the site. (Access to the video is open, but access to the teacher materials on the site is restricted to AACT members; however, those materials will be available for free until June 1, 2019.)

**Lessons and lesson plans**

**“Twizzler half-life” activity:** To develop an understanding of the concept of half-life, students continually divide a Twizzler in half and align a piece of each division on the x axis of the graph with the decay cycle, 1, 2, 3, etc. After marking the height of each piece (the y-axis), they draw the resulting curve on the paper. (<https://teachchemistry.org/classroom-resources/twizzler-half-life>)

**“Ptable.com Investigations” lesson:** This site provides three lesson plans and a link to an interactive periodic table that students can use first to explore information about the elements in a scavenger hunt activity, then, observe a periodic trend in a second activity, and finally, learn the basics of the periodic table in a third activity. (<https://teachchemistry.org/classroom-resources/ptable-com-investigations>)

**Projects and extension activities**

**“Element Baby Book” project:** In “Element Baby Book” students adopt an element and create a baby book about their “new baby” while they research and learn about the element. The activity suggests using elements 2–20 but you could adapt it to use the period 7 elements or restrict it to the superheavy elements 99–118.

(Access is restricted to AACT members, but the site will be available for free until June 1, 2019, at <https://teachchemistry.org/classroom-resources/element-baby-book>.)

**“ABC’s of Nuclear Science” experiments:** Besides additional information about nuclear structure, radioactivity, and nuclear reactions, this site provides links to nine nuclear experiments, including a cloud chamber experiment that allows students to visually observe nuclear decay. If you have access to radioactive sources, either at your school or through a local university, these activities provide the students with hands on experiences with radioactivity concepts. (<https://www2.lbl.gov/abc/Contents.html#experiment>)

# 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” chronicles the discovery of radiation and the creation of new elements in the experiments of Ernest Rutherford, Irene Joliot-Curie, Enrico Fermi, Edwin McMillan, and Glenn Seaborg, which eventually led to a reorganization of the periodic table (McClure, M. The New Alchemy. *ChemMatters*. 2006, *24* (3), pp 15–17)

This article describes how the elements were made in the stars by the process of nuclear fusion (nucleosynthesis) for elements helium through nickel in the younger stars, and the formation of the heavier elements by neutron capture and beta decay in supernovas.

(Ruth, C. Where Do Chemical Elements Come From? *ChemMatters*. 2009, *27* (3), pp 6–8)

The Teacher’s Guide for the October 2009 *ChemMatters* article above provides additional information about nucleosynthesis in stars, including nuclear equations for those fusion reactions. The guide also contains links to lessons on spectroscopy and supernova chemistry.

In this article about creating superheavy elements in a cyclotron, author Brownlee presents a schematic with an explanation of how a cyclotron works, as well as a discussion on the process for naming new elements.

(Brownlee, C. What Uuought to Know About Elements 112–118. *ChemMatters*. 2009, *27* (3), pp 9–10)

The Teacher’s Guide for the October 2009 *ChemMatters* article above contains nuclear equations for the formations of elements 110–118, as well as links to a discussion on how far the periodic table may extend, and multiple links to additional videos, simulations, and lessons.

“The Periodic Table Turns 150: Is the Best Yet to Come?” presents the history of the periodic table, including the discovery of the superheavy elements and Glenn Seaborg’s idea of an “island of stability” related to the organization of the particles in the nucleus. (Warmflash, D. The Periodic Table Turns 150: Is the Best Yet to Come? *ChemMatters*. 2019, *37* (1), pp 11–14)

The Teacher’s Guide for the February 2019 *ChemMatters* article above provides links to lesson plans, videos, and demos that help teach the logic behind the patterns in the table.

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The September 8, 2003 issue of *Chemical and Engineering News* celebrated the magazine’s 80th anniversary by presenting a variety of essays on the periodic table and the elements. Color graphics complement the essays. (Chem. Eng. News, 2003, *81* (36)

In “Rearranging the table” in the January 7, 2019 issue of *Chemical Engineering News*, author Sam Lemonick presents current discussions on changing the arrangement of the elements in different table formats, based strictly on atomic orbitals and electron-filling order. Particularly problematic for current tables is the question of which elements should belong in group three, under scandium and yttrium.

(Lemonick, S. Rearranging the table. *Chem. Eng. News*, 2019, *97* (1), pp 26–29; “The periodic table is an icon. But chemists still can’t agree on how to arrange it” [same article, different title], <https://cen.acs.org/physical-chemistry/periodic-table/periodic-table-icon-chemists-still/97/i1>. 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.)

The February 2019 special issue of *Science*, “The Periodic Table Turns 150” features six articles about the periodic table that highlight the superheavy elements, nucleosynthesis of the elements in the stars, the order of the table, *p*-block chemistry, the electronic structure of the transition metals, and the modern marvels of the rare earth metals.

(Science, 2019, *363* (6426), pp 464–493)

A special note from the above citation: Author Sam Kean includes his interview with Yuri Oganessian, the scientist for whom element 118 is named, in this article about the most recent superheavy elements. The article contains a schematic of the particle accelerator in Dubna, Russia, details about the difficulties encountered by the Japanese team in creating element 113, and projections of finding heavier elements in the future and where they will be represented on the periodic table. (Kean. S. The Quest for the Superheavies. *Science*, 2019, *363* (6426), pp 466–470)

# Web Resources for More Information

**IUPAC**

The website for the IUPAC contains information about the history of the organization, their current responsibilities, upcoming IUPAC sponsored events, as well as pictures and bios of the current leadership.

(<https://iupac.org/>)

**Element names**

“Explainer: How a new element gets its name” contains information about the history of some of the element names on the periodic table, as well as the IUPAC rules for naming a new element.

(<https://www.chemistryworld.com/news/explainer-how-a-new-element-gets-its-name/1017676.article>)

Besides explaining the conventions for naming the early elements, this article also discusses the controversy that surrounded the names for elements 104 and 105.

(<https://www.carolina.com/teacher-resources/Interactive/naming-the-elements/tr28303.tr>)

**Discovering the superheavy elements**

“The limits of nuclear mass and charge” is a scholarly article about the discovery of elements 113, 115, 117, and 118 and the challenges of analyzing the super heavy elements. The author discusses the isotopes that may confirm an “island of stability”, as well as how far the periodic table could possibly be extended.

(<https://www.nature.com/articles/s41567-018-0163-3>)

This article about the creation of the superheavy elements discloses the competitiveness that exists in discovering them and also explains where the upper limit to the number of elements yet to be discovered may be found.

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

**Elements 115 & 117 and the island of stability**

This article talks about the island of stability and how scientists believe they are getting close to it with the creation of element 117.

[(https://www.scientificamerican.com/article/superheavy-element-117-island-of-stability/](file:///C%3A%5CUsers%5COwner%5CDownloads%5C%28https%3A%5Cwww.scientificamerican.com%5Carticle%5Csuperheavy-element-117-island-of-stability%5C))

“Element 115 and the Island of Stability” discusses the challenges in the creation of element 115 and that it may be approaching a stable number of protons and neutrons.

(<http://www.physicscentral.com/explore/action/element-115.cfm>)

**Radiation**

This article describes alpha, beta, gamma, X-ray, and neutron radiations and contains several links to information about the different sources and effects of radiation.

(<https://www.mirion.com/learning-center/radiation-safety-basics/types-of-ionizing-radiation>)

**Particle accelerators**

This article explains the differences among cyclotrons (used for the creation of new elements), linear accelerators (like the 2 mile long SLAC at Stanford), and synchrotrons (like the Large Hadron Collider located in Switzerland).

(<https://www.machinedesign.com/whats-difference-between/what-are-differences-between-linear-accelerators-cyclotrons-and-synchrotron>)

**Naturally-occurring elements**

This Wikipedia site supports the idea of 94 naturally-occurring elements. It gives arguments for dismissing elements above atomic number 94 as only being the product of man-made synthesis. (<https://en.wikipedia.org/wiki/Chemical_element#Occurrence_and_origin_on_Earth>)

The article “How many elements can be found naturally?” supports considering 98 as the number of naturally-occurring elements. There are several links at the end of the article to more information on the elements.

(<https://www.thoughtco.com/how-many-elements-found-naturally-606636>)

**Other helpful videos**

This 2006 PBS video (6:52) examines the stability of certain elements and the projected stability of element 114. The animated protons and neutrons simulate the strong force of the nucleus and show the idea of patterns of organization of protons and neutrons in the nucleus.

(<https://www.pbslearningmedia.org/resource/lsps07.sci.phys.matter.stability/island-of-stability/>)

In the (5:40) video, “The Element Makers: Making Superheavy Elements”, a Lawrence Berkley scientist explains how mapping the decay products of newly-created elements can be used to prove their discovery.

(<https://www.chemistryworld.com/features/the-element-makers-making-superheavy-elements/3009554.article>)

**Interactive periodic tables**

The Royal Society of Chemistry’s interactive periodic table is complete through element 118. Each element is linked to information, and there’s a video about each one. The video for element 118 contains a good message for all budding science entrepreneurs.

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

This periodic table has information about the physical and chemical properties of each element that can be accessed for all elements simultaneously by changing the property displayed. Each element is linked to the Wikipedia information for the element.

(<https://ptable.com/>)

This site contains links to a plethora of periodic tables of various shapes and content, both chemical and some non-traditional, nonchemical tables.

(<https://www.meta-synthesis.com/webbook/35_pt/pt_database.php?Button=Top_10>)