



Landmark Lesson Plan:

The Periodic Table and Transuranium Elements

Grades: 9-12

Subject Areas: Chemistry and History

Based on the National Historic Chemical Landmark on [Discovery of Transuranium Elements at Berkeley Lab](#)

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The following inquiry-based student activities are designed for use in high school chemistry lesson planning, but they apply to all science subjects. Some middle school teachers may also find the lesson outline helpful. The lesson plan will help students understand the people and discoveries that led to the development of today's periodic table. The final activity integrates writing as students are asked to summarize what they have learned about the periodic table.

The content is designed as a ready-to-go lesson, easily implemented by a teacher or his/her substitute, to supplement a unit of study. Students will practice critical reading and writing skills as they develop a deeper understanding of the development of the periodic table.

All resources are available online at www.acs.org/LandmarkLessonPlans.

While these activities are thematically linked, each is designed to stand alone as an accompaniment for the handout. Teachers may choose activities based on curricular needs and time considerations.

- Take a few minutes to introduce the lesson with a few conversation starters. What is the periodic table? What might it be used for?
- If you use the Anticipation Guide, do not distribute the handout about the periodic table and the transuranium elements until students have indicated their initial opinions or (for the optional engagement exercise) come up with their own ideas. Then distribute the handout for students to check their answers and find the passage that supports or refutes their initial thoughts.
- For the remaining activities, distribute the exercise(s) selected for the class along with the handout about the periodic table and the transuranium elements. Make sure students understand the directions for each activity. While students are reading, they should complete the exercise(s).
- For additional information (and the final optional exercise), students may want to view the following videos:
 - The Periodic Table Table
<https://youtu.be/KyKEY01Lm5o>
 - The Disappearing Spoon, the Rooster and the Bearded Russian
<https://youtu.be/-ojcm3llf98>
 - Women in Chemistry: Heroes of the Periodic Table
<https://youtu.be/Zv8jECGdZAY>
 - Have We Found All the Elements?
<https://youtu.be/rwC9BBHkaAI>
 - What Are Isotopes?
<https://youtu.be/GyviEsmrVp0>
- After all students have read the handout and completed the exercise(s), use the Answer Guide for student feedback and further discussion.

Student Activities with Objectives

Anticipation Guide and Reading (5 minute introduction, followed by 15-20 minutes of reading)

- Students confront their ideas about the development of the periodic table.

History: Timeline of events (10-15 minutes)

- Students chronologically order events in the reading.

Graphic Organizer: Contributions of chemists leading to today's version of the periodic table (5-10 minutes)

- Students describe the contributions made by various chemists along with the significance of each contribution.

Graphic Organizer and Questions: Discovery of Elements (10-15 minutes)

- Students organize selected elements into a chart and answer questions about the problems that had to be overcome in discovering the transuranium elements.

Writing: The Value of the Periodic Table and Transuranium Elements (15-20 minutes)

- Students summarize the development of the periodic table and its importance to chemists.

Optional Video Summaries (15-30 minutes, depending on choices made by teacher)

- After reading the handout, students watch an ACS *Reactions* video related to the periodic table and share their learning with the class.

The Periodic Table and Transuranium Elements

The periodic table of elements represents a collaborative effort that crosses centuries and continents. Many researchers contributed to solving this atomic puzzle. In so doing, they designed an adaptable tool that has accommodated a growing understanding of chemistry and the discovery of new elements.

A pattern emerges

In the late 1860s, University of Saint Petersburg chemistry professor Dmitri Mendeleev was working on a second volume of his 1861 textbook, "Principles of Chemistry." Looking for a simple way to classify elements "by some exact, definite principle," he drew up a table. A pattern emerged: an obvious periodicity of chemical behaviors as a function of atomic mass. In March of 1869, Mendeleev delivered his discovery in a roughly drawn sketch to the Russian Chemical Society and published it later that year.

Two contemporary chemists — Karlsruhe professor Lothar Meyer (Germany) and industrial chemist John Newlands (England) — envisioned and published similar charts around the same time.

Since then, the table's form has evolved as researchers filled in gaps in knowledge and worked through serious disagreements on what should be placed where, and why. The table organized elements into columns based on their atomic number, electron configuration and chemical properties. This allowed researchers to predict the properties and behavior of as-yet undiscovered elements.

National Historic Chemical Landmarks

Discover more stories and activities about chemistry's history at www.acs.org/landmarks.

Several prominent U.S. chemists made vital contributions. At Harvard University, Theodore W. Richards and his graduate students remeasured the atomic weight of over 30 elements to pinpoint accuracy. Later, during Richard's investigation of lead, he found that its atomic mass depended on the metal's source. The discovery validated British chemist Frederick Soddy's theory of isotopes and provided nuance and depth to the ever-more-robust periodic table.

Richards and others provided sophisticated atomic mass measurements to U.S. Geological Survey Chief Chemist Frank W. Clarke, who in 1872 had been tasked to compile and produce an annual table of elemental weights. Clarke also chaired the International Committee on Atomic Weights, which published the table for an international audience, revising it annually until the work stalled in 1918 because of the ongoing First World War.

While Clarke and others were compiling data, Francis Preston Venable, a chemistry professor at the University of North Carolina, wondered why the periodic table was not used more, especially by teachers. He came to the conclusion that Mendeleev's table and those

created by others were not terribly inspiring.

Periodic law

In 1896, Venable published the first history of the periodic law. With his students in mind, he redrew the periodic table without the transition "periods" to simplify the graphic representation. (A period is a row within the table.) Confident in his ability to get complex topics across to students, in 1898 Venable co-wrote a chemistry textbook with James Lewis Howe, "Inorganic Chemistry According to the Periodic Law."



Glenn Seaborg, shown here in 1950, reshaped the periodic table with his discoveries of transuranium elements.

A quarter century later, Horace G. Deming, a University of Nebraska chemistry professor, published "General Chemistry." The textbook became an instant hit. It included his own "long form" periodic table, which separated elements within periods 2 and 3 by moving the first two elements in each period all the way to the left and the following elements to the right. He also delineated the columns into A and B groups. For the first time, a periodic table design made clear how elements transition from main group elements to transition elements.

Deming's version remained the most popular form of the periodic table into the mid-20th century, but further discoveries would reshape it yet again.

Heavy elements

Until 1940, uranium was the heaviest known element, but scientists wanted to create even heavier elements. To do so, they needed to fuse the nuclei of known atoms with other nuclei or with neutrons. Nuclei contain positively charged protons as well as charge-free neutrons, and fusing one nucleus with another requires overcoming tremendous repulsion between the two positively charged nuclei.



Researchers pose in a Berkeley Lab particle accelerator used in the discovery of five superheavy elements.

Glossary

Atomic number: The number of protons in an atom. Different elements have different atomic numbers. For instance, uranium has 92 protons, so its atomic number is 92.

Isotope: An element can have different isotopes, which contain the same number of protons but different numbers of neutrons. For example, there are three naturally occurring isotopes of uranium: U-235, U-236 and U-238. An atom of U-235 contains 92 protons and 143 neutrons in its nucleus, while an atom of U-238 contains 92 protons and 146 neutrons. Isotopes of the same element have the same chemical properties but differ in relative atomic mass.

Transition elements: Metallic elements that are listed in the middle columns of the periodic table. The other groups in the periodic table are the main group elements, lanthanides and actinides.

Transuranium elements: Elements with an atomic number greater than that of uranium, which is 92. In addition to those found at Berkeley Lab, many others (including elements 102, 107–112 and 114–118) were discovered at the Joint Institute for Nuclear Research in Russia and the GSI Helmholtz Centre for Heavy Ion Research in Germany in collaboration with international teams of scientists. Some of the new elements discovered by the Russian and German teams were named for famous scientists, including meitnerium (for physicist Lise Meitner), roentgenium (for physicist Wilhelm Röntgen) and copernicium (for astronomer Nicolaus Copernicus).

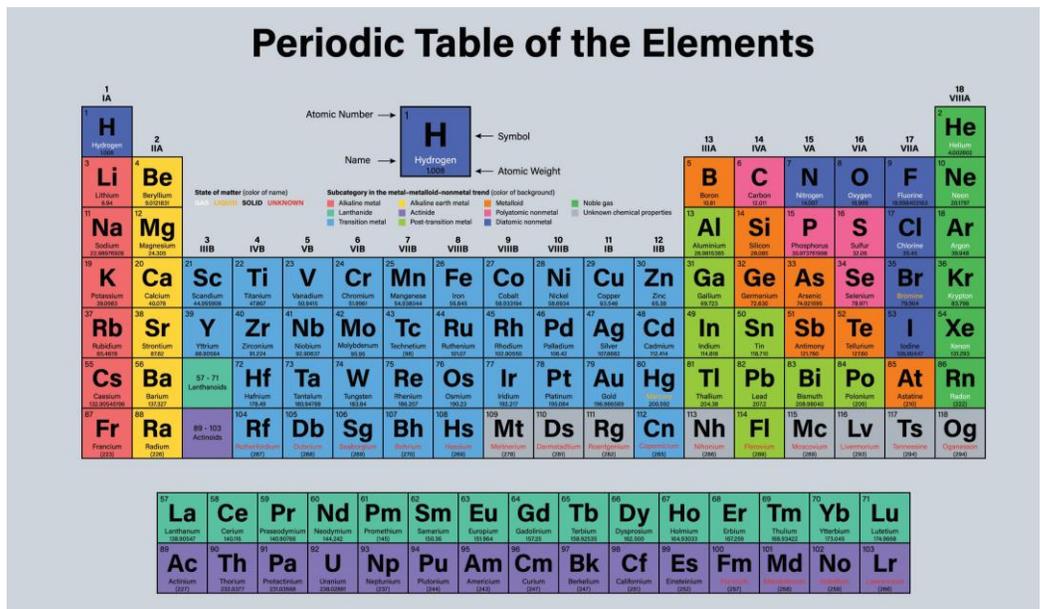
The forces needed are millions of times greater than those involved in, say, the explosion of TNT. Researchers produced these forces by building particle accelerators, which generate energetic beams of various charged particles to react with suitable targets.

One of the major centers for this work was Lawrence Berkeley National Laboratory, known as Berkeley Lab. Synthesis of new elements at the lab began with the creation in 1940 of neptunium (which has an atomic number of 93), the first element beyond uranium in the periodic table. Edwin McMillan and Philip Abelson formed the new element by irradiating a uranium target with neutrons. Also in 1940, a Berkeley Lab team led by nuclear chemist Glenn

Seaborg bombarded uranium with deuterons (the nuclei of deuterium atoms) to create plutonium (atomic number 94). Seaborg then moved temporarily to the University of Chicago in the early 1940s to help with the Manhattan Project, an effort to develop nuclear weapons during World War II. While there, he continued his work with collaborators from Berkeley Lab, resulting in the discovery of americium (95) and curium (96) in 1944. Seaborg and his research group returned to Berkeley Lab after the war and developed new methods to form and detect radioactive elements.

Many scientists believed that these new "transuranic" elements — meaning those with atomic numbers above uranium — would fit within the periodic table's main body. Seaborg disagreed, arguing that the elements would behave like

The modern periodic table includes rows of lanthanide and actinide elements, and ends with element 118, which was named oganesson and is the heaviest known element.



actinium (89) and therefore needed to be grouped with it in their own pullout row beneath the lanthanide series.

In 1945 Seaborg published his hypothesis along with a table showing an “actinide series” beneath the lanthanide row, with empty squares following plutonium for yet-to-be-determined elements. “My theory required a major realignment of the periodic table of the elements,” wrote Seaborg. “Senior colleagues counseled that advocating such a radical concept would ruin my scientific reputation. Fortunately for me, at the time my scientific reputation was nothing to worry about losing. And even more fortunate, I was right.”

In 1951, Seaborg received the Nobel Prize in Chemistry, which he shared with Edwin M. McMillan for their discoveries in the chemistry of the transuranium elements. The work of Seaborg and others in the Berkeley lab contributed to the synthesis of nine more transuranium elements in the actinide series,

making a substantial addition to the periodic table. The final transactinide synthesized by Seaborg’s team was element 106 in 1974, later named after its creator. Seaborg considered the addition of “seaborgium” to the periodic table be an honor even greater than the Nobel Prize.

In 2009, it was a partnership between researchers from Vanderbilt University, Oak Ridge National Laboratory, the University of Tennessee-Knoxville and Lawrence Livermore National Laboratory, along with the Joint Institute for Nuclear Research in Russia, that filled in the second-to-final square in the periodic table’s seventh row.

Element 117 — the most recent to be discovered — was later named tennessine to honor the state from which many of the researchers came. But this addition might not be the last periodic table revision. Now, researchers are trying to discover elements even heavier than the heaviest known element: oganesson, element 118.

The evolving concept of “elements”

The quest to understand what comprises the world around us dates back to ancient times. As early as the 4th century BCE, the Greek philosopher Aristotle proposed that the physical universe consisted of varying combinations of four “elements” — earth, water, air and fire. These are no longer considered true elements, but over the next few hundred years, practitioners isolated and used elements that meet our modern definition— fundamental substances of one type of atom that singly or in combination constitute all matter.

Some elements, like gold, silver and tin, were found in nature in relatively pure form and have been used for centuries. Others, such as lead, mercury and sulfur, had to be isolated from their ores. The 18th-century development of experimental science allowed rapid discovery of more new elements, including oxygen. But uranium, identified in 1789, remained the heaviest known element for more than 150 years.

Student Name: _____ Date: _____ Period: _____

Anticipation Guide The Periodic Table and Transuranium Elements

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement **before** reading each article. Then, **while** they read, students should look for evidence supporting or refuting their initial responses.

Directions: Before reading, in the first column, write "A" or "D" indicating your agreement or disagreement with each statement. Then, **while** you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Many researchers contributed to our current understanding of the elements.
		2. Mendeleev was the only chemist to develop a chart with known elements in the late 1860s.
		3. The atomic mass of some elements (such as lead) depends on where they are found.
		4. Mendeleev's periodic table placed the transition elements between the main group elements.
		5. Neptunium was the first synthetic element created at Lawrence Berkeley National Laboratory (Berkeley Lab) in California.
		6. Americium and curium were discovered at Berkeley Lab.
		7. The periodic table was realigned in the late 1940s to add the actinide series.

Student Name: _____ Date: _____ Period: _____

		8. Glenn Seaborg and his team at Berkeley Lab synthesized five elements.
		9. The number of protons and neutrons determines an element's atomic number.
		10. Element 106 was named "seaborgium" before Glenn Seaborg died.

Optional Engagement Idea:

Instead of using the Anticipation Guide, consider this idea to engage your students in reading:

1. Ask students to consider how the version of the periodic table we have today developed over time. Students can begin by thinking or writing their ideas, then sharing with a partner before having a class discussion.
2. After this discussion, invite students to read the article to find more details about the development of today's periodic table, including some of the notable people and discoveries.

Student Name: _____ Date: _____ Period: _____

Timeline: Chemists and the Elements

Challenge students to put the following events in chronological order prior to reading. (The teacher could provide the events on strips of paper to make this easier.)

While they read, students should re-order the events correctly, then summarize the important 20th century developments in a short paragraph.

Using the handout provided, put the following events in chronological order, with the earliest event "1" and the last event "10."

- a. ____ Neptunium was synthesized at Lawrence Berkeley National Laboratory.
- b. ____ The periodicity of chemical behaviors as a function of atomic mass was noticed.
- c. ____ Researchers are looking for elements heavier than oganesson.
- d. ____ The elements in periods 2 and 3 were separated in the periodic table, leaving a gap between them.
- e. ____ Element 106 was named "seaborgium."
- f. ____ Seaborg modified the periodic table to add an "actinide series."
- g. ____ Seaborg received the Nobel Prize in Chemistry.
- h. ____ Mendeleev published his version of the periodic table.
- i. ____ The first history of the periodic law was published.
- j. ____ Tennessine was discovered.

Summarize (one or two sentences) what surprised you as you worked to complete this task.

Student Name: _____ Date: _____ Period: _____

Notable Chemists and Their Contributions to the Periodic Table

Describe each person's contribution to the periodic table and its chemical significance in the table below.

Person	Contribution	Significance
Dmitri Mendeleev		
Frederick Soddy		
Frank W. Clarke		
Francis Preston Venable		
Horace G. Deming		
Glenn Seaborg		

Student Name: _____ Date: _____ Period: _____

Chemical Elements

Directions: In the columns below, list at least 4 elements that fit each description.

Known prior to 1940	Transuranium elements discovered at Berkeley Lab	Transuranium elements discovered somewhere other than Berkeley Lab

Synthesizing transuranium elements

1. How were the first transuranic elements synthesized?
2. What forces had to be overcome?
3. What important equipment was needed?

After reading the handout, write two paragraphs summarizing the following:

- Important changes to the periodic table in the **20th century**, including why the changes were made.
- Why the periodic table is more valuable to chemists (and others!) than an alphabetical table listing the elements with their symbols and other information such as atomic number and atomic mass.

Student Name: _____ Date: _____ Period: _____

Jigsaw Video Summaries

If students have access to the Internet, share the links for these ACS *Reactions* videos (each video is about 5 minutes long). Ask students to take notes to share what they learned with the class in a gallery walk or short presentation. After they share their learning, ask students what surprised or engaged them the most, and why.

Alternatively, choose one of the videos to show in class and discuss it, using the suggestions below.

- The Periodic Table Table

<https://youtu.be/KyKEY01Lm5o>

Theodore Gray displays some of the element samples he collected for his Periodic Table table. **Ask students to describe the properties of at least five of the element samples.**

- The Disappearing Spoon, the Rooster and the Bearded Russian

<https://youtu.be/-ojcm3Ilf98>

Ask students to explain where the name of the video came from.

- Women in Chemistry: Heroes of the Periodic Table

<https://youtu.be/Zv8jECGdZAY>

Ask students to describe the contributions of Marie Curie and Ida Tacke Noddack to the periodic table.

- Have We Found All the Elements?

<https://youtu.be/rwC9BBHkaAI>

Ask students to describe how new elements are found, some problems with finding new elements, and uses for some of the transuranium elements.

- What Are Isotopes?

<https://youtu.be/GyviEsmrVp0>

Ask students to define isotopes, and to describe how isotopes are involved in chemical and nuclear reactions.

Anticipation Guide

The Periodic Table and Transuranium Elements

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement **before** reading each article. Then, **while** they read, students should look for evidence supporting or refuting their initial responses.

Directions: Before reading, in the first column, write "A" or "D" indicating your agreement or disagreement with each statement. Then, **while** you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
	A	1. Many researchers contributed to our current understanding of the elements.
	D	2. Mendeleev was the only chemist to develop a chart with known elements in the late 1860s.
	A	3. The atomic mass of some elements (such as lead) depends on where they are found.
	D	4. Mendeleev's periodic table placed the transition elements between the main group elements. (Deming was the first to do so.)
	A	5. Neptunium was the first synthetic element created at Lawrence Berkeley National Laboratory (Berkeley Lab) in California.
	A	6. Americium and curium were discovered at Berkeley Lab and the University of Chicago.
	A	7. The periodic table was realigned in the mid-1940s to add the actinide series.

D	8. Glenn Seaborg and his colleagues at Berkeley Lab synthesized five transuranic elements. (They synthesized more than a dozen)
D	9. The number of protons and neutrons determines an element's atomic number. (The atomic number is based solely on the number of protons.)
A	10. Element 106 was named "seaborgium" before Glenn Seaborg died.

Optional Engagement Idea:

Instead of using the Anticipation Guide, consider this idea to engage your students in reading:

1. Ask students to consider how the version of the periodic table we have today developed over time. Ask students to begin individually by thinking or writing their ideas, then sharing with a partner before having a class discussion.

Do not correct students' ideas at this time.

Possible student misconceptions:

- Students may think that the periodic table developed by Mendeleev looked basically like the one we use today, with the inclusion of elements not known in Mendeleev's time.
 - Students may think that elements important to life, such as oxygen and carbon, were discovered first.
2. After this discussion, invite students to read the article to find more details about the development of today's periodic table, including some of the notable people and discoveries.

Timeline: Chemists and the Elements

Challenge students to put the following events in chronological order prior to reading. (The teacher could provide the events on strips of paper to make this easier.)

While they read, students should re-order the events correctly, then summarize the important 20th century developments in a short paragraph.

Using the handout provided, put the following events in chronological order, with the earliest event "1" and the last event "10."

- a. 5 Neptunium was synthesized at Lawrence Berkeley National Laboratory. (1940)
- b. 1 The periodicity of chemical behaviors as a function of atomic mass was noticed. (late 1860s)
- c. 10 Researchers are looking for elements heavier than oganesson. (today)
- d. 4 The elements in periods 2 and 3 were separated in the periodic table, leaving a gap between them. (1923)
- e. 8 Element 106 was named "seaborgium." (1974)
- f. 6 Seaborg modified the periodic table to add an "actinide series." (1945)
- g. 7 Seaborg received the Nobel Prize in Chemistry. (1951)
- h. 2 Mendeleev published his version of the periodic table. (1869)
- i. 3 The first history of the periodic law was published. (1896)
- j. 9 Tennessine was discovered. (2009)

Summarize (one or two sentences) what surprised you as you worked to complete this task.

Notable Chemists and Their Contributions to the Periodic Table

Describe each person's contribution to the periodic table and its chemical significance in the table below.

Person	Contribution	Significance
Dmitri Mendeleev	Developed the first periodic table of the elements	Organized elements according to properties and chemical behaviors
Frederick Soddy	Described isotopes	Helped explain variations in atomic mass for a given element
Frank W. Clarke	Published table of atomic weights	Precise measurements were shared with international audience
Francis Preston Venable	History of periodic law	Simplified representation of elements in periodic table
Horace G. Deming	"Long form" periodic table separated elements in periods 2 and 3	Most popular form of the periodic table until the mid-20 th century
Glenn Seaborg	Discovered plutonium and several more elements. Recognized that transuranium elements behave like actinium.	Added to our understanding of transuranium elements. Created the actinide series below the lanthanide series in the periodic table.

Chemical Elements

Directions: In the columns below, list at least 4 elements that fit each description.

Known prior to 1940	Transuranium elements discovered at Berkeley Lab	Transuranium elements discovered somewhere other than Berkeley Lab
<p>Choose any 4: gold silver tin lead mercury sulfur oxygen uranium, etc.</p>	<p>Choose any 4: neptunium plutonium seaborgium berkelium californium americium curium</p>	<p>Choose any 4: tennessine oganesson meitnerium roentgenium copernicium</p>

Synthesizing transuranium elements

1. How were the first transuranic elements synthesized? **Energetic beams of charged particles were aimed at suitable targets.**
2. What important equipment was needed? **Particle accelerators were needed to generate the beams of charged particles.**
3. What forces had to be overcome? **The repulsive nuclear forces between the nuclei of atoms had to be overcome. These forces exist because nuclei are positively charged due to the protons in the nucleus.**

After reading the handout, write two paragraphs summarizing the following:

- Important changes to the periodic table in the **20th century**, including why the changes were made.
- Why the periodic table is more valuable to chemists (and others!) than an alphabetical table listing the elements with their symbols and other information such as atomic number and atomic mass.

In the 20th century, periods 2 and 3 were separated, creating a “long form” of the periodic table, due to the work of Horace Deming. Later, Glenn Seaborg placed the actinide series below the lanthanide series on the periodic table. Elements heavier than uranium were created using particle accelerators.

The periodic table is more valuable than an alphabetical listing because in the periodic table, elements are arranged according to their properties, so predictions can be made regarding their properties and chemical behavior.

Jigsaw Video Summaries

If students have access to the Internet, share the links for these ACS *Reactions* videos (each video is about 5 minutes long). Ask students to take notes to share what they learned with the class in a gallery walk or short presentation. After they share their learning, ask students what surprised or engaged them the most, and why.

Alternatively, choose one of the videos to show in class and discuss it, using the suggestions below.

- The Periodic Table Table

<https://youtu.be/KyKEY01Lm5o>

Theodore Gray displays some of the element samples he collected for his Periodic Table table. **Ask students to describe the properties and/or uses of at least five of the element samples.**

Students should describe the samples in terms of color, density, uses, monetary value, etc. Elements shown include hydrogen, mercury, tungsten, titanium, niobium, noble gases, chlorine, bromine, bismuth, aluminum, silicon, sulfur, phosphorus, uranium, gold, silver and platinum.

- The Disappearing Spoon, the Rooster and the Bearded Russian

<https://youtu.be/-ojcm3Ilf98>

Ask students to explain where the name of the video came from.

Gallium is one of the elements (eka-aluminum) whose existence was predicted by the bearded Russian Mendeleev. Gallium has a very low melting point (about 30°C, or 86°F). It looks like silver, so if gallium is made into a spoon and you stir hot tea with it, the spoon will melt.

- Women in Chemistry: Heroes of the Periodic Table

<https://youtu.be/Zv8iECGdZAY>

Ask students to describe the contributions of Marie Curie and Ida Tacke Noddack to the periodic table.

Marie Curie recognized that uranium and thorium are naturally radioactive. Also, she worked with her husband Pierre Curie to isolate two new elements (polonium and radium) from pitchblende ore. She also determined the atomic weight of radium.

Ida Tacke Noddack and her husband noticed that some transition elements next to each other on the periodic table such as manganese, iron and cobalt were often found in the same ore samples. They predicted that as-yet undiscovered elements with atomic numbers 43 and 45 would be found in ore samples containing ruthenium (atomic number 44). They successfully isolated the two elements, naming them rhenium (45) and masurium (43). However, they were not able to obtain enough of element 43 to verify its discovery, so the discovery and naming of element 43 (technetium) was credited to chemists working in a nuclear reactor later.

○ Have We Found All the Elements?

<https://youtu.be/rwC9BBHkaAI>

Ask students to describe how new elements are found, some problems with finding new elements, and uses for some of the transuranium elements.

The elements that were known prior to the 17th century were solids that exist uncombined with other elements. In the 17th century, chemists began separating elements by boiling, examining air, or breaking down compounds found in ores and minerals.

Beginning in 1939, all new elements were discovered in the lab. Glenn Seaborg used a linear particle accelerator to aim deuterium nuclei at a uranium sample, producing plutonium. Elements after uranium are radioactive and have short half-lives, so they do not exist for long. Newer particle accelerators (atom smashers) were built to accelerate even heavier particles and create new elements in places such as CERN in Switzerland, or the heavy ion accelerator in Germany. Two reasons no new elements have been discovered since 2016 are that the heavy elements needed for targets only exist for a few thousandths of a second, and it is very difficult to accelerate heavier particles such as calcium ions.

Plutonium is used to power space probes, and americium is found in smoke detectors. Scientists would like to use transuranium element samples to test theories about how atoms behave.

○ What Are Isotopes?

<https://youtu.be/GyviEsmrVp0>

Ask students to define isotopes, and describe how isotopes are involved in chemical and nuclear reactions.

Isotopes are different forms of the same element with different numbers of neutrons. Isotopes were discovered by Thomson and Aston. Aston later developed a mass spectrograph to analyze isotopes of elements.

Since chemical reactions involve only electrons, all isotopes of the same element behave the same way chemically. It is important to remember that the number of protons determines the identity of the element.

Unlike chemical reactions, nuclear reactions involve changes in the nucleus, which can produce new isotopes and/or new elements. Nuclear reactions occur when nuclei are unstable. There are three basic types of nuclear reactions:

- Alpha decay creates a new element and a helium nucleus.
- Beta decay creates a new element because a neutron splits into a proton and an electron (beta particle), which is then ejected from the nucleus.
- Gamma decay releases energy in the form of gamma rays. No new elements are formed. However, the neutrons and protons in the nucleus are rearranged.