Module 2: The Periodic Table
Student Instructions

Name: ______________________________

CHEM1.PS1.12 Explain the origin and organization of the Periodic Table. Predict chemical and physical properties of main group elements (reactivity, number of subatomic particles, ion charge, ionization energy, atomic radius, and electronegativity) based on location on the periodic table. Construct an argument to describe how the quantum mechanical model of the atom (e.g., patterns of valence and inner electrons) defines periodic properties. Use the periodic table to draw Lewis dot structures and show understanding of orbital notations through drawing and interpreting graphical representation (i.e., arrows representing electrons in an orbital).

Directions:

1. **BEFORE reading the article** complete the "Me" column of the Anticipation Guide.
2. Read the article "The Periodic Table's Final Four".
3. Complete the Anticipation Guide, Graphic Organizer, and Student Reading Comprehension Questions.
4. Don't forget to complete the Critical-Thinking Questions.
5. Research each of the following questions. **If Internet access is unavailable,** you may skip these questions.
    a. How are the names of elements determined?
    b. Which countries have discovered elements and how many? https://www.businessinsider.com/this-brilliant-graphic-shows-you-which-country-discovered-every-element-in-the-periodic-table-2014-4
    c. Why are the atomic masses of some elements in brackets on the periodic table?
    d. The article states that there were more names for element 102. What were they?
    e. Most man-made elements are used only in nuclear research, providing insight and clues on how the neutrons and protons are organized in the nucleus. What purpose do each of the man-made elements 43 and 93-99 serve?

Atomic Number	Name	Use
43	Technetium	
93	Neptunium	
94	Plutonium	
95	Americium	
96	Curium	
97	Berkelium	
98	Californium	
99	Einsteinium	

Anticipation Guide

Name: ___________________________________

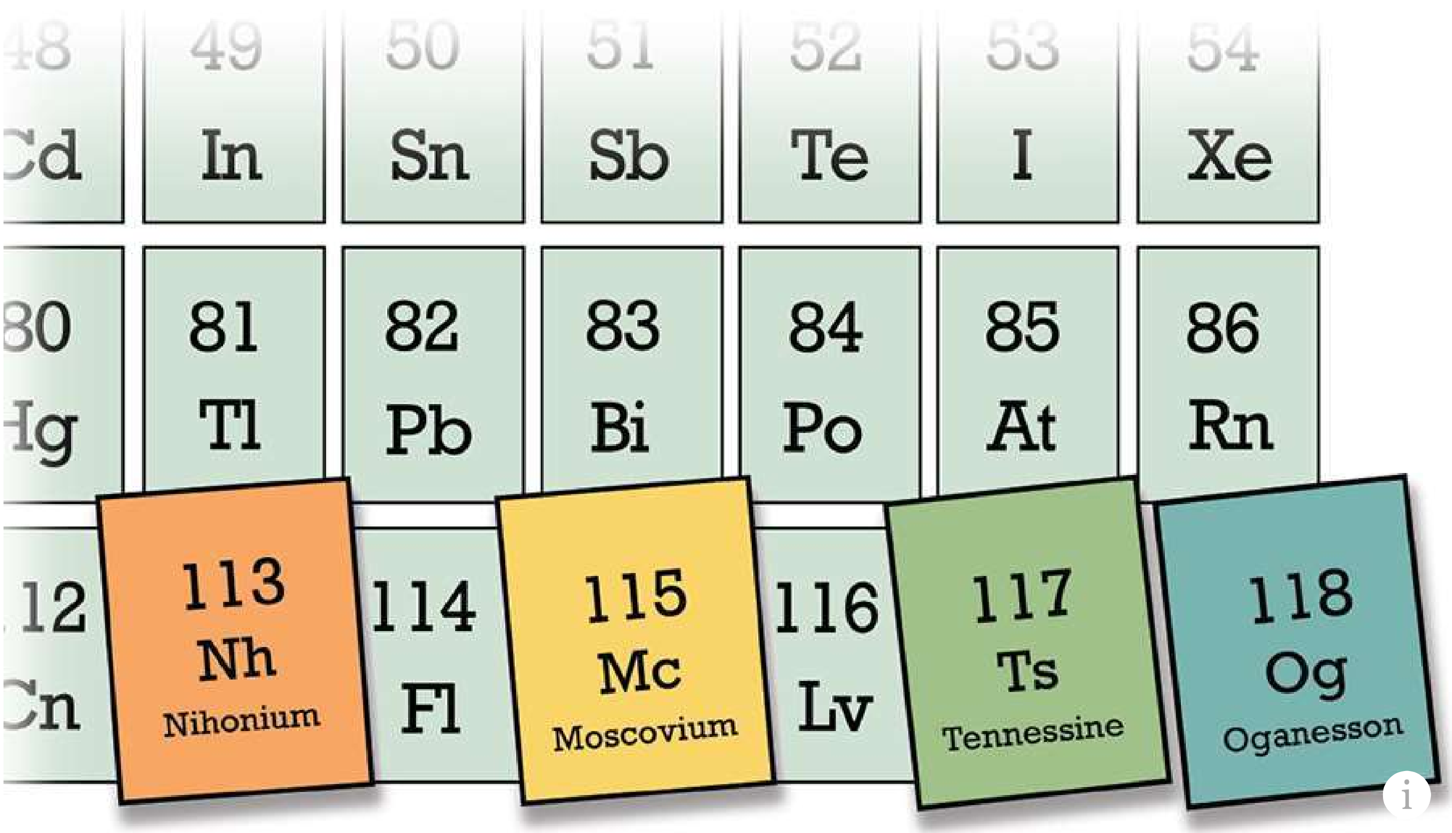
Directions: *Before reading the article*, in the first column, write "A" or "D," indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes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

Me	Text	Statement
		1. The last row of the Periodic Table was completed in 2018.
		2. All of the final four elements were named for the places where they were created.
		3. The first list of modern elements was published in the early 1800s.
		4. Most naturally occurring elements were discovered before 1900.
		5. Elements are defined by the number of protons and neutrons.
		6. Creating new elements requires overcoming strong repulsive forces between positively charged particles.
		7. No practical uses have been found for synthetic elements.
		8. Elements are officially named before the discovery is confirmed in a different laboratory than where they are discovered.
		9. All of the newest elements have half lives of less than one second.
		10. The last row of the Periodic Table was completed in 2018.

The Final Four

Scientists raced to complete the periodic table. Now what?

By Adrian Dingle



The periodic table is a marvel of organization, with each column and each row showing all kinds of complex relationships among the elements. Whenever a new element is discovered and added to the table, it's a really big deal in the world of science.

For years, scientists worked around the clock to fill the last four open spots in row (or period) 7 of the table. In 2016, they accomplished their goal. The International Union of Pure and Applied Chemistry (IUPAC), the organization that takes care of the official side of such things, declared the gaps filled. They recognized four new elements, approved their names, gave them symbols, and placed them in the final gaps in the table as we know it today. Elements with atomic numbers 113, 115, 117, and 118 were added to the table with the names nihonium, moscovium, tennessine, and oganesson, respectively.

So, what are these elements anyway? And why did it take so long to add them to the table?

The earliest "elements"

Before we consider how a new element is discovered, it's best to consider what an element actually is.

For millennia, the elements have been known to humankind, but humans didn't know what made an element, well, an element. The ancients in Greece, for example, thought that matter was made up of air, fire, water, and earth, and that those four things essentially constituted the elements.

The earliest civilizations were using several elements without realizing it. Carbon, copper, gold, and mercury are among some of the earliest substances known to humans. But it would take thousands of years before these materials would be recognized as elements.

It wasn't until the latter half of the 18th century that a modern understanding of what an element is began to develop. In 1789, French aristocrat and chemist Antoine Lavoisier published *Traité Elémentaire de Chimie (Elements of Chemistry)*, in which he identified 33 substances that he considered "simple" and that can reasonably be considered the first list of elements.

A lot of work happened in the next 80 years or so, culminating in Dmitri Mendeleev's 1869 table, which is generally regarded as the first organization of elements that most closely resembles the charts hanging on the walls of chemistry labs today.

In fact, most naturally occurring elements were discovered during the 18th and 19th centuries. Scientists identified the rest of them in the first half of the 20th century. All told, they found about 94 natural elements—give or take a few, depending on whom you ask.

So where do the other elements come from?

How to make a new element

Let's first look at what makes each element unique. Atoms—the smallest particles of matter that retain the properties of an element—are made from three subatomic particles: protons, neutrons, and electrons. It's the number of protons, also known as the **atomic number**, that defines any given element.

For example, atoms that contain 23 protons are atoms of the element vanadium. Thus, vanadium is assigned the atomic number 23. If atoms contain 36 protons, they are atoms of the element krypton, and they have the atomic number 36.

So, if we're going to make a new element, one that's not found naturally on Earth, we need to create an atom with a new and unique number of protons.

In 1944, scientists at the University of California, Berkeley, were the first to do just that. They created in their lab a synthetic, previously unknown element. It had 96 protons, and they named it curium (Cm), after Marie and Pierre Curie, scientists known for their pioneering work on radioactivity.

How did the Berkeley scientists accomplish this feat? With a bit of simple arithmetic, and a complex piece of equipment. Let's break down these two aspects of the process.

To make Cm, the scientists bombarded plutonium (Pu), which has 94 protons, with **alpha particles**, which are helium (He) nuclei with two protons (as well as two neutrons). When an atom of plutonium and an alpha particle fuse, the newly created atom has 96 protons. Curium is made!

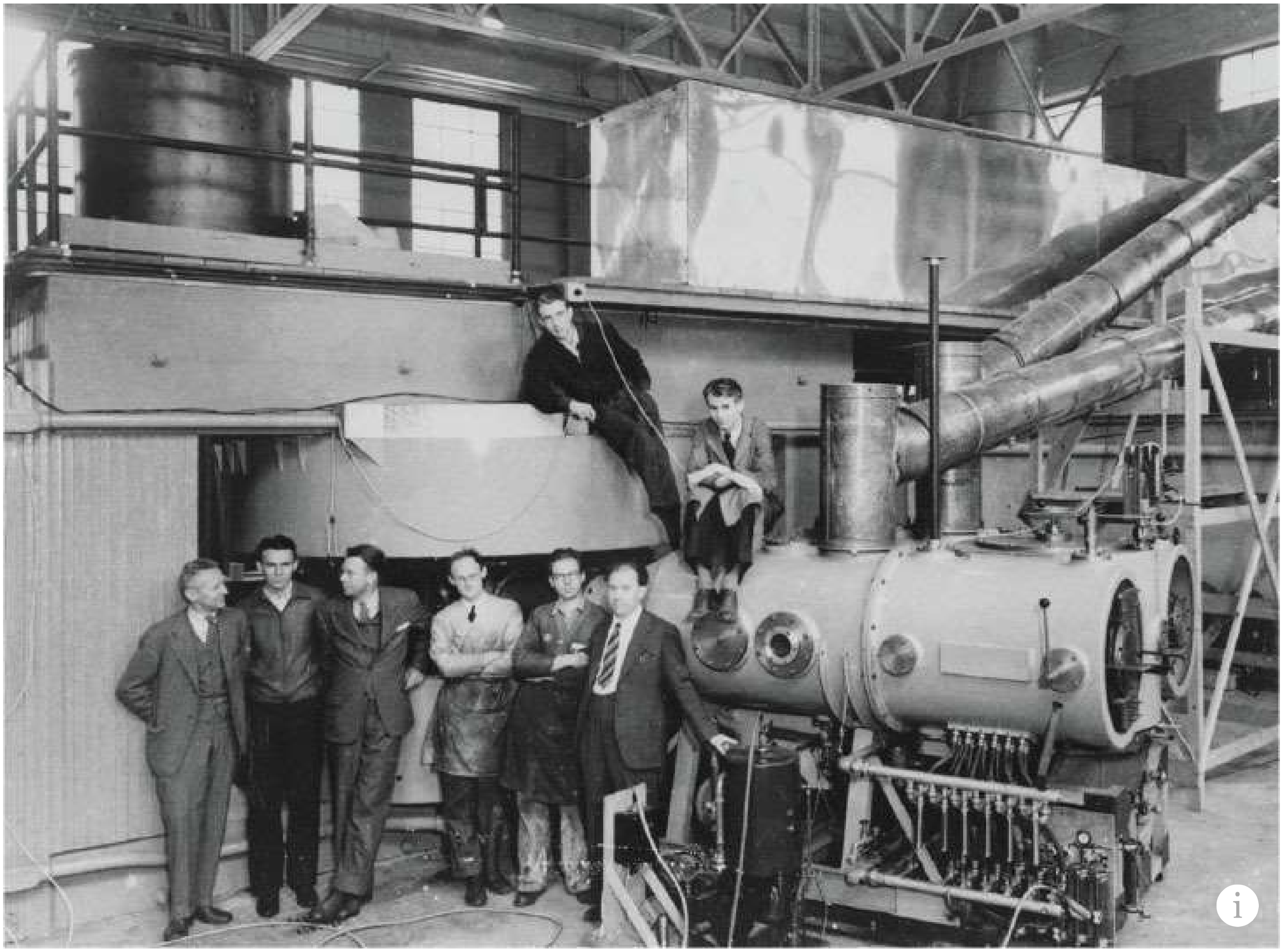
The tricky part of this process is overcoming the strong repulsive forces between positively charged alpha particles and proton-packed, positively charged nuclei of plutonium. Overcoming these forces requires a lot of energy.

So, the researchers used a cyclotron, which is a circular particle accelerator. The cyclotron accelerates a beam of particles along a spiral path. When they have enough energy to overcome the repulsive forces, the particles exit the circular route and are directed toward a target—in this case, atoms of plutonium.

The Berkeley scientists did this for weeks on end, and produced a tiny amount of curium. The process also released neutrons.

$$^{239}_{94}Pu + ^{4}_{2}He \rightarrow ^{242}_{96}Cm + ^{1}_{0}n$$

After that first successful synthesis, new and heavier elements started to be created in various labs around the globe, and the remaining spaces in the periodic table started filling up.



The Two Sides of Radioisotopes

Making new, synthetic elements might seem like an abstract scientific pursuit. But its history could have very real ties to your life, particularly if you or someone you know has undergone medical imaging or radiation therapy.

Synthetic elements are radioactive isotopes—that is, they are unstable forms of elements that emit radiation to change into a more stable form. Isotopes of an element have the same number of protons but different numbers of neutrons.

Soon after scientists succeeded in creating the first synthetic elements, they began to study the isotopes' use for medical purposes. But exposure to radioisotopes can cause serious health problems such as cancer. If these unstable isotopes are harmful to humans, how are they used for medical purposes?

The answer lies in their specific properties:

» Some radioisotopes are absorbed more easily by cancer cells than by healthy cells. They can be used to destroy cancer cells, leaving healthy cells unharmed.

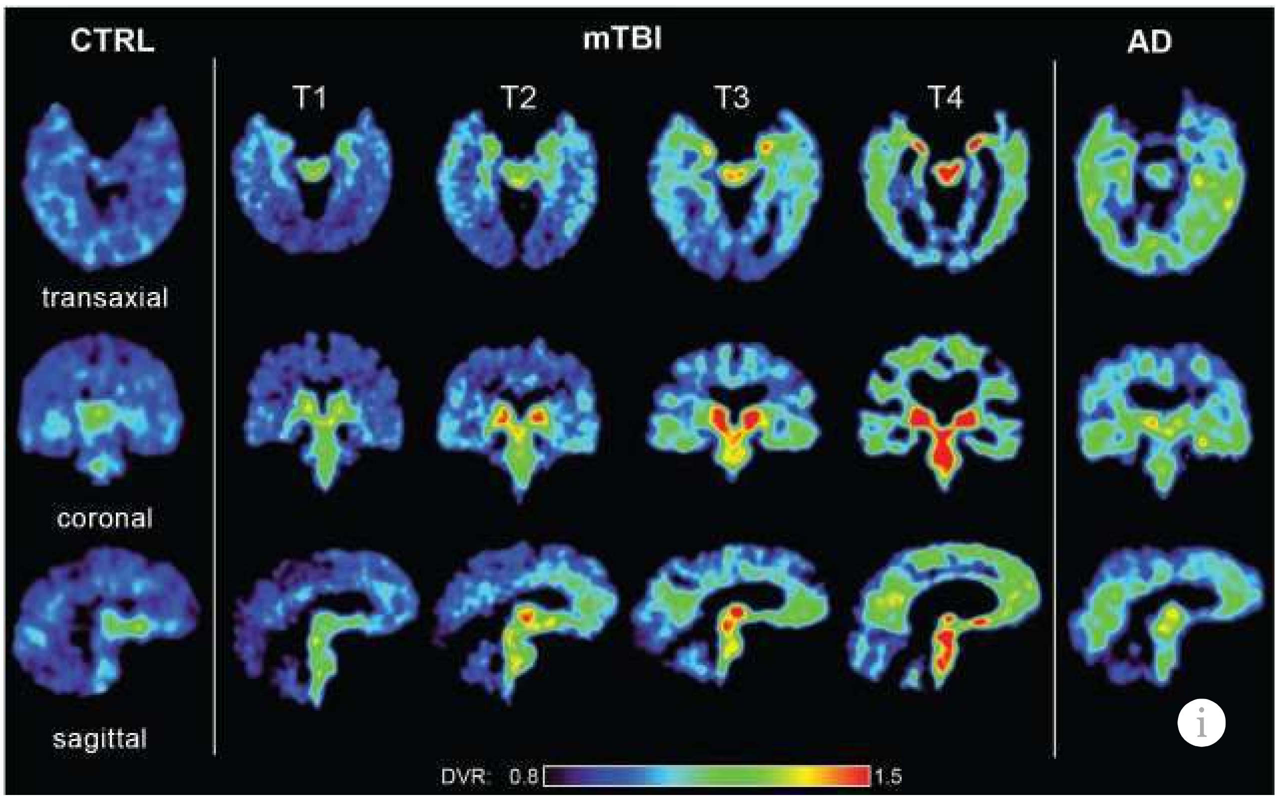
» Radioisotopes' half-lives—the time it takes for half of the radioisotope to decay—as well as the amount of energy they emit are also factors that help scientists decide which ones might be good candidates for medical use.

» Some radioisotopes emit types of radiation that readily escape the body. These do relatively little damage inside the patient, and can be detected to create images. The images help physicians diagnose diseases.

» Radioisotopes can target specific parts of the body. Radioisotopes of iodine, for example, are easily absorbed by the thyroid, and can target cancer cells in the gland.

So, although radioactive material at high doses can increase a person's risk for health problems, when used carefully, radioisotopes can be harnessed to do the opposite!

RADIOISOTOPE	HALF-LIFE	USES
Fluorine-18	110 minutes	PET imaging
Rubidium-82	65 hours	Imaging functions in the heart
Iodine-82	8 days	Treatment of thyroid cancer
Plutonium-238	87 days	Power source for spacecraft
Uranium-235	700 million years	Used in nuclear power plants and bombs



—Lisette Gallegos

Claims, names, and fame

During this phase, IUPAC didn't have the role of ratifying additions to the table. The discovery teams would publish their reports and propose a name for the newfound element. As is often the case in the competitive world of scientific discovery, disputes and counter-claims would erupt. But overall, the community would come to a general agreement over the addition of new elements to the table. This process continued through the discovery of element 101, mendelevium.

Then, things really heated up! Claims over the discovery of nobelium, element number 102, took a rocky turn. By 1957, three main groups were clamoring for credit, and at least two different names were being used to identify the element. Similar rivalries developed over naming additional elements as they were discovered.

To address these disputes and the confusion they caused, IUPAC intervened. In 1969, the organization, which was established in 1919 to set international standards in chemistry, declared that making a claim and publishing a new element name wasn’t going to cut it anymore.

IUPAC proposed that naming elements should occur five years after the initial announcement of discovery. Ideally, the waiting period would allow confirmation of the initial discovery in another laboratory, preferably in another country. Discoverers could still name the elements they found, within certain guidelines, but in case multiple scientists or teams claimed this privilege, IUPAC would assess who should ultimately have the honor.

After years of arguing, assessing claims, and naming and re-naming elements, IUPAC released the official names of elements 102 through 109 in the 1990s.

Completing the table

In May 2012, with all elements through number 112 plus numbers 114 and 116 confirmed and named, IUPAC invited the scientific community to claim discovery of elements with atomic numbers 113, 115, 117, and 118. Each of the new elements had already been claimed by various groups of scientists.

THE SHORT LIVES OF SUPERHEAVY ELEMENTS

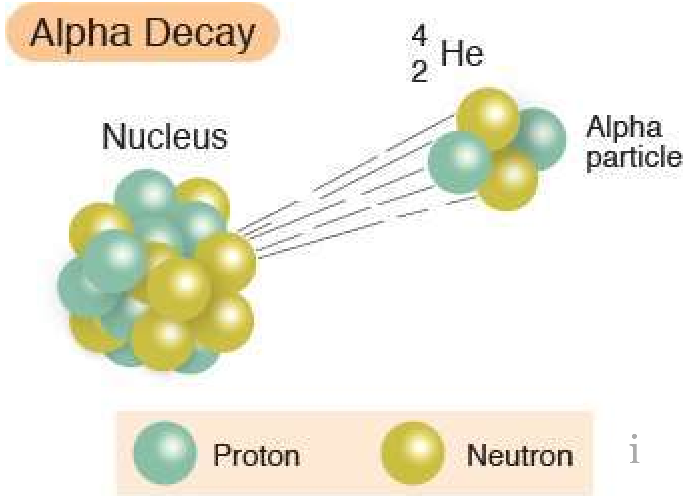
The four latest additions to the periodic table all decay within seconds or within a fraction of one second.

ATOMIC NUMBER	ELEMENT	ESTIMATED HALF-LIFE	HOW IT WAS MADE
113	Nihonium	20 seconds	By first producing moscovium, which decays into nihonium
115	Moscovium	220 milliseconds	By bombarding americium (atomic number 95) with calcium (20) ions
117	Tennessine	80 milliseconds	By bombarding berkelium (97) with calcium (20) ions
118	Oganesson	<1 millisecond	By bombarding californium (98) with calcium (20)

It took the organization three years to assess the work. In December 2015, the four new elements were confirmed as having been created and detected. In June 2016, the discoverers proposed names and symbols for the elements. Five months later the elements officially made their way onto the table.

With only a few atoms of each of these elements ever having been produced, they are currently not much more than chemical curiosities.

One of the most fascinating properties about these superheavy elements is that they are extremely radioactive and unstable. This means that very soon after they are made, their atoms decay, releasing alpha particles and turning into atoms of another element (Fig. 1).The transformation happens within a matter of seconds or a few milliseconds.



The latest additions to the periodic table are so short-lived, you might wonder, "What's the point of making them?" For one thing, the current periodic table is now satisfyingly complete! Also, by studying the new elements, scientists can explore the ultimate limits of the periodic table and push the boundaries of scientific knowledge.

So, now that the periodic table is full, what's next? Expanding the table even further by hunting for elements 119 and 120, naturally! The race is already on.

Adrian Dingle is a science educator who lives in Indiana.

SELECTED REFERENCES

International Union of Pure and Applied Chemistry. IUPAC Is Naming the Four New Elements Nihonium, Moscovium, Tennessine, and Oganesson, June 8, 2016: **https://iupac.org/iupac-is-naming-the-four-new-elements-nihonium-moscovium-tennessine-and-oganesson/** [accessed Feb 2019].

Scerri, E. R. *The Periodic Table: Its Story and Its Significance*. Oxford University Press: New York, 2007.

Seaborg, G. T. The Periodic Table, Tortuous Path to Man-Made *Elements. Chemical & Engineering News*, April 16, 1979: **https://escholarship.org/uc/item/10q263mc**[accessed Feb 2019].

Graphic Organizer

Name: ______________________________

Directions: As you read the article, complete the graphic organizer below to compare naturally occurring elements to synthetic elements.

	Natural Elements	**Synthetic Elements**
Examples (at least 5 for each)		
When discovered (range)		
Atomic Number (range)		
Location on the Periodic Table		

Use the graphic organizer below to describe an alpha particle:

	Structure	***Charge***	***Role in creating new elements***
Alpha Particle			

Summary: On the bottom or back of this paper, write a short (2-3 sentence) explanation of the role of IUPAC in confirming and naming new elements.

Student Reading Comprehension Questions

____
Name

Directions: Use the article to answer the questions below.

1. When were the four last open spots in the periodic table filled?

2. Complete the table below for the four elements most recently added to the periodic table.

New elements		
Atomic number	**Name**	**Origin of name**

3. (a) Who was the scientist who first published a textbook containing a table identifying 33 simple substances later recognized as the first list of modern elements, and (b) when was it published?

4. When and by whom was the first organization of elements that resembles the current periodic table established?

5. How many elements occur naturally on Earth?

6. What defines any given element?

7. What is required for creating a new element?

Student Reading Comprehension Questions, cont.

8. Give the name and atomic number, and the location and date of discovery of the first synthetic element produced.

9. What are the three main standards IUPAC proposed in regards to naming elements?

10. What are the most fascinating properties of the new superheavy elements?

11. Which element is associated with the production of three of the four newest elements?

Critical-Thinking Questions

Write your answers on another piece of paper.

1. Propose a possible procedure for making element 120.

2. Based on its expected position on the periodic table (directly under radium, element 88), what properties (e.g., outer energy-level electron arrangement) oxidation number, the formula of its compound with chlorine, reactivity with water, nuclear stability, and density) would you predict for element 120 (unbinilium, Ubn)? Explain your predictions.