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Chemistry

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Chemistry

Module 1: The Atom

1. Activity: Cherynobyl’s Legacy
2. Activity 2: Radiocarbon Dating

Module 1: The Atom
Student Instructions

Name: ______________________________

CHEM1.PS1.10 Compare alpha, beta, and gamma radiation in terms of mass, charge, and penetrating power. Identify examples of applications of different radiation types in everyday life (such as its applications in cancer treatment).

Directions:

1. **BEFORE reading the article** complete the "Me" column of the Anticipation Guide.

2. Read the article "Chernobyl's Legacy".

3. Complete the Anticipation Guide and the Student Reading Comprehension Questions.

4. Don't forget to complete the Questions for Further Learning.
   If Internet access is unavailable, you may skip questions 1 and 3 of this section.
   For help with question 1, Three Mile Island information can be found here:
   https://www.thebalance.com/three-mile-island-nuclear-accident-facts-impact-today-3306337

5. Complete the Radioactivity Puzzle.

6. Provide at least 1 type of nuclear reaction or particle that each of the words unscrambled in the Radioactivity Puzzle uses or produces. Also, identify the radioactive element(s) associated with each.
   If Internet access is unavailable, you may skip this question.

7. For additional learning you may wish to research how each is beneficial or dangerous in each situation.

8. Read the article "Open for Discussion: Can Nuclear Power Save the Planet".

9. Debate the pros and cons of nuclear power based on what you have learned from reading these two articles.

Anticipation Guide

Name: ______________________________

Directions: *Before reading the article*, in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.
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. Most of the people who left Chernobyl after the nuclear plant explosion have returned.
		2. The accident at Chernobyl occurred during a safety test.
		3. Temperatures inside the reactor during the explosion were as hot as parts of the Sun's atmosphere.
		4. The fuel in the reactor included U-238 from enriched uranium dioxide.
		5. A radioactive cloud blew across Northern Europe after the explosion.
		6. Isotopes of the same element have the same number of neutrons.
		7. When one mole of U-235 undergoes fission, the energy released can power about 400 average U.S. homes for a year.
		8. Nuclear reactors must have control rods to keep a chain reaction from occurring.
		9. Radioactive strontium can lead to bone cancer.
		10. The radioactive iodine released during the explosion still poses a health threat to people in Northern Europe.

Chernobyl’s Legacy

By Adrian Dingle

Chernobyl.

The name refers to both a town and a nearby, defunct nuclear power plant in what’s now Ukraine. But to many people, the name has become synonymous with nuclear disaster and what can go horribly wrong in the world’s quest to electrify cities with nuclear power.

The explosion of one of the plant’s reactors exposed hundreds of thousands of people to radiation. It forced some 350,000 people in the surrounding areas to leave their homes, according to the International Atomic Energy Agency.

Access is still restricted to what’s known as an "exclusion zone," which encompasses the land within 30 kilometers (18.6 miles) of the plant. But more than 100 people now live in or on the edge of the zone. Much of the soil remains contaminated with radioactive materials, but scientists monitoring the zone say that breathing the air is safe.

Details about the causes of the explosion have been well reported. But the world is still contending with its lingering effects and fears of another Chernobyl-like event. More than 30 years later, are the concerns still warranted?

What caused the explosion

In the spring of 1986, operators at the Chernobyl power plant set out to conduct a safety check to see if the plant could work safely if the main power source were interrupted.

As part of the safety test, one of the four reactors was reduced to a low power state. A series of operator errors coupled with the reactor's poor design led to a power surge at 1:24 a.m. on April 26.

The rush of energy was enormous: It caused thermal power to reach a level of 12 billion watts; the pressure inside the reactor shot up; and the temperature reached a staggering 4,650 °C (8,402° F)—about the same temperature as parts of the sun's atmosphere.

These conditions inevitably caused the reactor to meltdown, and an explosion blew the steel and concrete structure to bits. Metal, graphite, and lethal radiation was blown sky high. Winds blew a radioactive cloud across northern Europe.

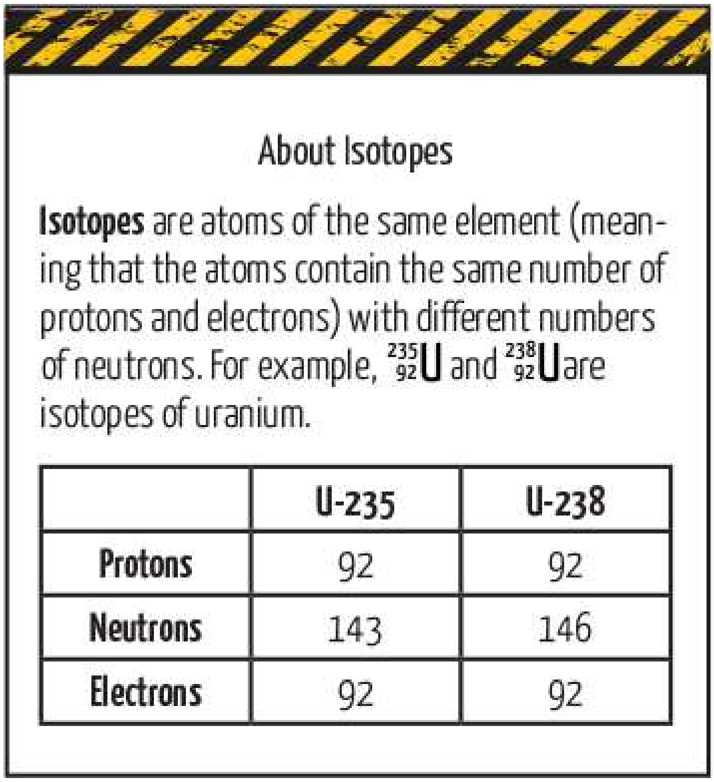
How did the reactor work?

The reactor was a Soviet-produced RBMK (reaktor bolshoy moshchnosti kanalnyy), which translated from Russian means "high-power channel-type reactor." In the core of the reactor was the fuel—190 tons of enriched uranium dioxide, UO_2. The uranium is said to be enriched because it contains a higher percentage of the isotope U-235, the isotope used for nuclear power, than is found in naturally occurring uranium. Naturally occurring uranium has approximately 0.7% of U-235 and more than 99% of the heavier isotope U-238. Enriched uranium is 3% to 5% U-235.

When the nucleus of a U-235 atom is bombarded by a neutron, a nuclear reaction takes place. The neutron splits open the nucleus—a process known as **fission**—and releases new daughter nuclei, more neutrons, and energy. The reaction can play out in many ways, generating different products, depending on the conditions. The following reaction is one example of what can happen to U-235:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3\,{}^{1}_{0}\mathrm{n} + \text{energy}$$

The reaction of a single atom of uranium does not release very much energy. The reaction above typically produces about 2.7×10^{-11} Joules (J). But repeated on the scale of the mole—that is, 6.02×10^{23} times, or 235 grams of U-235—the energy released becomes significant, about 1.6×10^{13} J. That's enough to power 400 average U.S. homes for an entire year, all from the reaction of about half a pound of U-235.



About Isotopes

Isotopes are atoms of the same element (meaning that the atoms contain the same number of protons and electrons) with different numbers of neutrons. For example, $^{235}_{92}U$ and $^{238}_{92}U$ are isotopes of uranium.

	U-235	U-238
Protons	92	92
Neutrons	143	146
Electrons	92	92

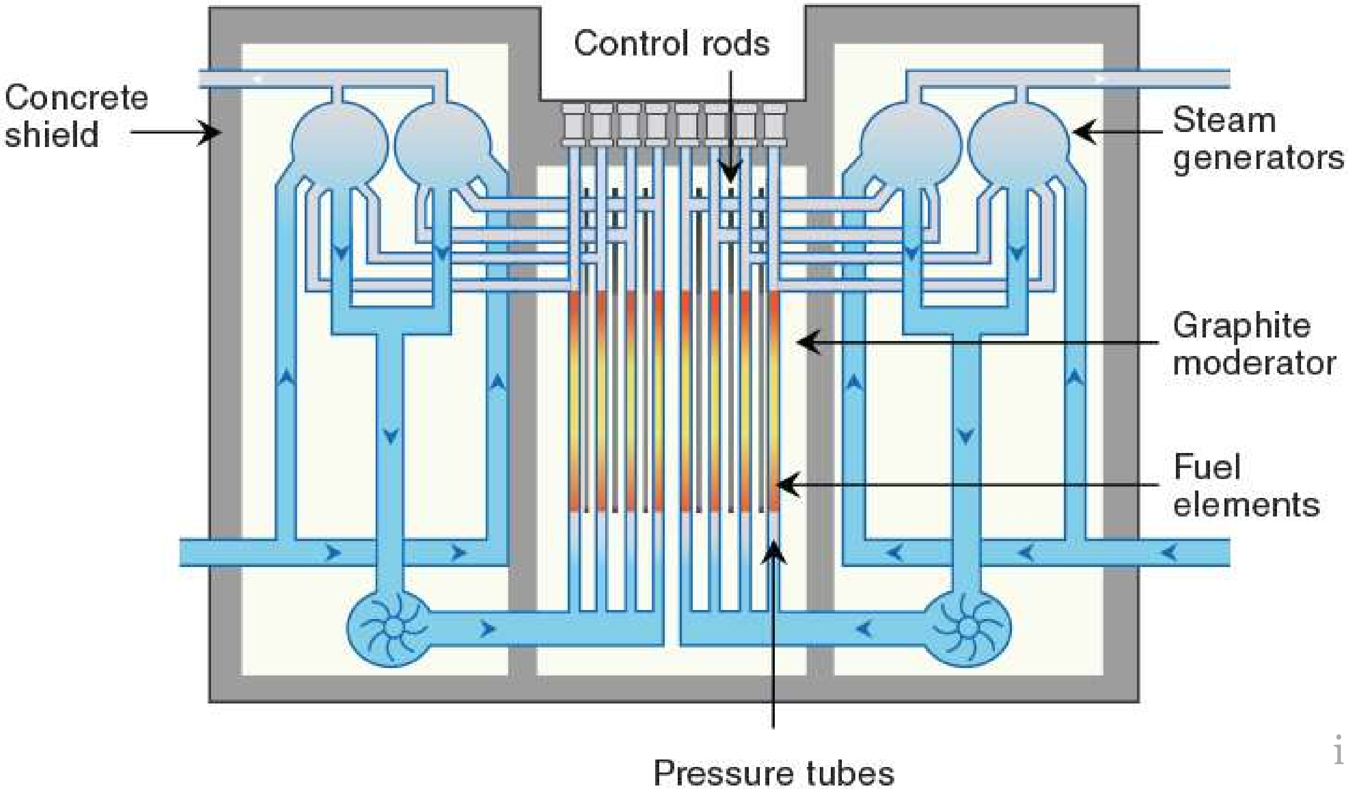
Controlling the reaction

Nuclear power is based on two properties of nuclear fission: 1) It produces a large amount of energy when scaled up; and 2) the neutrons that are produced can react with additional U-235 nuclei, breaking them apart and producing more neutrons. The result is a self-sustaining chain reaction.

The chain reaction produces a lot of energy very quickly. Without moderation, the process becomes dangerous. Careful monitoring and management are required.

One way to control the reaction is to lower control rods into a reactor's core. Control rods slow down nuclear reactions by absorbing neutrons, which prevents them from reacting with the uranium and generating more energy.

Chernobyl's RBMK reactor had 211 control rods. The accident investigation showed that at the time of the explosion, only eight control rods had been in the 7-meter tall core, when at least 15 should have been in place. This critical error along with subsequent missteps ultimately led to the explosion.



What Happened at Chernobyl?

What Exactly Happened at Chernobyl?

bit.ly/ACSReactions-Chernobyl

The human toll

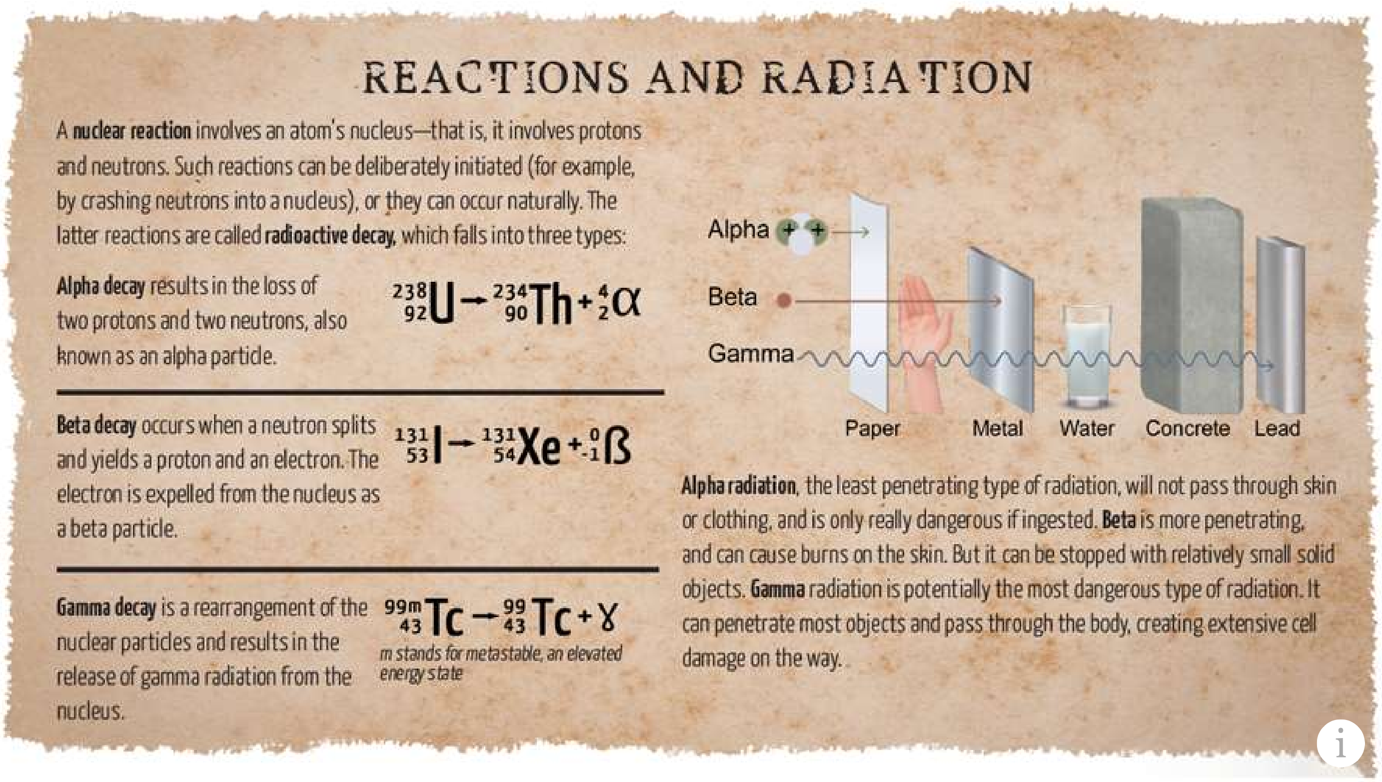
As a result of the initial explosion, two people were immediately killed. In the following two weeks, more than two dozen people died from acute radiation sickness (ARS), which occurs when exposure to radiation goes well beyond background levels. The ionizing radiation produced in nuclear reactions damages human cells. This leads to a host of symptoms, including vomiting, diarrhea, headaches, and fever. Over time, cancers, such as leukemia, can also result.

Long-term health effects can also result from the radioisotopes that the explosion spewed into the atmosphere and settled into the soil and water. As mentioned earlier, the nuclear fission of U-235 can yield many different, lighter products, which can undergo radioactive decay to create a mix of radioisotopes, such as iodine-131, cesium-137, and strontium-90.

These radioisotopes can cause a variety of health issues. For example, iodine-131 tends to concentrate in the thyroid gland and can cause cancer. Strontium-90 can mimic fellow Group 2 member calcium, accumulate in bones, and lead to bone cancer.

Iodine-131’s effect is relatively short-lived with a half-life of only eight days. In contrast, cesium-137 with a half-life of 30 years and strontium-90 with a half-life of 29 years remain threats for longer periods of time.

The number of premature deaths that have resulted from Chernobyl, however, is difficult to determine. An estimated 600,000 "liquidators" were brought in to clean up the mess that resulted from the accident. Some of them died of cancer, or became terminally ill. In addition, an increase in thyroid cancer rates in the region has been reported.



REACTIONS AND RADIATION

A **nuclear reaction** involves an atom’s nucleus—that is, it involves protons and neutrons. Such reactions can be deliberately initiated (for example, by crashing neutrons into a nucleus), or they can occur naturally. The latter reactions are called **radioactive decay**, which falls into three types:

Alpha decay results in the loss of two protons and two neutrons, also known as an alpha particle.

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$$

Beta decay occurs when a neutron splits and yields a proton and an electron. The electron is expelled from the nucleus as a beta particle.

$$^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}\beta$$

Gamma decay is a rearrangement of the nuclear particles and results in the release of gamma radiation from the nucleus.

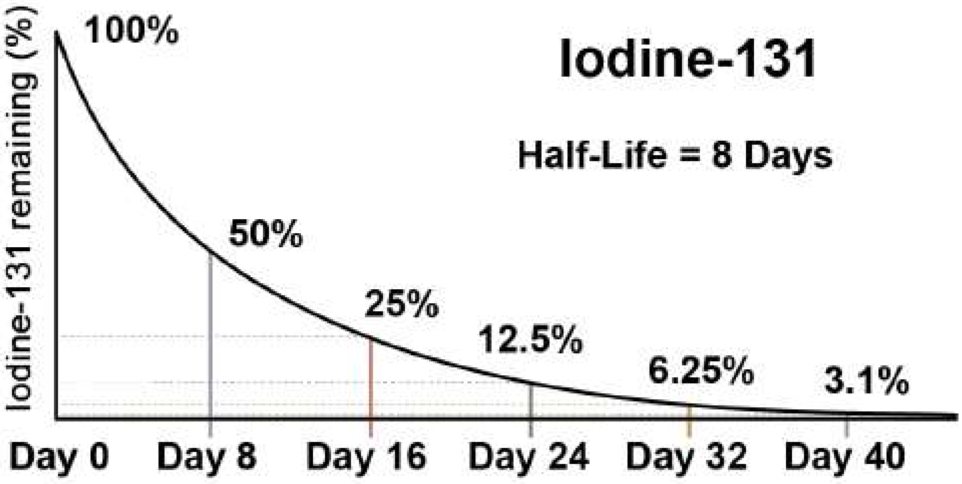
$$^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + \gamma$$

m stands for metastable, an elevated energy state

Alpha radiation, the least penetrating type of radiation, will not pass through skin or clothing, and is only really dangerous if ingested. **Beta** is more penetrating, and can cause burns on the skin. But it can be stopped with relatively small solid objects. **Gamma** radiation is potentially the most dangerous type of radiation. It can penetrate most objects and pass through the body, creating extensive cell damage on the way.

Understanding Half-life

The half-life of a radioactive isotope is the time it takes for half of a sample’s atoms to decay. For example, I-131 has a half-life of eight days. That means a sample of I-131 with an initial mass of 100 g would decay to 50 g of I-131 after eight days. After another eight days, the remaining I-131 would decay to 25 g, and so on, yielding an isotope of xenon and beta radiation.



Nuclear power today

After the Chernobyl disaster, RBMKs were redesigned, and no major incidents involving this type of reactor have been reported for two decades. The most recent nuclear meltdown occurred in 2011 in Japan when a tsunami flooded the Fukushima Daiichi power plant. No deaths or cases of ARS were reported.

Nuclear power continues to be an important contributor to low-carbon energy, although concerns about safety, long-term waste disposal, and high building costs have dampened the industry's growth. Moving forward, the world could become less reliant on it as renewable energy, such as solar and wind, continue to ramp up. Even then, the legacy of Chernobyl will endure.

Adrian Dingle is a science educator based in Indiana.

REFERENCES

Higginbotham, A. Midnight in Chernobyl: The Untold Story of the World's Greatest Nuclear Disaster; Simon and Schuster: New York, 2019.

The World Nuclear Association. Safety of Nuclear Power Reactors: Appendix I, The Hazards of Using Energy, updated March 2017: **https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/appendices/safety-of-nuclear-power-reactors-appendix.aspx** (accessed Dec 2019).

Mettler, F. A. Jr. et al. Health Effects in Those with Acute Radiation Sickness from the Chernobyl Accident. *Health Physics* 2007, 93 (5), pp 462–9.

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. Why is there an exclusion zone in Chernobyl?
2. How many nuclear reactors did Chernobyl have?
3. What type of fuel was used in the reactors in Chernobyl?
4. Describe the function of control rods in a nuclear reactor.
5. Nuclear reactions involve the nucleus of an atom. Which two subatomic particles are found in the nucleus of an atom?
6. What are isotopes? Give an example not cited in the article.
7. List the three radioisotopes that can result from the decay of U-235 in order of their half-lives.
8. Describe the process of fission in U-235.
9. If you start with a 30 g sample of I-131, how many grams of I-131 would there be after 16 days?
10. Explain how half a pound of U-235 can generate enough energy to power 400 average U.S. homes for a year.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. In 1979, the U.S. experienced a nuclear accident at Three Mile Island. Do some research and compare and contrast the two events.

2. Th-232 undergoes decay by emitting the following particles: alpha, beta, beta, alpha, alpha, alpha, alpha, beta, beta, alpha. What is the resulting isotope? Write out the entire decay series.

3. Do some research to conclude why alpha radiation is dangerous when ingested, beta particles cause damage to skin, and gamma radiation damages human cells.

4. Develop a list of at least three drawbacks and three benefits for using nuclear power as an energy source. Examine your list and explain whether or not we should continue to use nuclear power. Read the *Open for Discussion* article in this issue to help you decide.

Graphic Organizer

Name: ______________________________

Directions: As you read, complete the graphic organizer below to describe what happened during and after the explosion of the nuclear power plant at Chernobyl.

	Nuclear Explosion at Chernobyl
When did it happen?	
Where did it happen?	
What happened?	
How could the explosion have been prevented?	
What radioisotopes were produced?	
What kind of radiation was emitted?	
How were human beings affected?	

Summary: In the space below, or on the back of this paper, write three new things you learned about nuclear power plants and/or nuclear radiation.

Radioactivity Puzzle

Sources of ionizing radiation

A lot of radioactive elements are either mined in a quarry (like uranium) or made in a lab (like americium). But there are a lot of things in your everyday life that are sources of ionizing radiation. Unscramble the words and phrases below to find some of them.

1) UNS
2) PASS
3) CHEWSAT
4) ANABANS
5) BEANSTEMS
6) ARLBIZ STUN
7) COTTONPURSE
8) KOMES DECOTTERS

Uses of ionizing radiation

Radiation from unstable isotopes has more uses than you think. Unscramble these words and phrases to find a few of those uses.

9) AMBERSINUS
10) PROWE LTSNAP
11) PACES ORBSEP
12) KALE CITEDNOTE
13) ARCENC MATTRENTE
14) CLAIMED ADIOSSIGN
15) NUTRIMENTS INITIALZOSTER
16) ODOF INCANTATIONMODE

OPEN FOR DISCUSSION

Can Nuclear Power Save the Planet?

By Michael Tinnesand

Nuclear power, once hailed as the future of cheap electricity, is now often viewed by many as an extremely expensive and dangerous technology that should become a relic of the past. Nuclear power plants generate large amounts of electricity and lower carbon dioxide (CO_2) emissions than power plants that burn fossil fuels. Nuclear plants, however, also produce radioactive waste and are vulnerable to accidents. But as the world seeks to reduce CO_2 emissions to fight climate change, is it time to ramp up nuclear energy?

As is true for any energy technology, nuclear power comes with risk. Three high-profile accidents have served as frightening reminders of this fact. In 1979, a reactor at the Three-Mile Island nuclear plant in Pennsylvania partially melted down; in 1986, a reactor at the Chernobyl power plant in Russia exploded; and in 2011, three reactors at the Fukushima plant in Japan melted down after a tsunami flooded them.

Many experts, however, will point out that although nuclear accidents are indeed dangerous, they have resulted in fewer deaths than other energy-related disasters, including explosions at coal mines and oil refineries. Statistics show that nuclear power is safer than coal power plants in terms of deaths per unit of electricity generated. And some researchers have estimated that living in a large polluted city can be more harmful to a person's health than working as a Chernobyl clean-up worker.

The decline of nuclear power

How nuclear energy will fit into the future energy mix is unclear. Having fallen out of favor in some countries, the total amount of 18% of the worldwide total in the mid-1990s to only 10% today.

Nuclear by the Numbers

58 »	The number of commercially operating nuclear power plants in the U.S.
96 »	The total number of nuclear reactors at U.S. power plants
29 »	The number of U.S. states with nuclear power plants

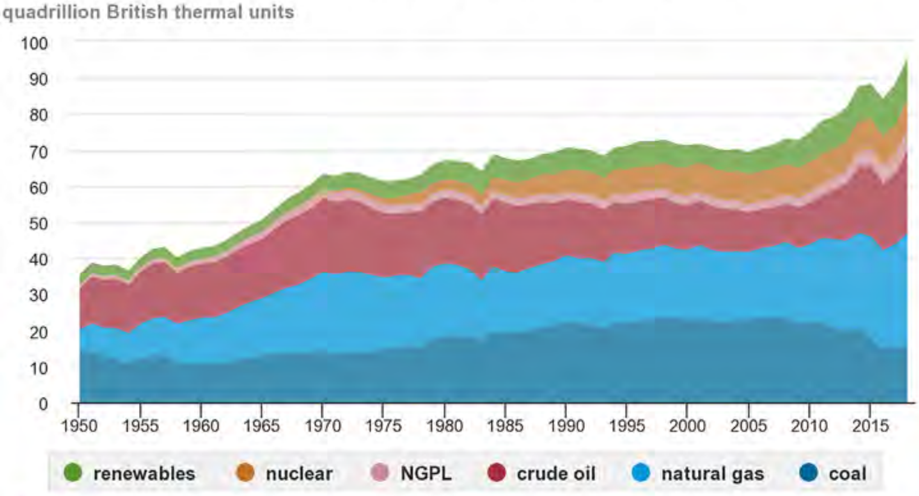
**Data as of October 2019*
Source: U.S. Energy Information Administration

This decrease is due to several factors. In addition to the public's wariness over nuclear accidents, nuclear power plants are very expensive. The electricity produced by these plants costs $112 to $189 per megawatt hour (MWh) compared with $36 to $44 per MWh for solar. Also, building new nuclear plants can take decades. Meanwhile, many of the existing plants are old and near the end of their useful lives. Additionally, most countries that use nuclear power still don't have long-term plans for dealing with the radioactive waste generated by nuclear power plants.

Global climate change, however, which is largely driven by how we produce energy, might motivate countries to invest more in low-carbon energy. Most energy production comes from burning fossil fuels, such as coal, oil, and natural gas. But burning these fuels releases CO_2 into the air. The more CO_2 we release, the more our climate changes. The consensus among scientists is that, among other solutions, the world must release less CO_2 during energy production. This means shifting energy production toward renewable sources, including wind, solar, and geothermal energy.


SHUTTERSTOCK

U.S. primary energy production by major sources, 1950-2018



Note: NGPL is natural gas plant liquids.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.2, April 2019

Renewed interest

Given that atmospheric CO_2 levels are at a record high and rising, some experts argue that nuclear energy is needed to help curb these emissions. Some countries, such as China, Russia, and India, are moving forward with plans to build more nuclear power plants, although in response to the Fukushima disaster, Japan, Germany, and others are scaling back.

The future of nuclear could also mean revisiting the technology involved. Most current nuclear power plant designs are decades old. New types of advanced nuclear reactors, however, are in the works. One type, backed by billionaire Bill Gates, called a traveling wave reactor, is being designed to use depleted uranium waste as its fuel source. So, this type of reactor would generate electricity with low CO_2 emissions, and reduce the amount of nuclear waste at the same time. Others in the industry are betting on small-scale reactors, which are currently still under development.

Can nuclear power save the day for climate change in the future? It's a question that is open for discussion.

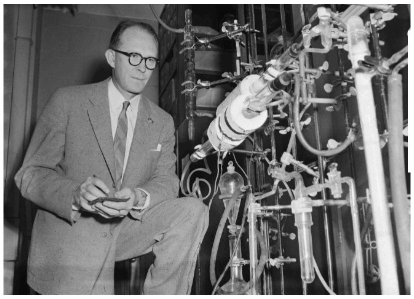
NATIONAL GEOGRAPHIC

Radiocarbon helps date ancient objects—but it's not perfect

For nearly 70 years, archaeologists have been measuring carbon-14 levels to date sites and artifacts.

BY ERIN BLAKEMORE

PUBLISHED JULY 12, 2019



Professor Willard Libby, a chemist at the University of Chicago, first proposed the idea of radiocarbon dating in 1946. Three years later, Libby proved his hypothesis correct when he accurately dated a series of objects with already-known ages.

PHOTOGRAPH BY BETTMANN, GETTY

Nothing good can last—and in the case of carbon-14, a radioactive isotope found in Earth's atmosphere, that's great news for archaeologists.

Over time, carbon-14 decays in predictable ways. And with the help of radiocarbon dating, researchers can use that decay as a kind of clock that allows them to peer into the past and determine absolute dates for everything from wood to food, pollen, poop, and even dead animals and humans.

Counting carbon:
While plants are alive, they take in carbon through photosynthesis. Humans and other animals ingest the carbon through plant-based foods or by eating other animals that eat plants. Carbon is made up of three isotopes. The most abundant, carbon-12, remains stable in the atmosphere. On the other hand, carbon-14 is radioactive and decays into nitrogen-14 over time. Every 5,730 years, the radioactivity of carbon-14 decays by half.

That half-life is critical to radiocarbon dating. Since carbon-12 doesn't decay, it's a good benchmark against which to measure carbon-14's inevitable demise. The less radioactivity a carbon-14 isotope emits, the older it is. And since animals and plants stop absorbing carbon-14 when they begin to decay, the radioactivity of the carbon-14 that's left behind reveals their age.

There's a catch: Atmospheric carbon fluctuates over time. But the amount of carbon-14 in tree rings with known ages can help scientists correct for those fluctuations. To date an object, researchers use mass spectrometers or other instruments to determine the ratio of carbon-14 and carbon-12. The result is then calibrated and presented along with a margin of error. (Discover other archaeological methods used to date sites.)

Chemist Willard Libby first realized that carbon-14 could act like a clock in the 1940s. He won the 1960 Nobel Prize in Chemistry for coming up with the method. Since Libby's discovery, radiocarbon dating has become an invaluable tool for archaeologists, paleontologists, and others looking for reliable dates for organic matter.

Challenges of the method:
The method has limitations: Samples can be contaminated by other carbon-containing materials, like the soil that surrounds some bones or labels that contain animal-based glue. Inorganic materials can't be dated using radiocarbon analysis, and the method can be prohibitively expensive. Age is also a problem: Samples that are older than about 40,000 years are extremely difficult to date due to tiny levels of carbon-14. Over 60,000 years old, and they can't be dated at all.

Calibration presents another challenge. With the dawn of the Industrial Age, humans began emitting much more carbon dioxide, diluting the amount of radiocarbon in the atmosphere. Nuclear testing affects radiocarbon levels, too, and dramatically increased carbon-14 levels starting in the 1950s. Modern statistical methods and updated databases allow scientists to take humans' effects on Earth's atmosphere into account. (See how radiocarbon dating helped researchers determine when this ship sank.)

Radiocarbon dating isn't a silver bullet: Context is everything, and it can be hard to determine if there's a temporal relationship between two objects at an archaeological site. But it's the most accurate dating tool at archaeologists' disposal, thanks to carbon-14's predictable disappearing act.

HOW CARBON-14 CAN HELP STOP ELEPHANT POACHERS
Scientists are turning to radiocarbon analysis to monitor when ivory was poached.

Questions:

1. Write out the decay of carbon-14 by beta emission.

2. Discuss several ways that carbon-14 is collected into any living thing. (How does carbon enter any organisms?) Because these processes cease to occur once an organism dies, this is why we can use the amount of carbon-14 in an organism to estimate how long ago they passed away.

3. Describe at least 3 limitations to using carbon-14 dating.

4. According to the Article, what is the half-life of carbon-14?

5. If 3 half-lives have occurred, how many years have passed? SHOW WORK!

6. Answer the following showing all work.
   a. If a panda died 45,840 years ago, how many half lives have occured?

   b. If this panda had 20 grams of carbon-14 originally, how much of ^{14}C remains currently? (Divide the initial mass in half, the number of half lives that have occurred).

7. A tree falls that has 160 grams of carbon-14. Show all work
   a. How many half-lives occurred if only 5 grams of carbon-14 remains? (Cut the initial amount by half until you get to the final amount).

   b. Calculate how many years in total have taken place (multiply the number of half-lives that have occurred by carbon-14's half life).

Chemistry

Module 2: Periodic Table and Quantum Mechanics

1. Activity 1: Stalk-Eyed Serotonin

2. Activity 2: Periodic Table’s Final Four

Name____________________

DATA Nugget

How do brain chemicals influence who wins a fight?

Featured scientists: Andrew Bubak and John Swallow from the University of Colorado at Denver, and Kenneth Renner from the University of South Dakota

Research Background:

In nature, animals compete for resources. These resources include space, food, and mates. Animals use aggression as a way to capture or defend these resources, which can improve their chances of survival and mating. **Aggression** is a forceful behavior meant to overpower opponents that are competing for the same resource. The outcome (victory or defeat) depends on several factors. In insects, the bigger individuals often win. However, if two opponents are the same size, other factors can influence outcomes. For example, an individual with more experience may defeat an individual with less experience. Also individuals that are fighting to gain something necessary for their survival have a strong drive, or motivation, to defeat other individuals.

Researchers Andrew, Ken, and John study what role an animal's brain plays in regulating behavior when motivation is present. They wanted to know if specific chemicals in the brain influenced the outcome of a physically aggressive competition. Andrew, Ken, and John read a lot papers written by other scientists and learned that there is a brain chemical that plays an important role in regulating aggressive behavior. This chemical is called **serotonin** and is found in the brains of all animals, including humans. Even a small amount of this chemical can make a big impact on aggressive behavior, and perhaps the outcome of competition.

Picture 1. Two stalk-eyed flies rearing/extending forearms in battle. Photo credit: Sam Cotton.

Name____________________

Picture 2. A male stalk-eyed fly compared to the size of a dime. Photo credit: Andrew Bubak, June 2016.

The researchers decided to do an experiment to test what happens to aggression during competition as serotonin levels in the brain increase. They used stalk-eyed flies in their experiment. Stalk-eyed flies have eyes on the ends of stalks that stick out from the sides of their heads (Pictures 1 & 2). They reasoned that brain serotonin levels in stalk-eyed flies influence their aggressive behaviors in battle and therefore impact the outcome of competition. If their hypothesis is true, they predicted that increasing the brain serotonin in a stalk-eyed fly would make it more likely to use aggressive behaviors, and flies that used more aggressive behaviors would be more likely to win. Battling flies use high-intensity aggressive attacks like jumping on or striking an opponent. They also use less aggressive behaviors like flexing their front legs or rearing up on their hind legs.

To test their hypothesis, the researchers set up a fair test. A **fair test** is a way to control an experiment by only changing one piece of the experiment at a time. By changing only one variable, scientists can determine if that change caused the differences they see. Since larger flies tend to win fights, the flies were all matched up with another fly that was the same size. This acted as an experimental control for size, and made it possible to look at only the impact of serotonin levels on aggression. The scientists also controlled for the age of the flies and made sure they had a similar environment since the time they were born. The experiment had 20 trials with a different pair of flies in each. In each trial, one fly received corn mixed with a dose of serotonin, while another fly received plain corn as a control. That way, both flies received corn to eat, but only one received serotonin.

Each pair of flies was placed in a fighting arena and starved for 12 hours to increase their motivation to fight over food. Next, food was placed in the center of the arena, but only enough for one fly! The researchers observed the flies, recording three types of behaviors for each opponent. High intensity behaviors were when the fighting flies touched one another. Low-intensity behaviors were when the flies did not touch each other, for example jump attacks, swipes, and lunges. The last behavior type was retreating from the fight. Flies that retreated fewer times than their opponent were declared the winners. After the battles, the researchers collected the brains of the flies and measured the concentration of serotonin in each fly's brain.

Scientific Question: How does serotonin level affect aggressive behavior and, therefore, the probability of winning against an opponent of similar size?

What is the hypothesis? Find the hypothesis in the Research Background and underline it. A hypothesis is a proposed explanation for an observation, which can then be tested with experimentation or other types of studies.

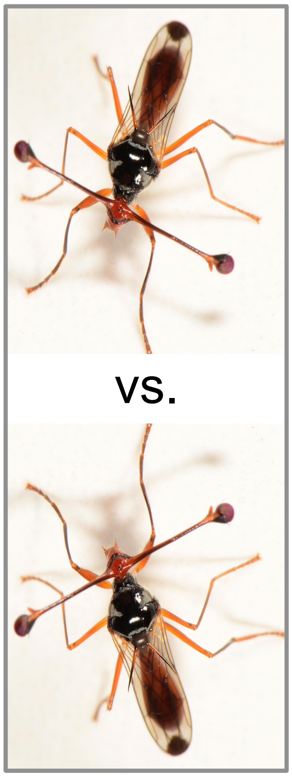
Name____________________

Scientific Data:

Use the data in the following two tables to answer the scientific question:

Table 1. Serotonin Levels vs. Outcomes of Stalk-Eyed Flies

	Serotonin Levels (concentration measured in picograms of serotonin per microgram of brain matter [pg/μg])	
Battle Number	Winner (pg/μg)	Loser (pg/μg)
Battle 1	62	45
Battle 2	190	38
Battle 3	34	113
Battle 4	57	24
Battle 5	99	59
Battle 6	23	32
Battle 7	139	21
Battle 8	67	16
Battle 9	80	26
Battle 10	121	26
Battle 11	42	15
Battle 12	49	22
Battle 13	19	16
Battle 14	69	29
Battle 15	75	24
Battle 16	89	21
Battle 17	46	38
Battle 18	97	36
Battle 19	151	24
Battle 20	21	106
Average serotonin level (pg/ug)		



The units used by the researchers are picograms (pg) and micrograms (μg). A picogram is one-trillionth ($1/10^{12}$) of a gram and a microgram is one-millionth ($1/10^{6}$) of a gram. The level of serotonin found in the brain is given using the ratio of serotonin measured in picograms to brain matter in micrograms.

Name____________________

Table 2. Stalk-Eyed Fly Behaviors vs. Outcomes In Battle

Observed Behaviors In Battle	How many winners did this?	How many losers did this?
High-Intensity	16	5
Swipe/lunge	11	4
Jump Attack	11	2
Retreats	2	20

High-intensity behaviors include any behavior where the flies came in contact with each other. Low-intensity behaviors included swipe/lunge and jump attacks.

Data for serotonin levels of the winners and losers are listed in Table 1. As mentioned before, the researchers fed one of the two stalk-eyed flies serotonin-rich food before each trial. They did this to make sure the difference in serotonin between the two flies was high enough to be measured and have an effect on behavior. However, there were times where the natural level of serotonin in the control fly was higher than that of the treated fly. Therefore, the data in Table 1 compares serotonin levels for winners and losers, but does NOT identify whether a fly was treated or not. Table 2 shows frequencies of behaviors compared to outcome.

What data will you graph to answer the question?

Table 1:

Independent variable: ________________________________

Dependent variable: ________________________________

Table 2:

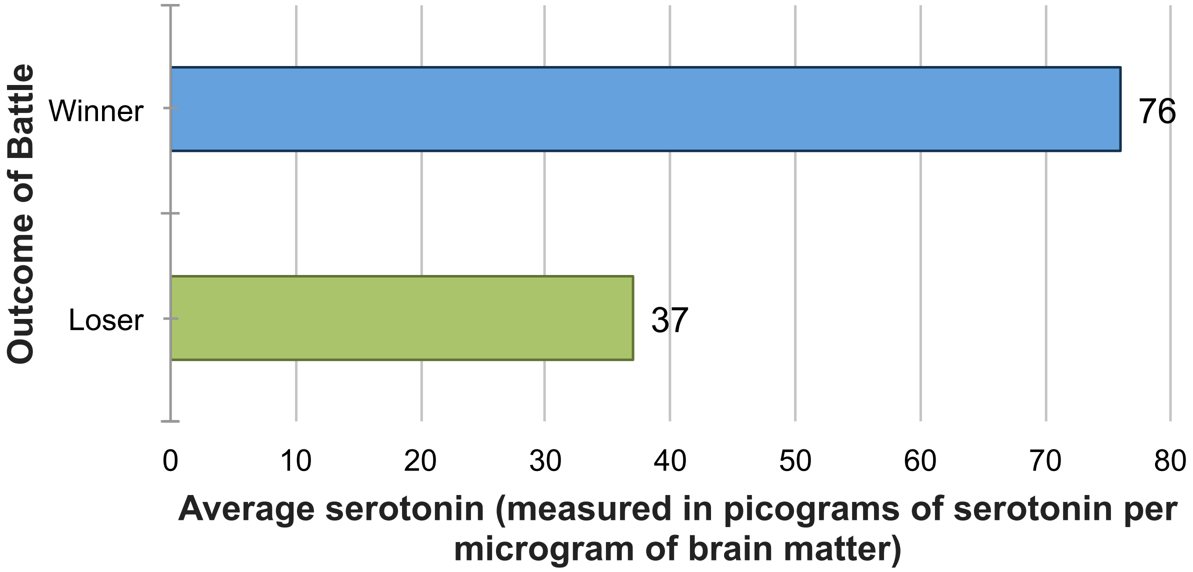
Independent variable: ________________________________

Dependent variable: ________________________________

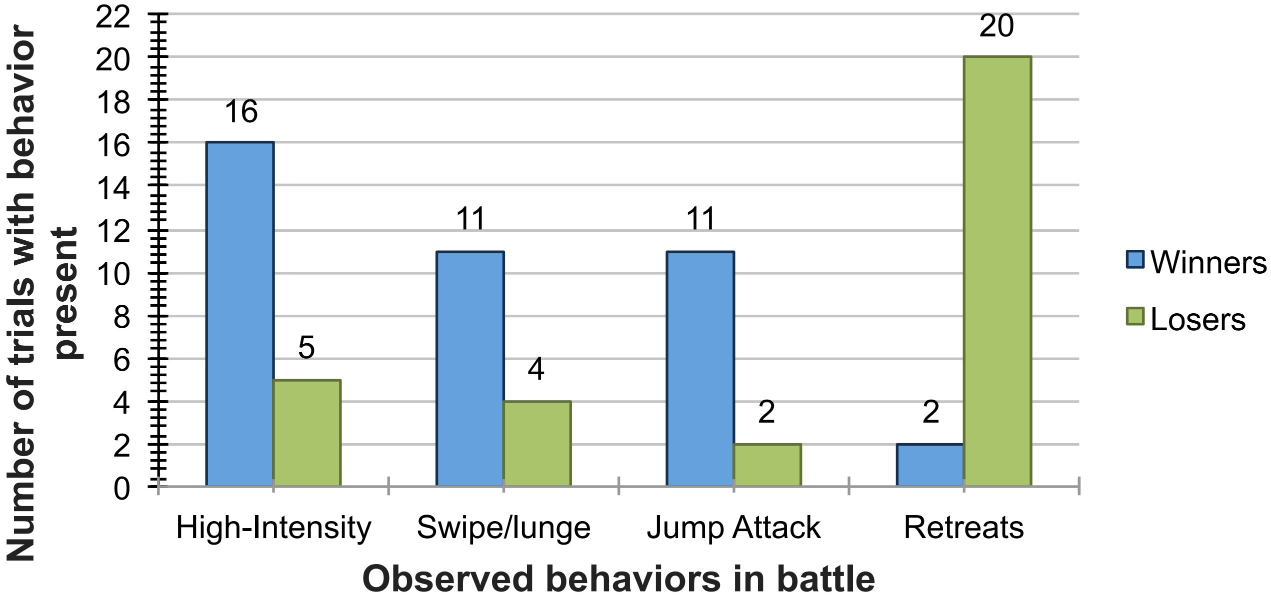
Name____________________

<u>Below are graphs of the data from Table 1 and Table 2</u>: Identify any changes, trends, or differences you see in your graphs. Draw arrows pointing out what you see, and write one sentence describing what you see next to each arrow.

Graph 1. Average Serotonin Levels vs. Outcomes of Battles



Graph 2. Frequencies of Behavior Types By Outcome of Battles



Name____________________

Interpret the data:

Make a claim that answers the scientific question.

What evidence was used to write your claim? Reference specific parts of the tables or graphs.

Explain your reasoning and why the evidence supports your claim. Connect the data back to what you learned about how brain chemicals influence animal behavior.

Name____________________

Did the data support Andrew, Ken, and John’s hypothesis? Use evidence to explain why or why not. If you feel the data were inconclusive, explain why.

Your next steps as a scientist: Science is an ongoing process. What new question(s) should be investigated to build on Andrew, Ken, and John’s research? What future data should be collected to answer your question(s)?

8. If a paleontologist finds 17 grams of carbon-14 in a 22,920 year old whale fossil in the Appalachian mountains. How much carbon-14 was in the whale when it passed away. Show all work
    a. Calculate how many half-lives have occurred first.
    b. Find the amount of ^{14}C (double the amount, the number of half lives that you calculated).

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: ___________________________________

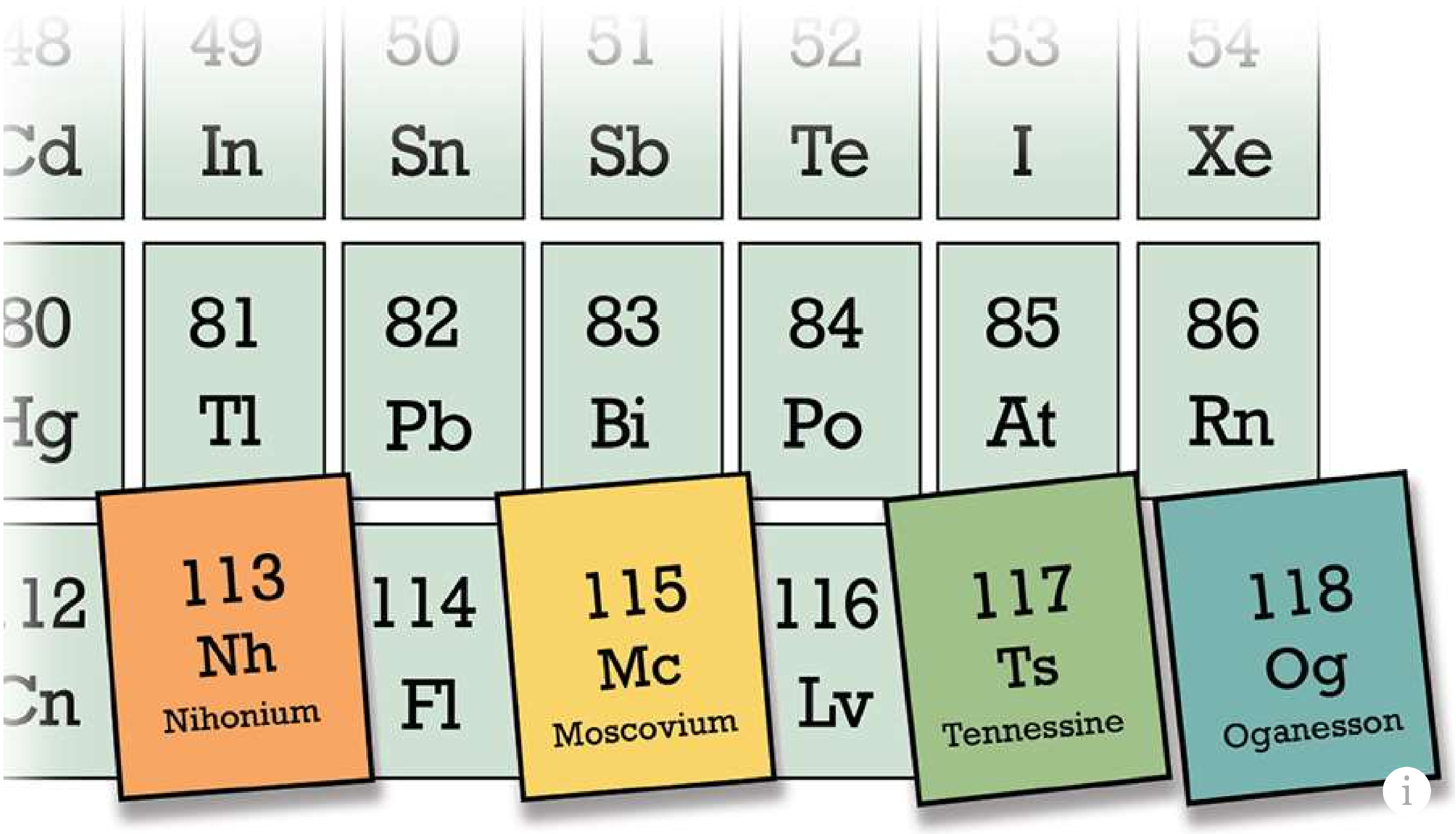
Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports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

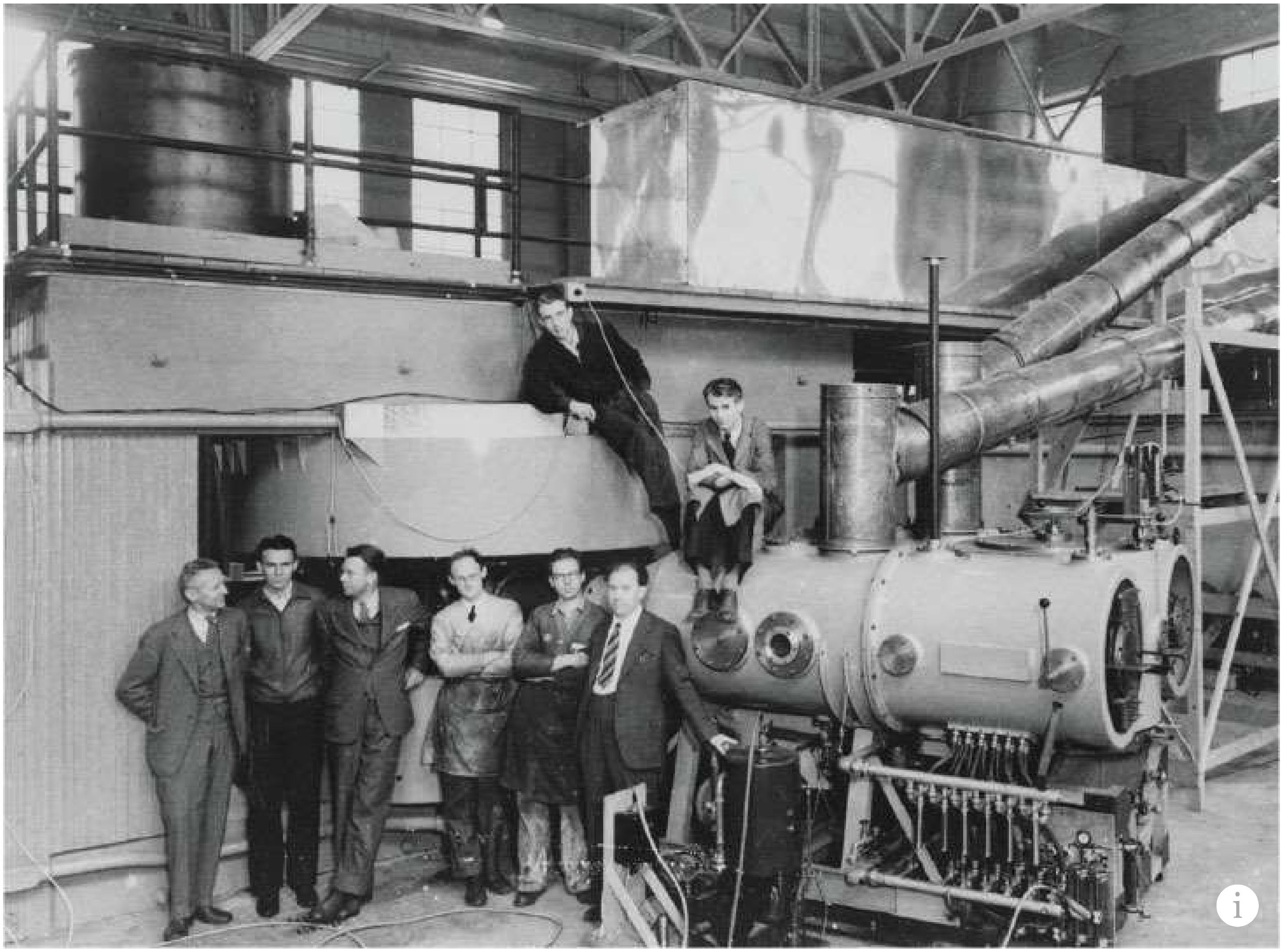
The tricky part of this process is overcoming the strong repulsive forces between positively charged alpha particles and proton-packed, positively charged nuclei of plutonium. Overcoming these forces requires a lot of energy.

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.

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

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:

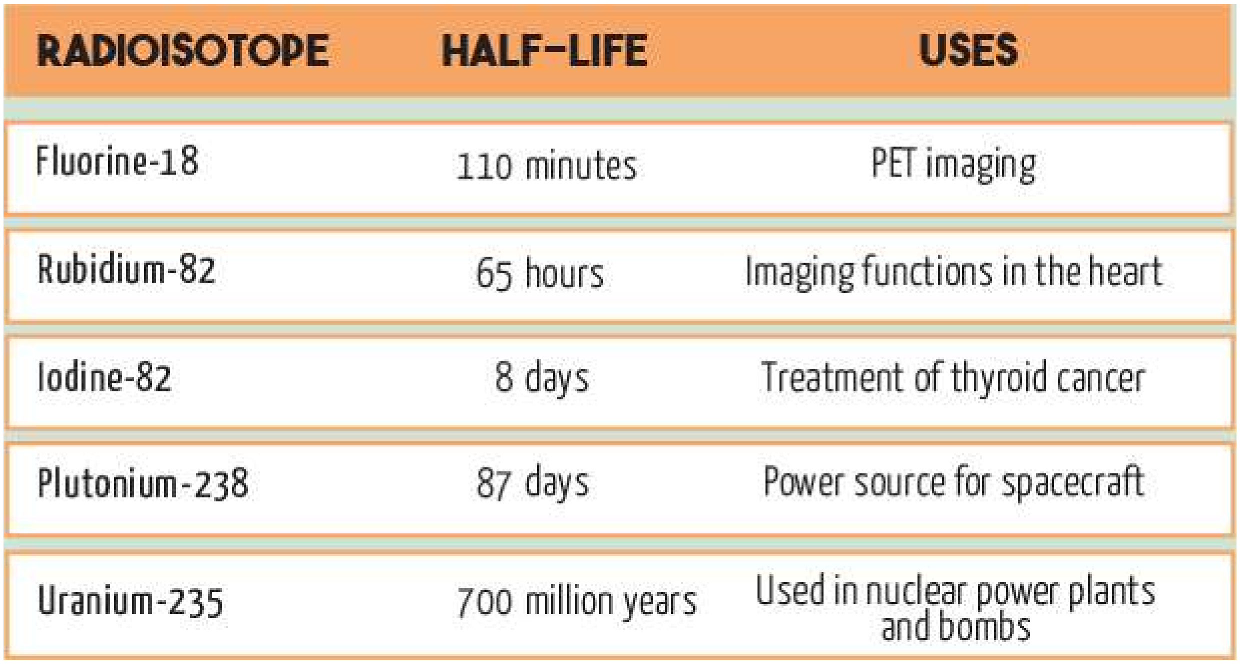
» Some radioisotopes are absorbed more easily by cancer cells than by healthy cells. They can be used to destroy cancer cells, leaving healthy cells unharmed.

» 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.

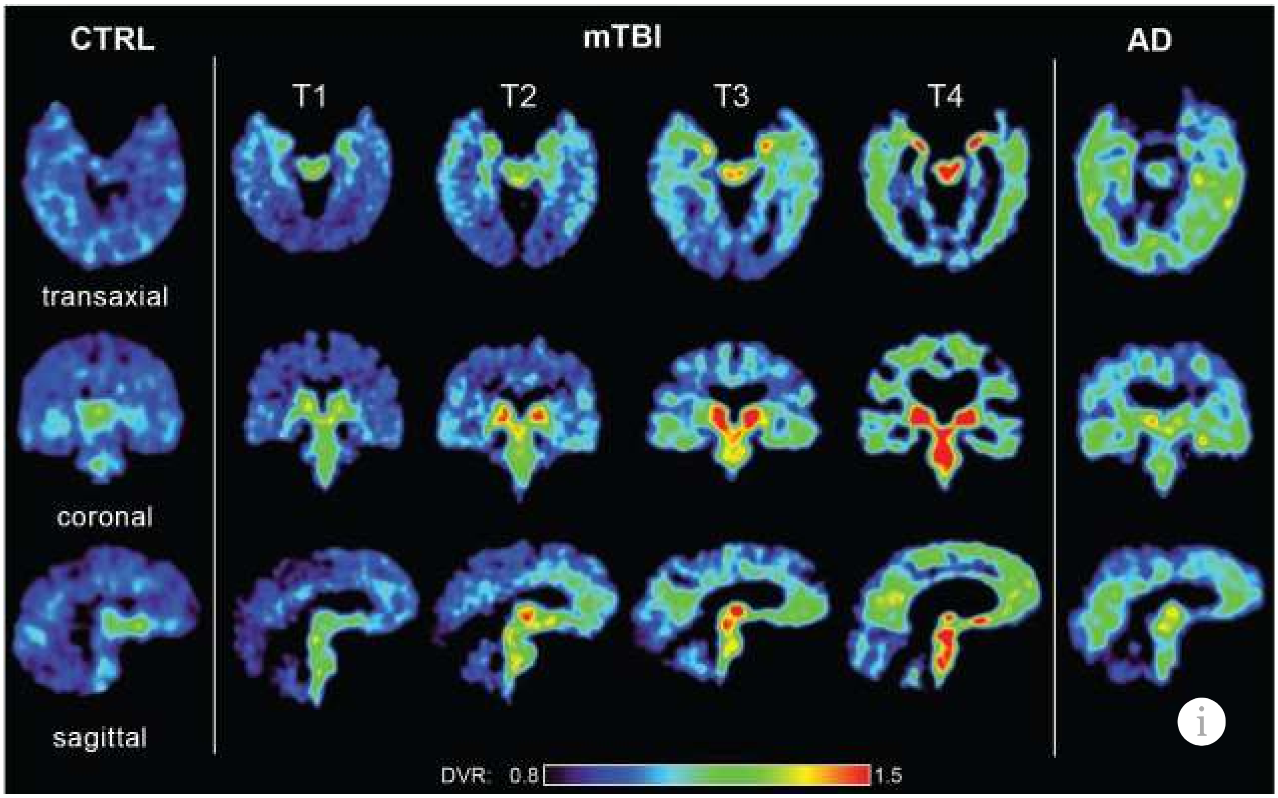
» Some radioisotopes emit types of radiation that readily escape the body. These do relatively little damage inside the patient, and can be detected to create images. The images help physicians diagnose diseases.

» 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.

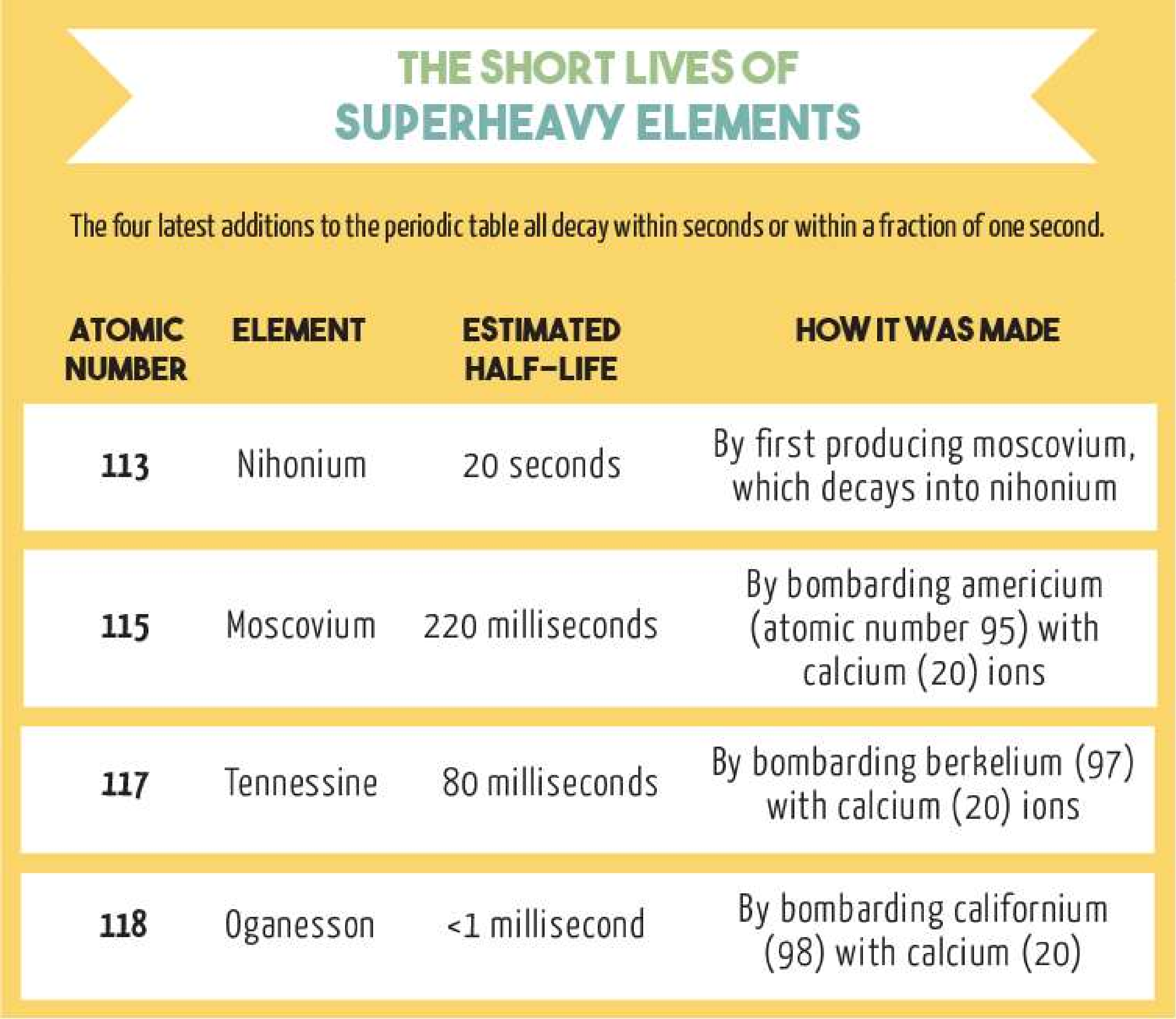
To address these disputes and the confusion they caused, IUPAC intervened. In 1969, the organization, which was established in 1919 to set international standards in chemistry, declared that making a claim and publishing a new element name wasn't going to cut it anymore.

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

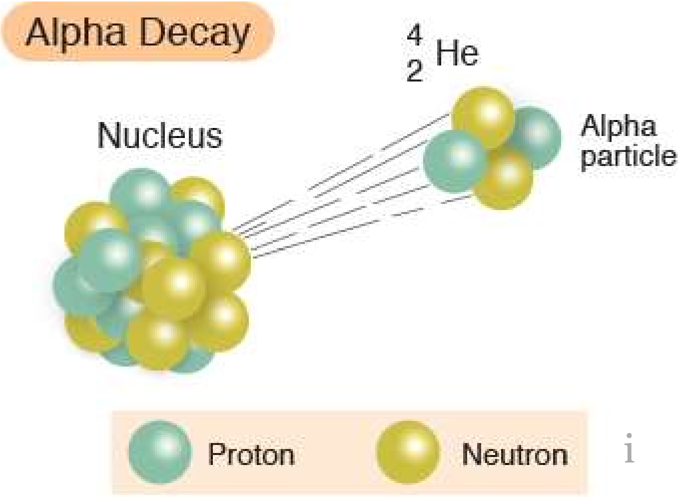
The four latest additions to the periodic table all decay within seconds or within a fraction of one second.

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.

Chemistry

Module 3: Bonding and Nomenclature

1. Activity 1: Life on Mars
2. Activity 2: Write Stuff

Name___________________

DATA Nugget

Alien life on Mars - caught in crystals?

Featured scientists: Charles Cockell, UK Centre for Astrobiology, University of Edinburgh, & Nikki Chambers, Astrobiology Teacher, West High School, Torrance, CA

Research Background:

Is there life on other planets besides Earth? This question is not just for science fiction. Scientists are actively exploring the possibility of life beyond Earth. The field of **astrobiology** seeks to understand how life in the universe began and evolved, and whether life exists elsewhere. Our own solar system contains a variety of planets and moons. In recent years scientists have also discovered thousands of planets around stars other than our Sun. So far, none of these places are exactly like Earth. Many planets have environments that would be very difficult for life as we know it to survive. However, there are life forms that exist in extreme environments that we can learn from. On Earth there are extremely hot or acidic environments like volcanic hot springs. Organisms also live in extremely cold places like Antarctic glacier ice. Environments with extremely high pressure, like hydrothermal vents on the ocean floor, also support life. If life can inhabit these extreme environments here on Earth, might extreme life forms exist elsewhere in the universe as well?


A view of the astrobiology lab.

Charles is an astrobiologist from Great Britain who is interested in finding life on other planets. The list of places that we might look for life grows longer every day. Charles thinks that a good place to start is right next door, on our neighboring planet, Mars. We know that Mars currently is cold, dry, and has a very thin atmosphere. Charles is curious to know whether there might still be places on Mars where life could exist, despite its extreme conditions. While there is no liquid water on the surface of Mars anymore, Mars once had a saltwater ocean covering much of its surface. The conditions on Mars used to be much more like Earth. Liquid water is essential for life as we know it. If there are places on Mars that still hold water, these could be great places to look for evidence of life. Charles thought that perhaps salt crystals, formed when these Martian oceans were evaporating, could trap pockets of liquid water.

Charles and his fellow researcher Nikki knew that there are a number of kinds of salts found in Martian soils, including chlorides, sulfates, perchlorates and others. They wanted to test their idea that water could get trapped when saltwater with these salts evaporate. They decided to compare the rate of evaporation for solutions with **magnesium sulfate** ($MgSO_4$) with another common salt solution: **sodium chloride**, or table salt (NaCl). They chose to investigate these two salts because they are less toxic to life as we know it than many of the other chloride, perchlorate, or sulfate salts. Also, from reading the work of other scientists, Charles knows the Martian surface is particularly rich in magnesium sulfate.

Charles and Nikki measured precise quantities of saturated solutions of magnesium sulfate and sodium chloride and placed them into small containers. Plain water was used as a control. There were three replicate containers for each treatment – nine containers in total. They left the containers open to evaporate and recorded their mass daily. They kept collecting data until the mass stopped changing. At this point all of the liquid had evaporated or a salt crust had formed that was impermeable to evaporation. They then compared the final mass of the control containers to the other solutions. They also checked the resulting crusts for the presence or absence of permanent **water-containing pockets**. Charles and Nikki used these data to determine if either salt makes crystals that can trap water in pockets when it evaporates.

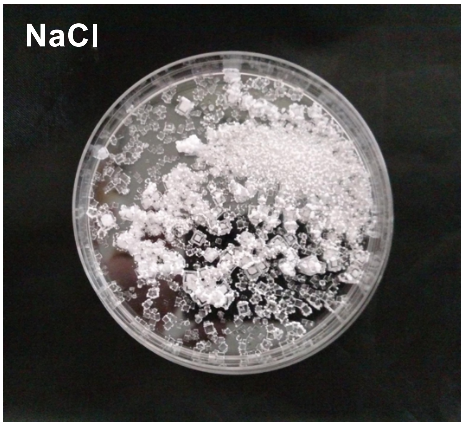
Scientific Question: Do pockets of liquid water form when a salt solution evaporates?

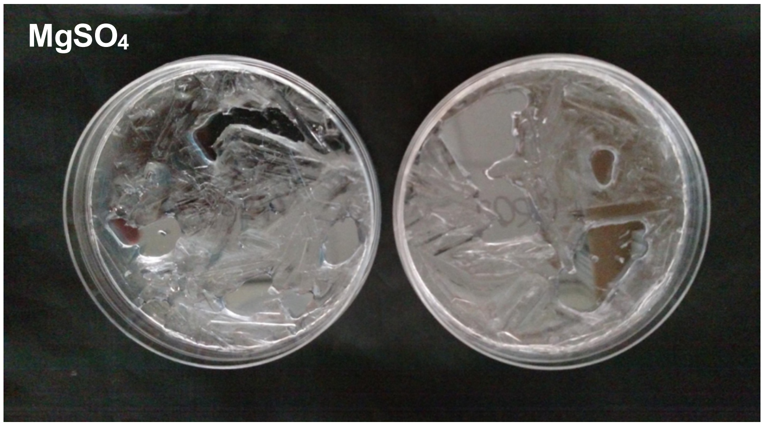
What is the hypothesis? Find the hypothesis in the Research Background and underline it. A hypothesis is a proposed explanation for an observation, which can then be tested with experimentation or other types of studies.

Scientific Data:

Use the images and data table below to answer the scientific question:

LEFT: Sodium chloride crystals, Day 14; little mass change due to evaporation observed. No liquid water is visible.
RIGHT: Magnesium sulfate crystals, Day 14; no further mass change due to evaporation observed. Liquid water is visible in pockets throughout the crystals.





Name___________________

		Control	NaCl	MgSO4
Date	Day	Average mass of container + water (g)	Average mass of container + NaCl (g)	Average mass of container + MgSO4 (g)
7/14/2017	1	26.27	29.96	31.45
7/15/2017	2	23.31	28.50	29.00
7/16/2017	3	21.74	27.79	27.72
7/17/2017	4	19.37	26.51	25.90
7/18/2017	5	17.51	25.62	24.73
7/19/2017	6	15.90	24.91	24.45
7/20/2017	7	14.37	24.32	23.75
7/21/2017	8	12.29	23.10	23.54
7/22/2017	9	10.32	22.18	23.40
7/23/2017	10	8.99	21.62	23.42
7/24/2017	11	7.64	20.99	23.37
7/25/2017	12	6.45	20.03	23.36
7/26/2017	13	6.45	19.18	23.36
7/27/2017	14	6.45	18.45	23.36
7/28/2017	15	6.45	18.37	23.36
7/29/2017	16	6.45	18.36	23.36
**the mass of the containers used = 6.45g*				

What data will you graph to answer the question?

Independent variable(s): ____

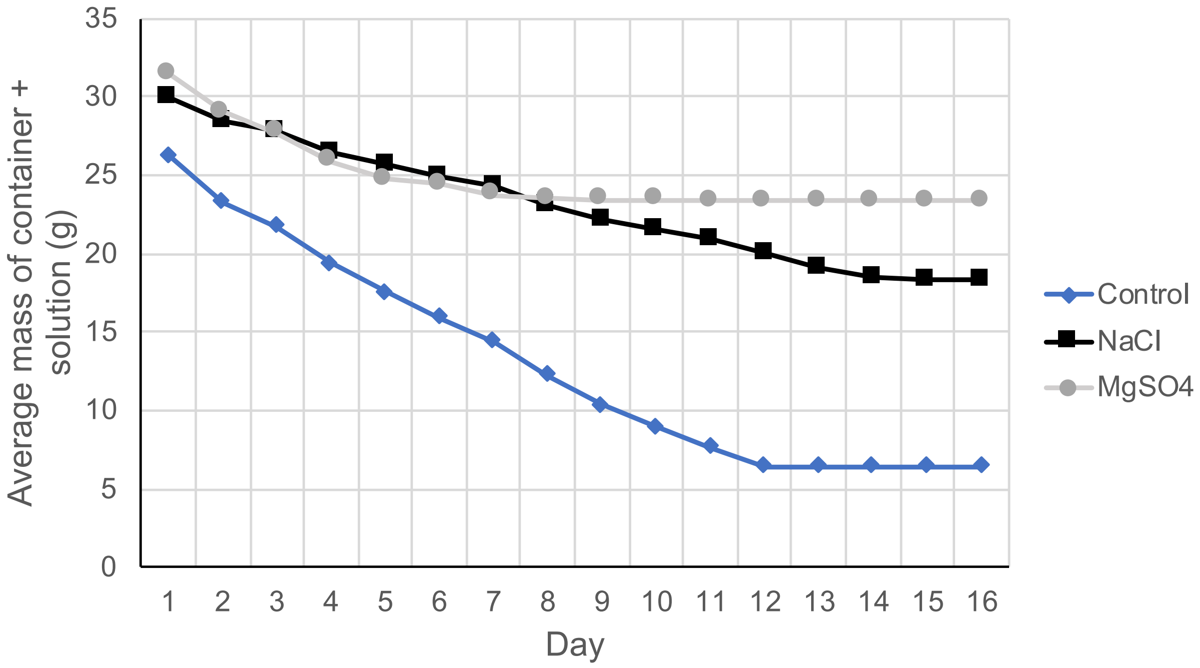
____

Dependent variable(s): ____

____

Name____________________

Below is a graph of the data: Identify any changes, trends, or differences you see in your graph. Draw arrows pointing out what you see, and write one sentence describing what you see next to each arrow.



Interpret the data:

Make a claim that answers the scientific question.

What evidence was used to write your claim? Reference specific parts of the table, images, or graph.

Name__________________

Explain your reasoning and why the evidence supports your claim. Connect the data back to what you learned about the conditions on Mars and whether these results indicate that life on Mars may be possible.

Did the data support Charles and Nikki's hypothesis? Use evidence to explain why or why not. If you feel the data was inconclusive, explain why.

Your next steps as a scientist: Science is an ongoing process. What new question do you think should be investigated? What future data should be collected to answer your question?

Module 3: Bonding and Nomenclature

Name: ______________________________

Student Instructions

CHEM1.PS1.13 Use the periodic table and electronegativity differences of elements to predict the types of bonds that are formed between atoms during chemical reactions and write the names of chemical compounds, including polyatomic ions using the IUPAC criteria.
CHEM1.PS2.1 Draw, identify, and contrast graphical representations of chemical bonds (ionic, covalent, and metallic) based on chemical formulas. Construct and communicate explanations to show that atoms combine by transferring or sharing electrons.
CHEM1.PS1.14 Use Lewis dot structures and electronegativity differences to predict the polarities of simple molecules (linear, bent, triangular, tetrahedral). Construct an argument to explain how electronegativity affects the shape of basic chemical molecules.
CHEM1.PS2.2 Understand that intermolecular forces created by the unequal distribution of charge result in varying degrees of attraction between molecules. Compare and contrast the intermolecular forces (hydrogen bonding, dipole-dipole bonding, and London dispersion forces) within different types of simple substances (only those following the octet rule) and predict and explain their effect on chemical and physical properties of those substances using models or graphical representation.

Directions:

1. **BEFORE reading the article** complete the "Me" column of the Anticipation Guide.

2. Read the article "The Write Stuff: The Fascinating Chemistry of Pencils".

3. Complete the Anticipation Guide, Graphic Organizer, and Student Reading Comprehension Questions.

4. Research each of the following questions. **If Internet access is unavailable,** you may skip these questions.

    a. Why is it called "lead" if pencils don't contain the element lead?
    b. Of what are colored pencils made? How are they made?
    c. How do they get the pencil lead into the center of the wooden pencil?
    https://www.youtube.com/watch?v=zZHp1fGdAWE
    d. Can you get lead poisoning from a pencil? Why or why not?
    e. The article states that the typical pencil mark on a piece of paper has a height of around 20 nm, which is 60 atoms thick? Assuming the atoms don't overlap, calculate the diameter of each atom.
    f. Discuss why graphite conducts electricity.

Anticipation Guide

Name ______________________________

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Me	**Text**	**Statement**
		1. Pencils do not contain lead.
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		4. The metal ring that holds the eraser on a pencil is made of iron.
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		8. The first electronic grading machines depended on the electrical conductivity of graphite to score tests.
		9. Pink erasers contain volcanic pumice to act as an abrasive.
		10. Particles of graphite are removed by rubber erasers in a chemical process.

The Write Stuff: The Fascinating Chemistry of Pencils

By Brian Rohrig

SHUTTERSTOCK

IN MOST CLASSES, IF A STUDENT RAISED HIS HAND AND ASKED TO USE THE PENCIL SHARPENER BECAUSE THE LEAD IN HIS OR HER PENCIL HAD BROKEN, this comment would not draw much attention. But if this request occurred **in a chemistry class**, a likely response from the teacher would be, ***"Pencils don't contain lead!"*** Yes, it's true—there is no lead in your pencil.

What is commonly referred to as pencil "lead" is actually graphite, which is a form of carbon. So if you accidentally impale yourself with the sharpened end of a pencil, you don't need to worry about lead poisoning.

The earliest writing utensils were made of lead—the ancient Romans used a lead stylus to make markings on papyrus. But the mark left by lead is rather light, so eventually lead was mixed with other metals, such as tin, to make alloys, which tended to leave a darker mark. The use of graphite for a writing instrument came about as a result of serendipity—a fortunate accident. In the 1500s in Borrowdale, England, a severe storm uprooted a large oak tree. Its roots had large chunks of a dark substance, and it was determined the tree was over a huge deposit of pure graphite. The locals soon discovered that this mysterious new substance could be used to make very dark marks on a variety of substances. At first it was used to mark their sheep. Eventually it was used to write on paper. Even though graphite was known before this discovery, it was rare and not widely used. With this discovery, its use as a writing instrument flourished.

About 14 billion pencils are produced annually, with 2 billion of these produced in the United States.

Graphite

Graphite looks so much like lead that it was originally called *plumbago*, which in Latin means "lead ore." But in 1778, Carl Wilhelm Scheele proved plumbago is actually carbon. Abraham Gottlob Werner gave plumbago its modern name graphite, from the German word "to write," in 1789. But since lead does resemble graphite, the name in the context of pencils stuck.

Both lead and graphite have a silvery-gray appearance, are good conductors, and are relatively soft. But lead has a density of 11.3 gram per milliliter (g/mL), while graphite has a density of 2.3 g/mL. If you pick up a similarly sized chunk of each, the lead would be noticeably heavier. But the biggest difference is that graphite leaves a very dark mark on a variety of substances.

The earliest pencils were thick slabs of graphite, dug up from the ground and used in their unaltered form. As technology progressed, they were manufactured into thinner rods, but they were hard to hold. Originally, they were wrapped in string. Sometime around the late 1500s, perhaps tiring of getting their hands black, someone came up with the idea of sandwiching the graphite between two pieces of wood. Thus the modern pencil was born, which has always been lead-free.

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A typical pencil mark on a piece of paper has a height of around 20 nanometers, which is 60 atoms thick.

The substance rubber gets its name for its ability to effectively rub out pencil marks.

The mark graphite leaves is easily smudged, since it is a very soft material. It wasn’t until 1790 that clay was added to graphite to make it harder. **When pencils are made, clay and graphite are ground into powder and then water is added, which forms a gray sludge.** After intense heating in a kiln, the final graphite product is formed. Since a harder pencil does not leave as much graphite behind, the mark is lighter. The most popular grade is the ubiquitous No. 2 pencil, which is still fairly dark, but durable enough that the "lead" doesn’t break easily.

Graphite is an allotrope of carbon. An allotrope is a different form of the same element due to a different arrangement of its bonds. Other allotropes of carbon include diamonds and buckminsterfullerene (commonly known as the buckyball). Each carbon atom in graphite covalently bonds with three other carbon atoms, forming layers of very thin sheets of rings (Fig. 1). These thin sheets are attracted to one another by London dispersion forces. Between these sheets of atoms are a vast number of delocalized electrons—electrons that are not tightly bound to any specific atom. The sheets can slide easily, which is why graphite is soft and slippery to touch. When force is applied to your pencil as you write, the graphite layers slide off in flakes and stick to the paper.

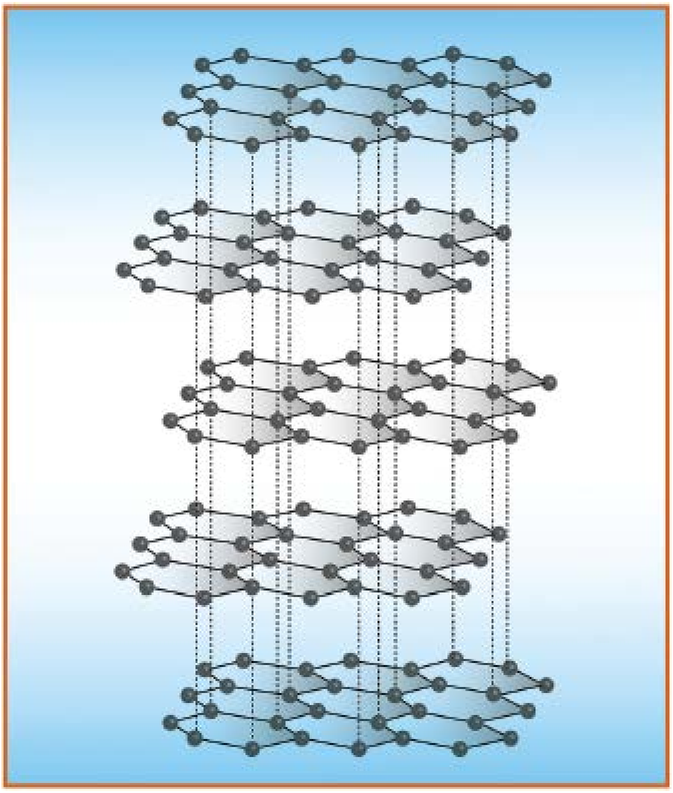

Figure 1. In graphite, carbons (black) form a two-dimensional sheet in ring formations. These sheets are attracted to each other, but not chemically bonded, and justify graphite’s brittle property.
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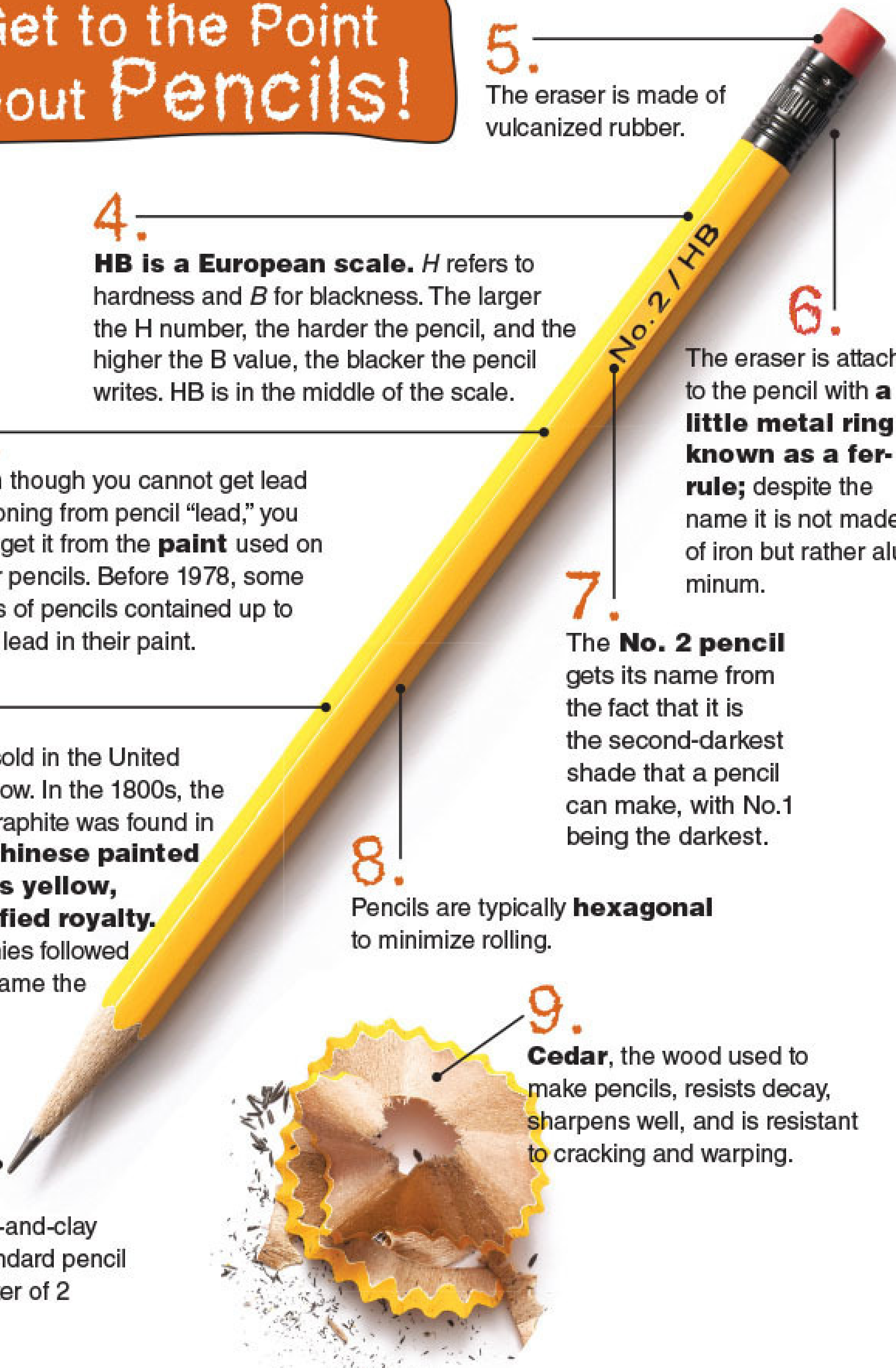
Get to the Point About Pencils!



1.

The graphite-and-clay core in a standard pencil has a diameter of 2 millimeters.

2.

Most pencils sold in the United States are yellow. In the 1800s, the world's best graphite was found in China. **The Chinese painted their pencils yellow, which signified royalty.** Other companies followed suit and it became the standard.

3.

Even though you cannot get lead poisoning from pencil "lead," you may get it from the **paint** used on older pencils. Before 1978, some types of pencils contained up to 12% lead in their paint.

4.

HB is a European scale. *H* refers to hardness and *B* for blackness. The larger the H number, the harder the pencil, and the higher the B value, the blacker the pencil writes. HB is in the middle of the scale.

5.

The eraser is made of vulcanized rubber.

6.

The eraser is attache to the pencil with **a little metal ring known as a ferrule;** despite the name it is not made of iron but rather aluminum.

7.

The **No. 2 pencil** gets its name from the fact that it is the second-darkest shade that a pencil can make, with No.1 being the darkest.

8.

Pencils are typically **hexagonal** to minimize rolling.

9.

Cedar, the wood used to make pencils, resists decay, sharpens well, and is resistant to cracking and warping.

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As you write or draw, flakes from the graphite-and-clay mix that make up your pencil’s "lead" cling to the cellulose fibers that make up your piece of paper. The fibers have a huge surface area that catches lots of flakes. Since graphite and cellulose are both nonpolar, the flakes attract to the paper via London dispersion forces.

The average pencil contains enough graphite to make a line approximately 35 miles long.

The eraser

If you make a mistake while using a pencil and you don’t have an eraser, a piece of bread will work. Indeed, using bread was the preferred method for erasing marks made with graphite for many years; some artists still use bread today to lighten pencil lines to achieve a desired effect. **It is reported that in 1770 the English engineer Edward Nairne accidentally picked up a wad of rubber instead of a piece of bread to erase a mark and found that it worked quite well.**

Once Charles Goodyear discovered the vulcanization process for rubber in 1844, the use of rubber in erasers became widespread. **Vulcanization involves adding sulfur to natural rubber (made of polymer chains) and heating it. The heat causes many crosslinkages between the polymer chains to form and creates a durable form of rubber.** The eraser attached to most pencils is made from rubber, but erasers can also be made of plastic or vinyl. Gum erasers, favored by artists, are made of a softer type of rubber. Often there is an abrasive substance added to aid in the erasing process. **The iconic Pink Pearl erasers contain volcanic pumice, which has abrasive properties.**

Erasers work by physically removing graphite particles from the paper. Both rubber and graphite are nonpolar substances, so there is a mutual attraction involving London dispersion forces. Paper is made of cellulose, which is also nonpolar, so only weak forces act to bind the graphite particles to the paper. However, the forces between the rubber eraser and graphite particles are stronger than those between the graphite and the paper.

If your eraser has been around awhile, you may have noticed that it doesn’t work well, if at all. Over time, rubber erasers get hard and brittle, and they tend to do more smearing than erasing. This degradation is due to oxidation of the rubber. Ultraviolet light, ozone, and oxygen can all act as oxidizing agents. Oxidation tends to break up the long polymer chains and create more cross-linkages, which makes the rubber harder and less flexible.

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The pencil is a marvel of chemistry and engineering—simple yet exquisite. Even though the pencil has undergone many incarnations in its history, it is still one of the most economical ways to write. So the next time you use a pencil, take a moment to marvel at the amazing cellulose-encased cylindrical piece of graphite that can so wondrously transcribe your thoughts. And they don’t even require batteries.


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The first electronic grading machines detected the electrical conductivity (graphite conducts) of the choices that were penciled in by running wire feelers along the paper as it was graded. Today's computerized image sensors can detect any type of graphite pencil, but perhaps that high-stakes exam is not the time to test its limits!

Brian Rohrig is a science writer who lives in Columbus, Ohio. His most recent *ChemMatters* article, "Chemistry Rocks!," appeared in the October 2017 issue.

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Graphic Organizer

Name: ______________________________

Directions: **Directions**: ***As you read***, complete the graphic organizer below to describe what you learned about the chemistry of all parts of pencils.

Pencil part	***What it is made of***	***The chemistry of how it works***
Pencil core ("lead")		
Painted part		
Metal holding eraser		
Eraser		

Summary: On the back of this paper, write a one-sentence summary (20 words or less) of the article.

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Student Reading Comprehension Questions

Directions: Use the article to answer the questions below.

____
Name

1. What is the material used in a pencil lead?

2. In ancient writing utensils, what element was mixed with lead to form an alloy making darker marks?

3. Explain the circumstances of when and how the lead in pencils was replaced.

4. In the table below, list and compare/contrast four properties of lead and graphite.

Property	Lead	Graphite

5. Why is clay added to most pencil leads?

6. What is an allotrope? Explain the reason for differences between allotropes.

Student Reading Comprehension Questions, cont.

7. Explain why graphite is soft and slippery to the touch.

8. Why are most pencils sold in the U.S. yellow in color?

9. How does pencil lead cling to paper?

10. What happens to rubber when it is vulcanized?

11. How do pencil erasers work to remove marks?

12. Why do rubber pencil erasers get hard and brittle over time and not work well?