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.

"The Write Stuff: The Fascinating Chemistry of Pencils" *ChemMatters*, December 2017/January 2018 Issue

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. Pencils do not contain lead.
		2. A mark from graphite is lighter than a mark from lead.
		3. Today's pencils write with a mixture of carbon and clay.
		4. The metal ring that holds the eraser on a pencil is made of iron.
		5. Graphite forms thin sheets that slide off and stick to paper.
		6. Graphite and the cellulose in paper are both nonpolar.
		7. Some erasers are made of plastic or vinyl.
		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.

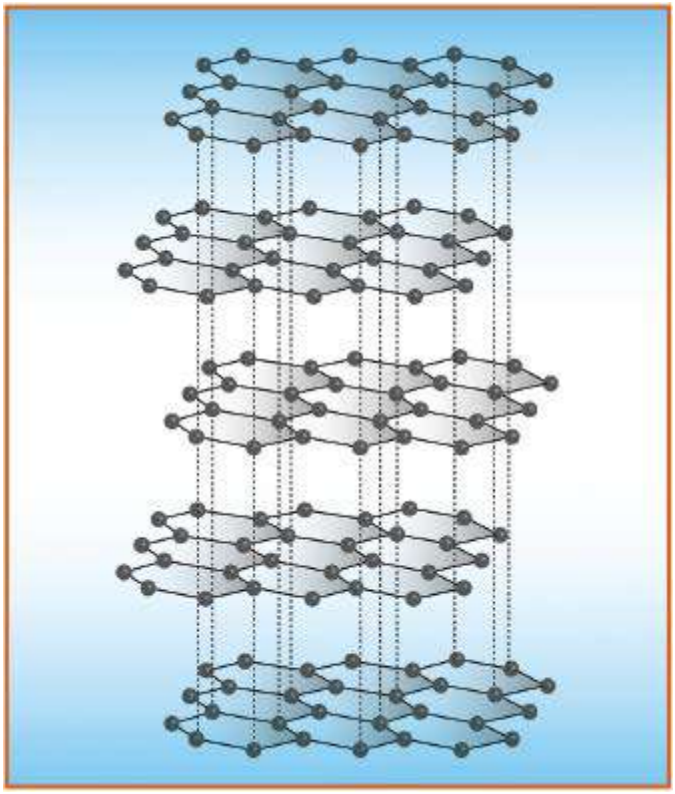
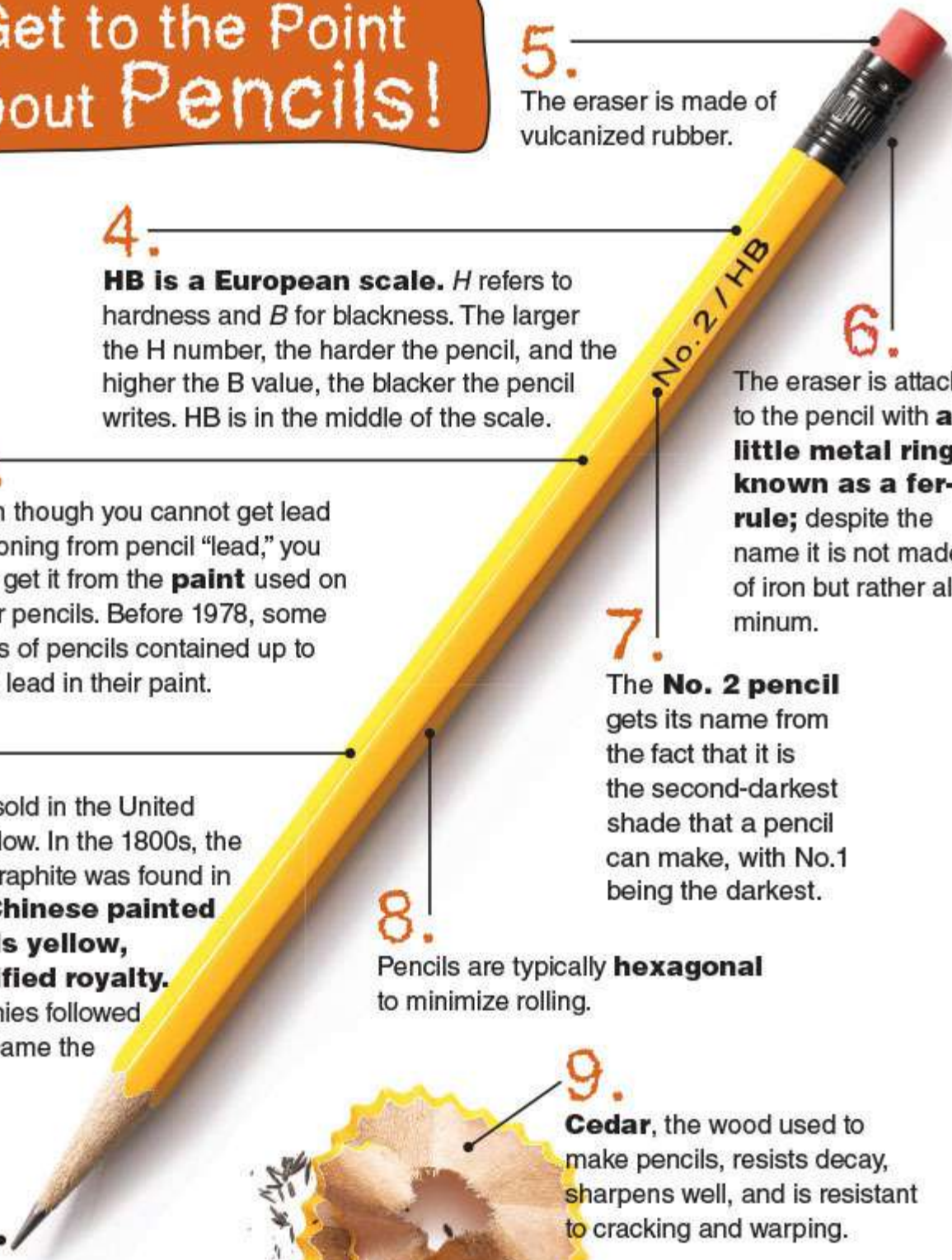


Figure 1. In graphite, carbons (black) form a two-dimensional sheet in ring formations. These sheets are attracted to each other, but not chemically bonded, and justify graphite’s brittle property.
THINKSTOCK

Get to the Point About Pencils!



5. The eraser is made of vulcanized rubber.

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.

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.

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.

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.

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.

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.

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

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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.