



**The Write Stuff:   
The Fascinating Chemistry of Pencils**

*December 2017/January 2018*

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

**Teacher’s Guide**



**Teacher's Guide for**

***The Write Stuff:   
The Fascinating Chemistry of Pencils***

**December 2017/January 2018**

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# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Covalent bonding** | Students may be familiar with covalent bonds in rings such as benzene; however, graphite may provide a more tangible and familiar example of covalent bonds in rings for students. |
| **Polarity** | Polar and nonpolar properties of substances are often demonstrated with solubility, such as the non-mixing of oil (nonpolar) and water (polar). Using graphite pencils to write on paper as an example of a nonpolar-nonpolar interaction will provide students with another example of polarity in action. |
| **Allotropes** | Students may struggle with understanding the concept of allotropes. By providing concrete examples of the allotropic forms of carbon (graphite, diamond, and buckminsterfullerene) or using physical models of them, students may better grasp the distinction caused by bonding arrangements of the carbon atoms. |
| **Chemical/Physical properties** | The article provides excellent examples comparing the physical properties of lead and graphite. Extending the comparison to chemical properties could make an interesting lesson. In addition, comparing the chemical and physical properties of the allotropes of carbon may help students to understand the effects of bonding on the properties of matter. |
| **London Dispersion forces** | Described as "weak" attractions, students may believe that London Dispersion forces are not important or significant. By using London Dispersion forces between sheets of graphite that result in a solid, or the London Dispersion forces that adhere graphite to paper, as tangible examples, students may better understand the collective strength of this weak, nonpolar interaction. |
| **Delocalized electrons** | The sometimes complex concept of delocalized electrons is frequently taught using the structure of benzene (an excellent example); however, using graphite as an additional example and allowing students to rub the graphite between their fingers will provide a tactile experience that may enhance student learning and understanding of delocalized electrons. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:

**ELA-Literacy.RST.9-10.1.** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

**ELA-Literacy.RST.9-10.5.** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, and energy).

**ELA-Literacy.RST.11-12.1.** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

**ELA-Literacy.RST.11-12.4.** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

* Links to **Common Core Standards for Writing**:

**ELA-Literacy.WHST.9-10.2F.** Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).

**ELA-Literacy.WHST.11-12.1E.** Provide a concluding statement or section that follows from or supports the argument presented.

* In addition to the writing standards above, consider asking students to debate issues addressed in some of the articles. Standards addressed:

**ELA-Literacy.WHST.9-10.1B.** Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and **counterclaims** in a discipline-appropriate form and in a manner that anticipates the audience’s knowledge level and concerns.

**ELA-Literacy.WHST.11-12.1.A.** Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence.

* Links to **Next Generation Science Standards**:

**HS-PS1-3:** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

* **Disciplinary Core Ideas**:
* PS1.A: Structure and properties of matter
* PS2.B: Types of Interactions
* **Crosscutting Concepts:**
* Patterns
* Structure and function
* **Science and Engineering Practices**:
* Developing and using models
* Obtaining, evaluating, and communicating information
* **Nature of Science**:
* Science addresses questions about the natural and material world

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in the December 2017/January 2018 issue:

* Metric units
* Structural Formulas
* Fermentation
* pH
* Electrochemistry
* Oxidation & Reduction
* Amines
* Allotropes
* Physical properties
* London dispersion forces

# Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher’s Guide—they have been formatted for ease of photocopying for student use.

* **Anticipation Guide (p. 8):** The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

As an alternative to using an Anticipation Guide, consider the following idea:

Ask students to examine their ordinary pencils (not mechanical pencils), and complete a chart like the one below. Encourage them to write at least two “I see, I think, I wonder” statements for each pencil part.

|  |  |  |  |
| --- | --- | --- | --- |
| ***Pencil Drawing*** |  | | |
| ***Name of part*** |  |  |  |
| ***I see . . .*** |  |  |  |
| ***I think . . .*** |  |  |  |
| ***I wonder . . .*** |  |  |  |

* **Graphic Organizer (p. 9):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

If you use the aforementioned organizers to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

* **Student Reading Comprehension Questions (p. 10):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.
* Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make decisions in their personal lives.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.
* You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.

“The Write Stuff”, *ChemMatters*, December 2017/January 2018 Issue)

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**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. |
|  |  | 1. A mark from graphite is lighter than a mark from lead. |
|  |  | 1. Today’s pencils write with a mixture of carbon and clay. |
|  |  | 1. The metal ring that holds the eraser on a pencil is made of iron. |
|  |  | 1. Graphite forms thin sheets that slide off and stick to paper. |
|  |  | 1. Graphite and the cellulose in paper are both nonpolar. |
|  |  | 1. Some erasers are made of plastic or vinyl. |
|  |  | 1. The first electronic grading machines depended on the electrical conductivity of graphite to score tests. |
|  |  | 1. Pink erasers contain volcanic pumice to act as an abrasive. |
|  |  | 1. Particles of graphite are removed by rubber erasers in a chemical process. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“The Write Stuff”, *ChemMatters*, December 2017/January 2018 Issue)

**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.

## Student Reading Comprehension Questions

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

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

* 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** |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. Why is clay added to most pencil leads?
  2. What is an allotrope? Explain the reason for differences between allotropes.

**Student Reading Comprehension Questions, cont.**

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

* 1. Explain why graphite is soft and slippery to the touch.
  2. Why are most pencils sold in the U.S. yellow in color?
  3. How does pencil lead cling to paper?
  4. What happens to rubber when it is vulcanized?
  5. How do pencil erasers work to remove marks?
  6. Why do rubber pencil erasers get hard and brittle over time and not work well?

## Answers to Student Reading Comprehension Questions

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

*A pencil lead is composed of graphite, a form of carbon.*

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

*In ancient writing utensils, the element mixed with lead forming an alloy making darker marks was tin.*

1. **Explain the circumstances of when and how the lead in the ancient writing stylus was replaced.**

*In the 1500s in England, a storm uprooted a tree growing over a deposit of pure graphite. Local people discovered that the graphite could produce dark marks on a variety of substances. With this discovery, graphite for use as a writing instrument grew rapidly.*

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

*Possible answers include any combination of these:*

|  |  |  |
| --- | --- | --- |
| ***Property*** | ***Lead*** | ***Graphite*** |
| ***Appearance*** | *Silvery gray* | *Silvery gray* |
| ***Conduction*** | *Good* | *Good* |
| ***Hardness*** | *Relatively soft* | *Relatively soft* |
| ***Density*** | *11.3 g/mL* | *2.3 g/mL* |
| ***Color of mark*** | *Lighter* | *Very dark* |

1. **Why is clay added to most pencil leads?**

*Clay is added to most pencil leads to increase the hardness of the graphite in the pencil leads, so that it is less likely to smudge or break.*

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

*“An allotrope is a different form of the same element, due to different bond arrangements in the substances.”*

1. **Explain why graphite is soft and slippery to the touch.**

*Graphite is soft and slippery to the touch because it is composed of carbon atoms bonded with three other carbon atoms forming thin sheets of rings. These sheets are weakly held together by London Dispersion forces, allowing the sheets to easily slide off of each other.*

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

*Most pencils in the U.S. are yellow because, in the 1800s, the world's best graphite came from China where pencils were painted yellow to signify royalty. Others followed the trend, and yellow became the standard color for pencils.*

1. **Why does pencil lead cling to paper?**

*Pencil lead clings to paper when the graphite "lead" flakes off as you write or draw. The cellulose fibers in paper have a large surface area and catch many of the graphite flakes. Because graphite and cellulose are both nonpolar, the flakes attract to the paper due to London Dispersion forces.*

1. **What happens to rubber when it is vulcanized?**

*When rubber is vulcanized, sulfur is added to natural rubber and heated. The heat causes crosslinks between the rubber polymer chains and the sulfur, producing a more durable material.*

1. **How do pencil erasers work to remove marks?**

*Pencil erasers work by physically removing the graphite particles from the paper. Because rubber, graphite, and cellulose are nonpolar substances, only weak, London Dispersion forces bind the graphite to the paper. The nonpolar forces between the eraser and the graphite are stronger than the nonpolar forces between the graphite and the paper, so the eraser removes the mark.*

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

*Rubber pencil erasers get hard and brittle over time and don't work well because the rubber is oxidized. The oxidation from ultraviolet light, ozone, and oxygen causes the long polymer chains of the soft rubber to break up, creating more cross-linkages between the chains, making the eraser harder and less effective.*

# Possible Student Misconceptions

1. **“Wooden pencils are the same throughout the world.”** *While there are many similarities, there are also differences among pencils in the world. Most pencils in the U.S. have erasers on the end, but few pencils do in Europe. In the U.S., a system of numbers from 1–4 to designate the grade of graphite hardness, but in Europe, a lettered system is used, such as HB. There are also some differences in countries for the degree of hardness of the pencil leads and the type of wood used to encase the lead.*
2. **“Wooden pencils and mechanical pencils use the same type of lead.”** *Both wooden and mechanical pencils typically use a mixture of graphite and clay for the lead. However, mechanical pencil lead may also contain a polymer material to allow their (often) smaller diameter lead to be strong and yet flexible. Mechanical pencil leads made only with graphite and clay that are smaller than 0.9 mm are brittle enough to break under normal writing stresses.*
3. **“You can get lead poisoning from a pencil.”** *Many people understand that the "lead" in a pencil is not made of elemental lead. So, you cannot get lead poisoning from the graphite core of a pencil. However, before the 1970s, the yellow color popular on most pencils contained as much as 12% lead in the paint. If a people chewed on that yellow lead-based paint, they would ingest a small amount of lead. Under most circumstances, the amount would not have been sufficient to cause lead poisoning. Today, the yellow paint on pencils is lead free.*

# Anticipating Student Questions

1. **“Why is it called "lead" if pencils don't contain the element lead?”** *Ancient writing utensils often contained the element lead. However, in the 1500s, graphite (called plumbago—meaning “lead ore”—due to its similar appearance to lead) began to replace lead. The name "lead" stuck due to its earlier usage and similarities to lead.*
2. **“Why do scanned answer sheets suggest using only #2 pencils for marking?”** *Scanned answer sheets are scored by optical mark readers registering light reflected from the answer sheet. The marks on the answer sheet must be dark enough to absorb (not reflect) light but not smear and make erroneous marks. The #2 pencil happens to be the perfect combination of darkness and smudge-resistance. Harder pencils (#3 or #4) make marks that are too light or too hard, tearing the paper, while softer #1 pencils make too many smudges.*
3. **“How are colored pencils made?”** *Colored pencils, unlike writing pencils, do not contain graphite. Instead, colored pencils have a core made from wax or oil containing binders, additives, and colored pigments. These substances are blended, shaped, and sandwiched into a wooden case similar to graphite pencils.*
4. **“How do they get the pencil lead into the center of the wooden pencil?”** *Pencil lead is much too soft and brittle to insert it into a hollow cylinder inside of the wooden pencil without breaking. Instead, manufacturers groove out a space in each half of the wooden pencil blank, drop a pencil lead in the half-groove on one side of the wooden blank, and then glue the top half over the bottom with the pencil lead now trapped inside. The finished pencil then can be shaped into a hexagon (to minimize rolling) or finished as a round shape. See "How pencils are manufactured" in Web Sites for Additional Information (below) for links to two videos on pencil manufacturing.*

# Activities

**Labs and demos**

**Lab measuring the electrical resistance of graphite from a pencil:** Graphite is a conductor, and this simple activity from Flinn Scientific directs students to study the relationship between the length of graphite and its resistance. Student directions and the worksheet are provided, along with tips for success. (<https://www.flinnsci.ca/api/library/Download/f685c456a24b4886a835ebe5b9096cf5>)

**Demonstration of delocalized electrons in graphite analogy:** To demonstrate an analogy of graphite with its sheets of carbon atoms loosely attached by delocalized electrons, teachers/students can use a small stack of sheets of loose writing or copy paper. The sheets of paper are loosely attracted (try gently lifting one sheet of paper from the stack) by weak forces which hold the sheets together (similar to delocalized electrons in graphite), and can easily slide (like graphite) when the stack of papers is sheared between the palms of the hands.

**Simulations**

**Simulation of polarity:** The PhET simulation, “Molecule Polarity”, allows students to manipulate the electronegativity of atoms in a molecule to observe how that affects its polarity. Students observe how the molecule behaves in an electric field and how the bond angle affects both molecular shape and polarity. (<https://phet.colorado.edu/en/simulation/molecule-polarity>)

**Simulation of, and an activity for, intermolecular forces:** This activity, “Intermolecular Forces”, from the American Association of Chemistry Teachers (AACT) uses student worksheets, questions, and a simulation comparing dipole-dipole to London Dispersion forces. The Web site is complete with a teacher guide, the student activity, answer key, and a link to the simulation. (<https://teachchemistry.org/classroom-resources/intermolecular-forces>. Note that this link is only available to AACT or ACS members.)

**Media**

**Video explaining intermolecular forces:** "Intermolecular Forces" (8:35) from the Khan Academy reviews all of the intermolecular forces using diagrams. The explanation of London Dispersion forces, which are emphasized in the Rohrig pencil article, begins at 5:50 in this video: <https://www.khanacademy.org/science/biology/chemistry--of-life/chemical-bonds-and-reactions/v/intermolecular-forces-and-molecular-bonds>.

**Video of the carbon allotropes:** “Diamonds, Pencils, and Buckyballs: A Look at Buckminsterfullerene” (6:00) focuses on the discovery of buckyballs, but it also illustrates and explains the carbon allotropes. This video is part of the National Science Foundation's, *Science 360* video collection. [(https://science360.gov/obj/video/19bd995d-4ff6-44c6-83ca-d3bac9bc8f6d/diamonds-pencils-buckyballs-look-buckminsterfullerene](file:///C:\Users\Bill\AppData\Local\Packages\Microsoft.MicrosoftEdge_8wekyb3d8bbwe\TempState\Downloads\(https:\science360.gov\obj\video\19bd995d-4ff6-44c6-83ca-d3bac9bc8f6d\diamonds-pencils-buckyballs-look-buckminsterfullerene))

**Lessons and lesson plans**

**Carbon allotropes lessons and activities:** “Allotropes of Carbon : It's All in the Way You're Put Together” is a lesson series of 2.5–3 hours total time, where students learn about four carbon allotropes (including nanotubes) through student worksheets and modeling. The resource is complete, providing student pages, teacher support, materials list, expected answers, background material, and references. (<http://www.physics.purdue.edu/psas/docs/Allotropes%20of%20Carbon.pdf>)

**Cross-curricular lessons about pencils:** The Mineral Information Institute's *Everyday Uses of Minerals* guide includes in the series “How Many Countries Does It Take to Make a Pencil?” Lessons related to science, math, language arts, and geography provide writing, research, and science activities which may be a bit elementary, but may be useful or could be modified. (<http://www.kennecott.com/library/media/everyday.pdf>)

**Projects and extension activities**

**Modeling carbon allotropes and understanding hydrocarbons:** This series of four activities provides extensions for building carbon allotropes and organic molecule models, constructing and naming hydrocarbons, and making marbled paper. The materials needed are inexpensive and readily available; however, there are few teacher resources provided. (<https://www.rainbowresource.com/pdfs/products/prod032392_smpl1.pdf>)

**Conductivity of pencil lead:** Graphite pencil lead is an electrical conductor and that property can be used to in the project, Pencil Lead Light Bulb, which has Next Generation Science Standards identified. D-cell batteries, mechanical pencil leads, and assorted wire and clamps are assembled to produce the primitive light bulb. (<http://scactivities.cikeys.com/pencil-lead-lightbulb/for-teachers/>)

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles   
published from the magazine’s inception in October 1983 through April 2013; all available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen)**

**Selected articles and the complete set of   
Teacher’s Guides for all issues from the past three   
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**



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This article compares graphite and diamond with respect to properties and bonding. Author Wood also explains the process of forming diamonds by chemical vapor deposition. (Wood, C. Two Faces of Carbon. *ChemMatters*, 2004, *22* (4), pp 4–6)

The serendipitous discovery of graphite for writing is only one example of an accidental discovery. Vaseline, Silly Putty, and aspartame are other serendipitous discoveries detailed in this interesting article. (Rohrig, B. Serendipitous Science. *ChemMatters*, 2007, *25* (3), pp 4–6)

Read this *ChemMatters* article for additional information and pictures about pencils and graphite that was reprinted from *Chemical and Engineering News* (see reference below). (Ritter, S. What's That Stuff? Pencils & Pencil Lead. *ChemMatters*, 2007, *25* (3), pp 11–12)

The Teacher's Guide for “What's That Stuff? Pencils & Pencil Lead” (above) provides additional information on allotropes, graphite, and student projects using graphite pencils.

For more information on diamond and graphite allotropes of carbon including van der Waals forces, bonding, chemical structures, and properties read this *ChemMatters* article. (Sicree, A. Graphite versus Diamond: Same Element but Different Properties. *ChemMatters*, 2009, *27* (3), pp 13–14)

The Teacher's Guide for “Graphite versus Diamond: Same Element but Different Properties” (above) provides more details on allotropes, graphite, pencils, and building a model of diamond from a template that appeared in an April 1990 issue of *ChemMatters*.

This article examines graphene (graphite that is only one atom thick) for potential uses in flexible solar panels, foldable cell phones, and bionic devices. Atomic structures of six common forms of carbon and a link to a video podcast are provided. (Tinnesand, M. Graphene: The Next Wonder Material? *ChemMatters*, 2012, *30* (3), pp 6–8)

The Teacher's Guide for “Graphene: The Next Wonder Material?” (above) provides background information on carbon allotropes, an activity with sticky tape to produce graphene, and numerous resources on graphene.

This *ChemMatters* article explains these serendipitous chemical discoveries: the synthesis of urea, radioactivity and the discovery of radium, and buckyballs. (Haines, G. "Chance Favors the Prepared Mind": Great Discoveries in Chemistry. *ChemMatters*, 2012, *30* (3), pp 17–19)

The Teacher's Guide for "’Chance Favors the Prepared Mind’": Great Discoveries in Chemistry” (above) provides additional information on each of the three discoveries. Additional information on the carbon allotrope buckyballs relates to the Rohrig pencil article.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

This article complements the Rohrig pencil article, providing details on the history of writing, the modern pencil, and making the pencil lead. A table with chemicals used (and their source) in making a pencil is provided. (Encke, F. The Chemistry and Manufacturing of the Pencil Lead. *J. Chem. Educ.*, 1970, *47* (8), pp 575–576; <http://pubs.acs.org/doi/pdf/10.1021/ed047p575>. Note that this link takes you to a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal.)

This is the original publication of “Pencils and Pencil Lead”, which was reprinted in the *ChemMatters* October 2007 issue as “What's That Stuff? Pencils & Pencil Lead”. (Ritter, S. Pencils and Pencil Lead. *Chem. Eng. News.*, 2001, *79* (42), p 35; <http://pubs.acs.org/doi/pdf/10.1021/cen-v079n042.p035>. Note that this link takes you to a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal; however, the article is available free at <http://pubs.acs.org/cen/whatstuff/stuff/7942sci4.html>.)

The origin of the chemical term allotrope is detailed in this article. (Jensen, W. The Origin of the Term Allotrope. *J. Chem. Educ.*, 2006, *83* (6), pp 838–839; <http://pubs.acs.org/doi/pdf/10.1021/ed083p838>. Note that this link takes you to a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal.)

With proper equipment and support, high school students can build and operate a fullerene generator using graphite for the source material, and study properties of fullerenes. Supporting material and resources are provided in the article. (Davis, S., et al. Exploring Carbon's Allotropy: A Pupil-Led Synthesis of Fullerenes from Graphite. *J. Chem. Educ.*, 2015, *92* (7), pp 1263–1265; <http://pubs.acs.org/doi/pdf/10.1021/ed500709f>. Note that this link takes you to a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal.)

# Web Sites for Additional Information

**Pencils**

**“**20 Things You Didn't Know About…Pencils” presents some interesting (and short) facts about pencils from *Discovery* magazine. (<http://discovermagazine.com/2007/may/20-things-you-didnt-know-about-pencils>)

Numerous links to articles and publications related to everything about pencils, pencil collecting, pencil history, and pencil essays can be found at The Pencil Pages Web site. (<http://www.pencilpages.com/articles/index.htm>)

**How pencils are manufactured**

The History Channel provides this informative video, “How a Pencil Is Made” (5:42), which shows the steps in making a pencil with an emphasis on the graphite/clay lead, and following up with sandwiching it in wood, painting, attaching the eraser, and sharpening the finished product. (<https://www.youtube.com/watch?v=zZHp1fGdAWE>)

For another look at how pencils are made with greater details on the wooden pencil case and shaping the pencil, see <https://www.youtube.com/watch?v=WgiOvepQ6B0&feature=youtu.be>.

**Erasers**

The *New York Times Magazine* provides information about the history and invention of the built-in pencil eraser in “Who Made that Built-in Eraser?” at <http://www.nytimes.com/2013/09/15/magazine/who-made-that-built-in-eraser.html?mcubz=0>.

Interesting facts from *The Atlantic* about pencil erasers are located at <https://www.theatlantic.com/technology/archive/2013/08/10-things-you-probably-did-not-know-about-eraser-technology/279028/>.

**Serendipitous science**

The Rohrig pencil article described the discovery of graphite for writing as serendipity. The Mental Floss Web site highlights twenty-four additional scientific discoveries made as a fortunate accident, including Post-it Notes, the heart pacemaker, and Viagra—plus a video, "24 Unintended Scientific Discoveries" (10:16), on these discoveries; they can be found at <http://mentalfloss.com/article/53646/24-important-scientific-discoveries-happened-accident>.

"Scholars and Scientists Explore Factors Underlying Serendipitous Discoveries", published by the University of Chicago explores possible factors which may influence serendipitous discoveries, such as having teams of people collaborating who may not normally work together or looking at phenomena with a different mind-set. (<https://news.uchicago.edu/article/2014/06/19/scholars-and-scientists-explore-factors-underlying-serendipitous-discoveries>)

**Rubber and vulcanization**

Natural latex rubber is too gummy to be used as an eraser, but Charles Goodyear is credited with learning how to modify latex with heat and sulfur. Read more about his discovery at <https://connecticuthistory.org/charles-goodyear-and-the-vulcanization-of-rubber/>.

The in-depth report, "Rubber Chemistry", from Matador Rubber, includes structure, synthesis, properties, synthetic rubbers, reactions of rubbers, and various methods of vulcanization. You can find it at <http://laroverket.com/wp-content/uploads/2015/03/rubber_chemistry.pdf>.

**Carbon allotropes**

The University of Colorado Web site, Chapter 3.3 “Carbon – An Amazingly Allotropic Element”, provides an excellent explanation of the carbon allotropes, including carbon allotrope diagrams, hybridization of carbon orbitals, and descriptions of the carbon allotropes. (<http://virtuallaboratory.colorado.edu/CLUE-Chemistry/chapters/chapter3txt-3.html>)

For a simpler explanation of the carbon allotropes graphite and diamond, see this short *Scientific American* article, "How Can Graphite and Diamond Be So Different If They Are Both Composed of Pure Carbon?" (<https://www.scientificamerican.com/article/how-can-graphite-and-diam/>)

**London Dispersion forces**

The Chemistry LibreTexts™ Web site provides a clear explanation of London Dispersion forces and includes a quick animation. Induced dipoles and interaction energy are also included in the article, "London Dispersion Interactions". (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Physical_Properties_of_Matter/Atomic_and_Molecular_Properties/Intermolecular_Forces/Specific_Interactions/London_Dispersion_Interactions>)

**Delocalized electrons**

The Chemistry LibreTexts™ Web site includes explanations and useful diagrams to introduce the concept of delocalized electrons using molecular orbital theory. The information provides numerous methods of indicating electron movement and resonance structures. (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Chemical_Bonding/Valence_Bond_Theory/Delocalization_of_Electrons>)

An in-depth discussion of delocalized electrons is found on this California Institute of Technology Web site. Information includes hybrid orbitals, single and multiple bonds in carbon atoms, delocalized orbitals in benzene, and polyatomic molecules. (<https://authors.library.caltech.edu/25050/14/Chapter_13.pdf>)

**Graphite as a lubricant**

Find a diagram of the structure of graphite indicating the van der Waals attractions and an explanation of why graphite is an excellent dry lubricant at <http://www.substech.com/dokuwiki/doku.php?id=graphite_as_solid_lubricant>.

Compare the properties and uses of common dry lubricants including graphite, molybdenum disulfide, PTFE, and boron nitride. The site includes structures for molybdenum disulfide and graphite. ([http://www.tribology-abc.com/abc/solidlub.htm#graphite](http://www.tribology-abc.com/abc/solidlub.htm%23graphite))

**Pencil sharpeners**

For a picture of the mechanical pencil sharpener that African-American inventor John Lee Love designed, and his patent application, read "Pencil Patents: John Lee Love's Portable Pencil Sharpener". (<https://pencils.com/pencil-patents-john-lee-love-s-portable-pencil-sharpener/>)

"How the Pencil Sharpener Was Invented" from the Gizmodo Web site provides additional mechanical pencil sharpeners from French and British inventors with links to several other writing-related sources; see <https://gizmodo.com/how-the-pencil-sharpener-was-invented-1682242025>.

**Mechanical pencils**

This brief article, "History of the Mechanical Pencil – Inventor of Mechanism", explains the history of the mechanical pencil. (<http://www.historyofpencils.com/writing-instruments-history/history-of-mechanical-pencils/>)

**Optical mark recognition machines**

The rise of standardized multiple choice testing is linked to the use of answer sheets which could be scanned and scored by machine. "Multiple Choice and Testing Machines: A History" explains and shows a diagram and the patent for an early optical scoring machine. (<http://hackeducation.com/2015/01/27/multiple-choice-testing-machines>)

The explanation for why test takers must use #2 pencils on machine-scored (Scantron) forms is found at <http://www.todayifoundout.com/index.php/2010/10/why-you-used-to-have-to-use-2-pencils-with-scantron-forms/>.

**Yellow paint on pencils**

Many pencils are painted yellow as the Rohrig article explains. Before the 1970s, that paint may have contained the element lead, and an analysis of that paint is found in "Lead in Paint on Pencils" from the National Center for Biotechnology Information at <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1937194/pdf/hsmhahr00011-0009.pdf>.

# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at <http://tinyurl.com/o37s9x2>.