



**Indigo: The "Blue"   
in Blue Jeans**

*February/March 2018*

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

**Teacher’s Guide**



**Teacher's Guide for**

***Indigo: The "Blue" in Blue Jeans***

**February/March 2018**

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# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Hydrogen bonding** | Hydrogen bonding is often associated with the water molecule. This article provides another practical context for hydrogen bonding that you can use in class, the binding of indigo to fibers, as a cause for the fading of blue denim clothing. |
| **Multiple bonds/ Conjugated bonds** | The alternating single and double bonds (conjugated system) in the indigo molecule allow it to absorb light energy. Indigo is an example of a chromophore with a conjugated system of multiple bonds. |
| **Electron transitions** | Electrons in the indigo molecule absorb light energy and move from ground state to an excited state and provide a different context for students to understand electron transitions. |
| **Oxidation-reduction reactions** | The process of extracting and using indigo dyes is a series of oxidation and reductions reactions. Some students may relate to this concept with greater interest, with the practical and visual oxidation and reduction reactions involved in the transition between blue-colored indigo and the yellowish-white indigo white. |
| **Properties of light** | The colors of dyed clothing are related to the wavelengths and frequencies of light energy both absorbed and released. The indigo molecule absorbs light in the 613 nm wavelength range but the item appears bluish in color due to the reflected wavelength of visible light. |
| **Solubility** | Because indigo is insoluble in water, it cannot easily be used in that form as a dye. However, converting it, by oxidation, to indigo white makes the dye soluble in water and able to react to color fibers. |

# 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, 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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* Some of the articles in this issue provide information about carbon dioxide and its role in the environment.
* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# 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.

*NEW! Instead of using the aforementioned anticipation guide, consider this idea to engage your students in reading.*

Ask students to describe why blue jeans have been popular for more than a hundred years, and how their color might relate to chemistry.

* **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.

|  |  |  |
| --- | --- | --- |
| **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. 10-11):** 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.

Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

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. The “Web Sites for Additional Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

“Indigo: The ‘Blue’ in Blue Jeans", *ChemMatters*, February/March 2018

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. More than a billion pairs of jeans were sold around the world in 2015. |
|  |  | 1. Indigo dye penetrates the cloth’s threads. |
|  |  | 1. The woad plant that natural indigo dye comes from has bright blue flowers. |
|  |  | 1. Indigo absorbs orange light and reflects purplish-blue light. |
|  |  | 1. Indigo white molecules are oxidized in air to produce blue indigo. |
|  |  | 1. The blue color of jeans slowly fades because the indigo is attached to the cloth by weak intermolecular forces. |
|  |  | 1. Indigo is soluble in water. |
|  |  | 1. The person who first synthesized indigo in a laboratory won the Nobel Prize. |
|  |  | 1. The first mass-production synthesis of indigo used a chemical from coal. |
|  |  | 1. Today indigo is usually produced using chemicals from petroleum. |

## Graphic Organizer

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

“Indigo: The ‘Blue’ in Blue Jeans”, *ChemMatters*, February/March 2018

**Directions**: As you read the article, complete the graphic organizer below to describe what you learned about the chemistry of indigo dye.

|  |  |  |
| --- | --- | --- |
| ***Problem*** | ***Solution*** | ***Chemicals involved*** |
| ***How to get indigo dye from the woad plant*** |  |  |
| ***How to use indigo (which is insoluble) to dye cloth*** |  |  |
| ***How to synthesize indigo*** |  |  |

**Summary**: On the back of this paper, write a tweet (280 characters or less) about indigo, based on what you learned from reading the article.

“Indigo: The ‘Blue’ in Blue Jeans,” *ChemMatters*, February/March 2018

“Indigo: The ‘Blue’ in Blue Jeans”, *ChemMatters*, February/March 2018

## Student Reading Comprehension Questions

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

Name

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

* 1. How much indigo is produced annually?
  2. What improvement to denim jeans did Jacob Davis make during the 1870s?
  3. How is indigo different from other natural dyes in binding to fibers?
  4. What is the name, color, and source of the compound in woad plants from which indigo is formed?
  5. How does the indoxyl (formed from indican in woad plants) finally form indigo and turn a blue color?
  6. Describe a chromophore and its typical chemical structure.

**Student Reading Comprehension Questions, cont.**

“Indigo: The ‘Blue’ in Blue Jeans”, *ChemMatters*, February/March 2018

* 1. Why does indigo look purplish-blue in color if it absorbs orange light?
  2. What are the attractive forces that bind indigo white to cellulose molecules?
  3. Explain the chemistry of why the blue color of jeans slowly fades with wear and washing.
  4. Who was the German scientist who discovered a synthetic synthesis for indigo in the late 1800s?
  5. What is the starting chemical used in the modern production of indigo?
  6. How is the ring structure of aniline different from that of naphthalene?

## Answers to Student Reading Comprehension Questions

1. **How much indigo is produced annually?**

*Each year, about 20 million kilograms of indigo is produced.*

1. **What improvement to denim jeans did Jacob Davis make in the 1870s?**

*In the 1870s, Jacob Davis improved denim jeans by using copper rivets at points of strain, such as pocket corners and the base of the button fly.*

1. **How is indigo different from other natural dyes in binding to the fibers?**

*Indigo is different from other natural dyes because it binds externally to the fibers, rather than penetrating the fibers directly, like most natural dyes.*

1. **What is the name, color, and source of the compound in woad plants from which indigo is formed?**

*The compound in woad plants from which indigo is formed is indican, which is a colorless compound found in the plant tissues.*

1. **How does the indoxyl (formed from indican in woad plants) finally form indigo and turn a blue color?**

*The indoxyl formed from indican in woad plants finally forms indigo and turns a blue color when the indoxyl is stirred to mix with air, and oxygen oxidizes the indoxyl to form indigo.*

1. **Describe a chromophore and its typical chemical structure.**

*A chromophore is a region in a molecule, usually containing alternating double and single bonds, that produces color.*

1. **Why does indigo look purplish-blue in color if it absorbs orange light?**

*Indigo looks purplish-blue because the human eye sees indigo's complementary color, not the orange color of light that it absorbs.*

1. **What are the attractive forces that bind indigo white to cellulose molecules?**

*The chemical forces that bind indigo white to cellulose molecules are hydrogen bonds.*

1. **Explain the chemistry of why the blue color of jeans slowly fades with wear and washing.**

*The blue color of jeans slowly fades with wear and washing because the indigo dye is bonded to the surface of the fibers with hydrogen bonds, intermolecular bonds, which are weaker than chemical bonds. Thus, some indigo molecules separate from the fibers with each laundering, and the blue color slowly fades.*

1. **Who was the German scientist who discovered a synthetic synthesis for indigo in the late 1800s?**

*The German scientist, Adolf von Baeyer, discovered a synthetic synthesis for indigo in the later 1800s.*

1. **What is the starting chemical used for the modern production of indigo?**

*The starting chemical used for the modern production of indigo is naphthalene.*

1. **How is the ring structure of aniline different from that of naphthalene?**

*The ring structure of aniline and naphthalene are different in that aniline is composed of a single ring and naphthalene is composed of a double ring.*

# Possible Student Misconceptions

1. **“Only seven spectral colors exist (red, orange, yellow, green, blue, indigo, and violet—‘ROY G BIV’).”** *The number of spectral colors is unlimited, and humans can see hundreds of colors. The colors we see and identify are dependent upon physiological, psychological, and cultural factors.*
2. **“Levi Strauss invented denim jeans.”** *Levi Strauss owned a wholesale dry goods store in San Francisco during the California Gold Rush. The miners needed durable work clothes that would not easily rip or tear. Denim clothing was popular, but would sometimes rip at stress points such as pockets and the crotch. Jacob Davis, a Nevada tailor and one of Strauss’s customers, had an idea to add copper rivets to strengthen those stress points and reduce rips. Davis needed a business partner to help patent and produce his improved denim jeans, and Strauss agreed. Their patent was granted on May 20, 1873. So, while denim jeans existed prior to Levi Strauss, the blue jeans worn today started with the partnership between Davis and Strauss. (*[*https://www.smithsonianmag.com/smithsonian-institution/the-origin-of-blue-jeans-89612175/*](https://www.smithsonianmag.com/smithsonian-institution/the-origin-of-blue-jeans-89612175/)*)*
3. **“The color (that we see) of an object is due to the color absorbed.”** *The color of an object that humans see is due to the colors absorbed by the object, as well as the colors it reflects. An apple appears red in color because most of the colors of the visible spectrum are absorbed by the apple pigments, leaving primarily red wavelengths of light reflected and received by the eyes. The red color of an apple is not due just to red light being reflected, it is also influenced by other wavelengths that are reflected, giving rise to various hues of red.*
4. **“Because hydrogen bonds are weak, they must not be****very important.”** *While intermolecular hydrogen bonds are certainly weaker than chemical bonds like ionic or covalent, they are nonetheless very important. Hydrogen bonds are the primary force adhering indigo to clothing fibers. In addition, hydrogen bonds are responsible for holding the double helix strands of DNA together, joining H2O molecules together to form liquid water—or even ice, and many other important roles. The strength of the attraction does not parallel its importance.*

# Anticipating Student Questions

1. **“I heard that the color indigo was being removed from the seven colors of the rainbow. Is this true?”** *Isaac Newton first set the colors of the rainbow, and he named seven colors—including indigo. School children learn the colors as ROY G BIV. Many people believe that the number seven has significance and it is associated with completion or perfection such as seven days per week, seven notes in the diatonic music scale, and the seven seas. Newton may have identified indigo as a primary color to round out the number of colors defined in the rainbow. There are some who omit indigo when painting or depicting a rainbow. Many people have difficulty distinguishing indigo from blue or purple which may lead to its omission. However, ROY G BIV is still in use and indigo has its place in the rainbow.*
2. **“When I mix red and green paint, I make brown paint, but when I mix red light and green light, I get yellow light. Why?”** *Color theory can be complex. There are two aspects to color theory: additive (light) and subtractive (pigment). In light (additive), the presence of all colors forms white; but in pigments (subtractive), the presence of all colors forms black. Pigment colors (subtractive color theory) are more intuitive because we experience them frequently in daily life. Light colors (additive) are less intuitive because we work with light colors less, and light is different than mixing physical substances. For a full explanation, please see* [*http://ux1.eiu.edu/~cfadd/3050/Ch17Color/ToC.html*](http://ux1.eiu.edu/~cfadd/3050/Ch17Color/ToC.html)*.*
3. **“How is natural indigo chemically different from synthetic indigo?”** *There is no chemical difference between natural and synthetic indigo. A chemical does not change its chemical or physical properties based upon whether it is extracted from natural sources or synthesized in a laboratory. There ARE some differences between them, though, that are inherent in their methods of production. Some of these differences between natural and synthetic indigo (or any chemical) are costs of production, sources of reactants, energy and time required to produce, safety in production, and wastes formed.*

# Activities

**Labs and demos**

**Lab synthesizing indigo dye:**  "The Chemistry of Dyes, Part I: The Synthesis of Indigo Dye" provides complete student background theory and procedures for students to synthesize indigo dye. The lab procedure prompts students to complete a data table, complete with calculations, limiting reactant, percent yield, and cost per pound; however, no teacher support is included. (<http://faculty.trinityvalleyschool.org/pricep/Chem/labs/indigo>)

**Microscale lab synthesizing indigo dye:**  The student lab procedure in "The Microscale Synthesis of Indigo Dye" from the Royal Society of Chemistry requires only 10 minutes to complete, and includes chemical structures for the indigo synthesis reactions. Note though, that there are no teacher resources, student questions, or extensions provided. ([http://www.rsc.org/learn-chemistry/resource/res00000560/the-microscale-synthesis-of-indigo-dye#!cmpid=CMP00000575](http://www.rsc.org/learn-chemistry/resource/res00000560/the-microscale-synthesis-of-indigo-dye%23!cmpid=CMP00000575))

**Simulations**

**Simulation of seeing colors:** "The Colors of Light" from PhET is a 30-minute activity to accompany the simulation, "Color Vision," which allows students to manipulate colors of light and color filters to explore how color is perceived by the human eye and brain. Registering for a free account is required to access the student activity materials but not the simulation. (<https://phet.colorado.edu/en/simulation/color-vision>)

**Activity modeling hydrogen bonds:** This *JCE Classroom Activity* prompts students to use K'Nex toy components and Velcro to model hydrogen bonding. Instructor information, possible student answers, plus the student activity sheet are all included, along with student questions to expand the lesson. (<http://pubs.acs.org/doi/pdf/10.1021/ed082p400A>. 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.)

**Media**

**Video explaining intermolecular forces, including hydrogen bonding:** "Intermolecular Forces" (8:35) from the KhanAcademy reviews all of the types of intermolecular forces, with diagrams. The explanation of hydrogen bonding begins at 2:54 in this video. (<https://www.khanacademy.org/science/biology/chemistry--of-life/chemical-bonds-and-reactions/v/intermolecular-forces-and-molecular-bonds>)

**Video of blue jeans:** The ACS Reactions video "How Do Jeans Get Blue?" (3:06) is a quick history of jeans and the chemistry of indigo. This video is targeted to students. (<https://www.youtube.com/watch?v=kiMBFKwnxzI&t=1s>)

**Lessons and lesson plans**

**Lesson on light and color:** The PBS LearningMedia lesson "Light and Color" is targeted for grades 6-12 and includes a 3:55 video clip, a background essay, discussion questions, and education standards to instruct students about the relationship between light photons and visible color. ([https://aetn.pbslearningmedia.org/resource/lsps07.sci.phys.energy.lightcolor/light-and-color/#.WibFW0qnFhE](https://aetn.pbslearningmedia.org/resource/lsps07.sci.phys.energy.lightcolor/light-and-color/%23.WibFW0qnFhE))

**Lesson on colors of light and pigments:**  Although "Physics of Light: Light, Energy, and Color" is a lesson for light and solar cells, the lesson also includes detailed information on color, with specific background information on the electromagnetic spectrum, light absorption and reflection, and why we see color related to pigments. A general procedure using red and green gummy bears and red and green lasers, plus review questions and analysis, are provided for teachers to develop their student lesson aligned with NGSS. (<http://thesolararmy.org/wp-content/uploads/2014/12/Physics-Revisions-High-School-Lesson-Plan-Final.pdf>)

**Projects and extension activities**

**Synthesizing and using an azo dye:** The Royal Society of Chemistry publishes "The Microscale Synthesis of Azo Dyes", providing student directions and reactions with the chemical structures, to prepare a red azo dye from aniline and use the dye on a piece of cotton fabric. No teacher support or detailed safety guidelines are included. (<http://www.rsc.org/learn-chemistry/resource/res00000559/the-microscale-synthesis-of-azo-dyes>)

**Synthesizing and dyeing with indigo and comparing it to alizarin red S dye:** "Chemistry of Blue Jeans: Indigo Synthesis and Dyeing" involves preparing and using indigo dye and comparing it to a mordant dye, alizarin red S. Extensive background information, procedures with chemical structures, and a testing procedure for comparing the dyes is included; however, teachers should carefully consider whether the chemicals required, the procedures, and the safety of the project are appropriate for their teaching environment. (<https://scilearn.sydney.edu.au/fychemistry/labmanual/e04.pdf>)

# 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”*.**



***30* Years of *ChemMatters !***

Available Now!

This 1986 article contains a large section on dyes extracted from plants, including indigo. The article also provides a sidebar on chromophores with chemical structures (Wood, C. Natural Dyes. *ChemMatters*, 1986, *4* (4), pp 4–8)

Also in the 1986 issue is a short article on denim blue jeans providing a brief history of Levis Strauss jeans and how the traditional blue denim cloth is manufactured. (Robson, D. Blue Jeans. *ChemMatters*, 1986, *4* (4), p 9)

In the “Matter of Fact” feature of the *ChemMatters* October 1998 issue, a student asked, "Why are blue jeans so blue?" The one-page answer complements the present Deakin and Cooper article about indigo. (Becker, R. As a Matter of Fact: Why are blue jeans so blue? *ChemMatters*, 1998, *16* (3), p 16)

This article contains a sidebar on the discovery of mauve, the first synthetic dye that was produced from aniline and other chemicals. (Hersey, J; Helzel, C. Graphene: Your Colorful Food. *ChemMatters*, 2007, *25* (1), pp 12–15)

For an excellent explanation and more information on hydrogen bonding, including illustrations, please see this article about paintballs. (Rohrig, B. Paintball! Chemistry Hits Its Mark. *ChemMatters*, 2007, *25* (2), pp 4–7)

Read this *ChemMatters* article for additional information and pictures about the chemistry of dyes. Information on chromophores and a brief sidebar on tie-dyeing may also be of interest. (Wood, C. The Art and Chemistry of Dyes. *ChemMatters*, 2009, *27* (1), pp 13–15)

This *ChemMatters* article discusses food colors and it includes illustrations of chemical ring structures with alternating single and double bonds (conjugation, as in chromophores). The article also contains a graphic (Figure 4) illustrating colors produced by absorbed and transmitted light. (Rohrig, B. Eating with Your Eyes: The Chemistry of Food Colorings. *ChemMatters*, 2015, *33* (3), pp 5–7)

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In 1930, the *Journal of Chemical Education* included a thorough biography of Adolf von Baeyer (1835–1917) that contains photographs, summaries of his discoveries and chemical syntheses, and collaboration with other scientists. (Henrich, F. Adolf von Baeyer (1835-1917).   
*J. Chem. Educ.*, 1930, *7* (6), pp 1231–1248; <http://pubs.acs.org/doi/pdf/10.1021/ed007p1231>. 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 1983 article provides additional background information about, and chemical structures for, indigo. It includes more details on the synthetic manufacture of this dye. (Fernelius, W; Renfrew, E. Indigo. *J. Chem. Educ.*, 1983, *60* (8), pp 633–634; <http://pubs.acs.org/doi/pdf/10.1021/ed060p633>. 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.)

ACS members or subscribers to *J. Chem. Ed.* can read about the microscale synthesis of indigo from *o*-nitrobenzaldehyde in this article. The article also provides the chemical reaction, illustrated with the chemical structures. (McKee, J; Zanger, M. A Microscale Synthesis of Indigo: Vat Dyeing. *J. Chem. Educ.*, 1991, *68* (10), pp A242–A243; <http://pubs.acs.org/doi/pdf/10.1021/ed068pA242>. Note that this article is only available to American Chemical Society members or subscribers to the journal.)

This is a short article on the indigo dye in blue jeans. It discusses the color-addition and color-removal chemistry involved in dyeing and then fading the color to produce the worn look. (Wolf, L. Blue Jeans. *Chem. Eng. News*, 2011, *89* (43), p 44; <http://pubs.acs.org/doi/10.1021/cen-v089n043.p044>. 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. It is also available for free access at <https://pubs.acs.org/cen/science/89/8943sci3.html>.)

This book is filled with pictures, research, and the history of indigo. The cultural impact of indigo, as well as dyeing techniques from ancient to more modern times, is presented. (Balfour-Paul, J. *Indigo: Egyptian Mummies to Blue Jeans*; Firefly Books: Richmond Hill, ON, 2011.)

Beautiful photographs highlight indigo and its place in world history and culture. This book references the Balfour-Paul book (above) and is considered a companion piece. (Legrand, C. *Indigo: The Color that Changed the World*, 1st ed.; Thames & Hudson: New York, NY, 2013.)

# Web Sites for Additional Information

**Indigo**

Additional history and background information on indigo, including many photographs with indigo-dyed fabrics, are located at <http://facweb.cs.depaul.edu/sgrais/indigo.htm>.

**History of indigo**

The University of Minnesota Web site article "Indigo in the Early Modern World" briefly describes the history of indigo from about 2500 B.C. through the 1700s. (<https://www.lib.umn.edu/bell/tradeproducts/indigo>)

Indigo was a valuable crop in the U.S. southern states during the 18th century. The *South Carolina Encyclopedia* Web site published the article, "Indigo", and the site has links to related information and historical documents, including the use of slave labor in the production of indigo. (<http://www.scencyclopedia.org/sce/entries/indigo/>)

**Indigo problems**

*Popular Science* reports in 2013 on "The Problem with Indigo." The short article describes the problem of pollution in Bangladesh and China from the dye industry and the use of indigo and mordants. ([https://www.popsci.com/blog-network/techtiles/problem-indigo#page-2](https://www.popsci.com/blog-network/techtiles/problem-indigo%23page-2))

"Blue Jeans: Environmental Aspects and Opportunities to Reduce the Environmental Impact" is a 2013 report commissioned by the International Solid Waste Association. It examines the history, manufacturing, environmental impact (including climate), and opportunities to reduce the environmental impact of blue jeans made from cotton and treated with indigo and other chemicals. (<http://www.iswa.org/index.php?eID=tx_iswaknowledgebase_download&documentUid=3184>)

**Indican (soluble indigo)**

The University of California Berkeley provides “A Green Solution to Blue Denim” Web site, with tabs for "Project Blue Jeans" that includes an introduction to the problem of indigo dyeing of three billion pairs of jeans annually, using biosynthesis to produce indigo, and harnessing recombinant technology to produce indican. Additional information, including details on these and other components of making the use of indigo more environmentally friendly, is provided, along with photographs and reactions. (<http://2013.igem.org/Team:Berkeley>)

**Levi Strauss**

The Biography.com Web site includes an article on the life of Levi Strauss. The article begins with his birth in 1929 in Germany, immigrating to the U.S., his success with the birth of blue jeans, and concludes with his death in 1902. (<https://www.biography.com/people/levi-strauss-9496989>)

The Levi Strauss & Co. Web site also highlights their founder in a link, "A full biography of Levi Strauss," located at the bottom of their Web page, titled "Our Story." Additional links are provided at the bottom of the Web page to other articles, videos, and recommended readings. (<http://www.levistrauss.com/our-story/>)

**Jacob Davis**

One of the links at the bottom of the “Our Story” Web page on the Levi Strauss & Co. Web site takes you to "A biography of Levi Strauss's business partner, Jacob Davis," where a bulleted list of information on the life of Davis can be obtained. (<http://www.levistrauss.com/wp-content/uploads/2014/01/Jacob-Davis-His-Life-and-Contributions1.pdf>)

Another brief biography of Davis is supplied by the *History of Jeans* Web site. A partial copy of U.S. Patent No. 139121 granting Strauss and Davis ownership of the copper rivets in jeans is included. (<http://www.historyofjeans.com/jeans-inventor/jacob-w-davis/>)

**Blue jeans**

An interesting infographic, "Chemistry of Levi's," along with a short explanation, is located at <https://jameskennedymonash.wordpress.com/2014/07/31/why-are-jeans-blue-new-infographic-chemistry-of-levis/>.

A Web site, *History of Jeans*, is a fun site to read about all things jeans. Tabs on the site include history, inventors, facts, and making jeans. (<http://www.historyofjeans.com/>)

**Adolf von Bayer**

*The New World Encyclopedia* Web site details the life and accomplishments of Johann Friedrich Wilhelm Adolf von Baeyer, the noted organic chemist who won the Nobel Prize in Chemistry in 1905. (<http://www.newworldencyclopedia.org/entry/Adolf_von_Baeyer>)

The *Nobel Prize* Web site also has a page devoted to von Baeyer, recognizing his award in chemistry in 1905. The site contains links to information about von Baeyer for facts, biography, his 15 nominations for the Nobel Prize, and other resources. (<https://www.nobelprize.org/nobel_prizes/chemistry/laureates/1905/baeyer-facts.html>)

**Chromophores**

The University of Western Ontario has a slideshow converted to pdf, "Colours and Chromophores," which explains color theory, electron energy-level transitions, and chromophores, using diagrams, pictures, and text. (<https://instruct.uwo.ca/chemistry/2223/downloads/chromphores.pdf>)

This site is a succinct but complete explanation of chromophores, the different types, their role in human eyes, and other applications for them. (<http://www.innovateus.net/science/what-chromophore>)

**Glycosides / glycosidic bonds**

The Khan Academy supplies a video, "Glycoside Formation" (10:42), explaining the formation and mechanisms of glycosides at a collegiate level. (<https://www.khanacademy.org/test-prep/mcat/chemical-processes/nucleic-acids-lipids-and-carbohydrates/v/carbohydrate-glycoside-formation-hydrolysis>)

**Oxidation and reduction reactions**

The "What Is a Redox Reaction?" article by Khan Academy is a straight-forward lesson (or review) of oxidation and reduction reactions. The lesson includes example practice questions for engagement, balancing simple redox reactions, and some practice problems to balance. (<https://www.khanacademy.org/science/chemistry/oxidation-reduction/redox-oxidation-reduction/a/oxidation-reduction-redox-reactions>)

Khan Academy also provides a video, "Introduction to Redox Reactions" (10:53), which follows the article referenced above. The video illustrates assigning oxidation numbers, oxidation and reduction half-reactions, electron transfers, and balancing redox reactions. (<https://www.khanacademy.org/science/chemistry/oxidation-reduction/redox-oxidation-reduction/v/oxidation-reduction-or-redox-reactions>)

**Hydrogen bonds**

The LibreTexts Web site has a lesson, "Hydrogen Bonding," which is a clear explanation of simple and more complex examples of hydrogen bonding. The text is supplemented with diagrams and examples of hydrogen bonding found in nature. (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Physical_Properties_of_Matter/Atomic_and_Molecular_Properties/Intermolecular_Forces/Specific_Interactions/Hydrogen_Bonding>)

"Hydrogen Bonding" is a useful resource from the Purdue Chemistry Department. This concise and colorful lesson is an effective review of hydrogen bonding and its physical consequences. (<https://www.chem.purdue.edu/gchelp/liquids/hbond.html>)

**Intermolecular forces (IMFs)**

Boise State University provides a jigsaw activity (see explanation below) to help students learn about different intermolecular forces. Four student groups each study one of the intermolecular forces: London dispersion forces, induced dipole, dipole-dipole, and hydrogen bonds; the site provides links for more information, videos, and extension learning. In a jigsaw activity, each student becomes an expert on one aspect of a topic and teaches that topic to others in their group/class until all students have taught and learned all aspects. (<http://edtech2.boisestate.edu/lindabennett1/502/Bonds%20and%20IMFs/bonding%20jigsaw.html>)

The Khan Academy Web site has a valuable lesson, "Intramolecular and Intermolecular Forces," explaining each of these types of attraction. The portion focusing on IMFs includes dipole-dipole, hydrogen bonding, and London Dispersion forces, all clearly illustrated and explained. (<https://www.khanacademy.org/test-prep/mcat/chemical-processes/covalent-bonds/a/intramolecular-and-intermolecular-forces>)

**Color**

"Additive and Subtractive Color Mixing" is an informative article on the ColorBasics.com Web site. Additional tabs on the Web site take readers to information on color temperatures, history of color science, human eyesight, and numerous other items that may be of interest. (<http://www.colorbasics.com/AdditiveSubtractiveColors/>)

Eastern Illinois University provides a robust Web site, “Color and Vision,” that explains the complexities of understanding color addition and color subtraction (see Anticipating Student Questions, number 2, above). Additional tabs on the site address Color and Wavelength," "Dispersion and Spectra," "Rainbows," and "Color Vision", plus a summary and homework with answers. (<http://ux1.eiu.edu/~cfadd/3050/Ch17Color/ToC.html>).

**Electron excitation by light**

A Web site at Michigan State University publishes "Visible and Ultraviolet Spectroscopy,” which presents information and illustrations on the visible light spectrum, color, and conjugated pi-electron systems often found in chromophores. The site provides a diagram explaining electron transitions and relates these to UV and visible absorption spectra. (<https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/spectrpy/uv-vis/spectrum.htm>)

Another explanation of light causing electron excitation comes from LibreTexts. "What Causes Molecules to Absorb UV and Visible Light" contains clear diagrams showing the electron energy-level changes with light absorption and relates the changes to chromophores. (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Spectroscopy/Electronic_Spectroscopy/Electronic_Spectroscopy_Basics/What_Causes_Molecules_to_Absorb_UV_and_Visible_Light>)

**Conjugated bond systems**

A simple review of the chemistry of double covalent-bond formation is found at <https://www.chemguide.co.uk/atoms/bonding/doublebonds.html>.

Chromophores use alternating double and single bonds in a conjugated system, and this video, "Conjugated Pi Bonds" (13:53), explains and illustrates conjugated systems. (<https://www.youtube.com/watch?v=QJ_Z91bqfk0>)

**Aniline**

Aniline was the reactant von Baeyer used to synthesize indigo. Additional information on the synthesis, uses, derivatives, history, and toxicology of aniline is located at <http://www.toxipedia.org/display/toxipedia/Aniline>.

*Scientific American* published an excerpt from the book *Toms River: A Story of Science and Salvation* that tells the history of how William Henry Perkin revolutionized the dye industry using aniline. Aniline was a precursor in synthesizing numerous dyes in the latter 1800s, and Toms River, NJ, became an EPA Superfund site in 1983 due to vat dye manufacturing wastes. (<https://www.scientificamerican.com/article/toms-river-excerpt-on-aniline-dye/>)

**Naphthalene**

A fact sheet from the U.S. Environmental Protection Agency provides information about the hazards, uses, sources, and health effects of naphthalene. (<https://www.epa.gov/sites/production/files/2016-09/documents/naphthalene.pdf>)

A more reader-friendly article from the National Pesticide Information Center shares a general fact sheet containing an explanation of naphthalene, products that use it, how it works, symptoms of exposure, effects in the environment, and more. (<http://npic.orst.edu/factsheets/naphgen.html>)

# About the Guide

Teacher’s Guide team leader William Bleam and editors Pamela Diaz, Steve Long and Barbara Sitzman created the Teacher’s Guide article material.

E-mail: [bbleam@verizon.net](mailto:bbleam@verizon.net)

Susan Cooper prepared the anticipation and reading guides.

Terri Taylor, *ChemMatters* Teacher’s Guide interim editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher’s Guide.

E-mail: [chemmatters@acs.org](mailto:chemmatters@acs.org)

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>.