



**Tools and Resources**

***“Celebrating Paper!”***

April/May 2019

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

**Teacher’s Guide:**



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**Tools and Resources**

***“Celebrating Paper!”***

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# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Hydrogen bonds** | This article provides multiple examples where hydrogen bonds are important in both the formation and the properties of paper products. |
| **Covalent bonds** | As described in the article, paper towels use a polymeric cross-linker to form covalent bonds between cellulose fibers giving them greater strength when wet. |
| **Hydrophilic / Hydrophobic** | The cellulose used in paper is hydrophilic but can be treated with a sizing agent to make it more hydrophobic for special uses. |
| **Polymers** | The article explains that cellulose is a long-chain polymer of glucose units and provides an example of a natural polymer, cellulose. |
| **Amorphous** | Hemicelluloses and lignin are described in the article as being amorphous and contribute to paper’s flexibility. |
| **Crystalline** | Microfibrils in paper form hydrogen bonds to each other which results in rigid crystalline regions contributing to paper’s strength. |
| **Saccharides / Polysaccharides** | A sidebar in the article explains what sugars are, and gives an explanation of sugars, table sugar, and the polysaccharide, cellulose. |

# 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.

## Vocabulary

* **Vocabulary** and **concepts** that are reinforced in this issue:
  + Structural formulas
  + Proteins
  + Hydrogen bonding
  + Environmental impacts of personal and societal decisions
  + Periodic properties
  + Nuclear chemistry
  + Equilibrium
  + Green chemistry
* Consider asking students to read “Open for Discussion: Paper vs. Pixel” on page 4 before or after they read “Celebrating Paper!” to help them understand the complexity of making decisions about whether to use paper or electronic versions of paper products such as e-textbooks.
* The theme of Chemists Celebrate Earth Week (CCEW) this year is “The Chemistry of Paper,” so you and your students can check out some of the activities that can be found at the website found on the back cover.
* The engaging video “Is it OK to pee in the pool?” (see p. 18), produced by ACS, has excellent chemistry information.
* 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, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.

# Possible Student Misconceptions

1. **“United States paper money is made of paper.”** U.S. “paper” money is not really made of paper! It is made of 75% cotton and 25% linen with a few colored silk fibers running through it. Paper, cotton, and linen all are primarily composed of cellulose fibers, but the fibers in cotton and linen are stronger than the cellulose fibers in paper. The cotton and linen used in U.S. money give the currency its unique look and feel, make the bills more durable and waterproof (if you forget and wash them in your pocket), and make the money harder to counterfeit.
2. **“Using paper products destroys trees and forests.”** Trees are the most popular source of cellulose fibers for paper products and, certainly, trees are killed when they are cut down for use. However, most trees used in paper production come from managed forests—places where trees that are cut down for use are replaced with seedlings that are either planted or grow naturally in their place. In the past 100 years, the forested land of the U.S. has remained constant at about 750 million acres. It is beneficial for the paper companies to manage the forests well to ensure that they have an adequate supply of raw materials for the future. The paper industry estimates that about 40% of all trees harvested in the U.S. are used for paper, with the remainder going for lumber and construction. The old practice of clear-cutting large swaths of land is not commonly used today in the paper industry.
3. **“Because paper can be easily recycled, there is no need to cut down new trees.”** It is true that paper can be recycled; however, the fibers in paper products cannot be recycled infinitely. Most paper fibers can only be used and recycled about 4–6 times before they become so short or damaged that they are no longer useful (think of washing a shirt until it falls apart). Paper manufacturers must use some new fibers in their products; the percent of new fibers required is dependent upon the specific paper product. Certainly, by recycling most of paper used, the number of new fibers from trees is greatly reduced, but there will always be a need for new, replacement fibers even if demand for paper products remains at a constant level.
4. **“Printing is dead; electronic documents will soon replace all paper ones.”** Even in the “digital age”, there is a need for printed documents, and there will be for the foreseeable future. Electronic documents are certainly handy for many tasks, like for e-books, bills, bank statements, correspondence, email, and advertising. But many people prefer printed documents over electronic because they find it easier to read and comprehend printed material rather than electronic documents. Also, people who use electronic documents frequently print them for ease of reading and use or for long-term storage. Electronic documents have a useful place in the world, but printing is not dead, and paper documents have a useful place in most people’s lives, too.
5. **“All types of paper can, and should be, recycled.”** While it may be possible that all types of paper *can* be recycled, the better thought might be, “*Should* all types of paper be recycled?” The answer to that last question is, probably not. Most types of common paper can be, and are, recycled, such as newspapers, corrugated boxes, chipboard (cereal boxes), office (printer) paper, and junk mail. In 2015, paper products were the largest component (by weight) of US municipal solid waste, at 25.9%. Each person generates an average of 4.48 pounds of paper waste daily (<https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials>). Paper products had the highest recycling rate and accounted for about 67% (by weight) of all recycled materials in 2015. There are some types of paper that may be too expensive to successfully recycle, such as specialty papers with wax, foil, or plastic coatings; papers printed with oil-based inks; soiled papers (used pizza boxes, dirty napkins and paper towels); or even shredded papers, due to the shorter length and, thus, weakening of the paper fibers. Other types of paper that would be undesirable to recycle include toilet paper and disposable diapers. While people can always improve their recycling habits, U.S. citizens are doing a good job of recycling the appropriate types of paper.
6. **“It is better for the environment to recycle rather than to burn paper.”** The initial response from most people would be, yes, which is why paper recycling has a high participation rate in the U.S. Like many environmental issues, the accuracy of the answer is very complicated. Recycling paper certainly reduces the need to cut down new trees, energy used to produce virgin paper, the release of possible toxins (dioxin and metals used in inks) into the air, and the production of greenhouses gases from burning the paper. However, recycling paper is not as green as many people believe. Paper is dense and requires a lot of fuel to collect and haul it to recycling centers. The deinking process produces a toxic mess, and the amount of water used is greater than that used in producing virgin paper. Part of the energy used to produce virgin paper comes from burning the waste products (bark, etc.) from the trees. Much of the energy used to recycle paper comes from electricity, which may be generated from mining and burning coal. Either recycling or burning paper is preferable to throwing it away.

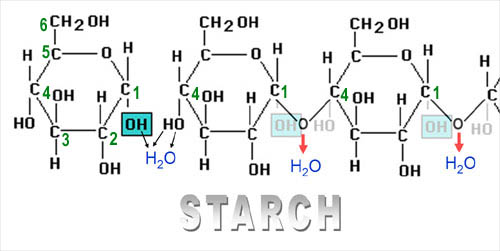
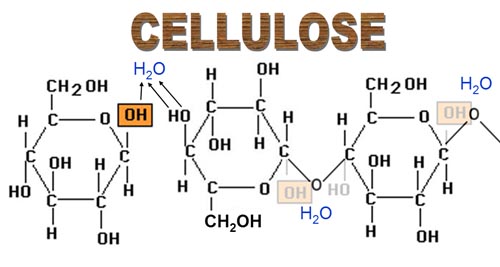
# Anticipating Student Questions

1. **“If paper is made of cellulose, and cellulose is made of the common sugar glucose, why can’t people digest paper?”** Cellulose and starch are similar polymers, both made of the repeating glucose monomer. The short answer why people can’t digest paper as they can starch is that humans don’t have the appropriate enzyme to break down the cellulose molecule. The primary difference between starch and cellulose is that the bonds between glucose monomers are not the same. The bonds between glucose molecules in starch are called alpha (α) linkages, and the bonds between glucose molecules in cellulose are called beta (β) (linkages. (See the diagrams below.)

In the diagram of a starch molecule below, the glucose monomers all have the same orientation and the α linkages are all below the plane of the glucose monomers, while in the diagram of the cellulose molecule, successive glucose monomers are flipped 180o, producing β linkages as the bonds that link successive monomers alternately form above and below the plane of the monomers.

This simple, but significant, difference in the structures requires different enzymes to break the alpha and beta linkages in these molecules. No vertebrate animal has the necessary enzyme to digest cellulose directly, but some animals (horses, cattle, sheep, and goats) have symbiotic bacteria in their guts that allow them to break down the cellulose (found in plants and grasses), benefitting both the bacteria and the animal. Even termites, known for destroying wood (made of cellulose), cannot digest cellulose without symbiotic bacteria.

*(*[*http://www.chemistryland.com/CHM107Lab/Exp03\_DetectOzone/OzoneLab/GlucoseMakesStarch.jpg*](http://www.chemistryland.com/CHM107Lab/Exp03_DetectOzone/OzoneLab/GlucoseMakesStarch.jpg)*)*

([*https://mybiochem.wordpress.com/tag/cellulose/*](https://mybiochem.wordpress.com/tag/cellulose/)*)*

1. **“When was paper invented?”** It is believed that the Chinese made the first true paper (thin sheets of macerated plant fibers) around 100 CE, and its manufacture spread to the Islamic world through the Silk Road during the 6th to 8th centuries. Papyrus and parchment were used in the Mediterranean and other areas of the world before then, but the pulping of the plant fibers and production of sheets (true paper) originated with the Chinese. The Chinese used the paper for writing and for religious art using woodblock printing.
2. **“How many different kinds of paper are there?”** The Web site <https://rbms.info/vocabularies/paper/th343.htm> lists over 80 types of paper, and many of them could have multiple subdivisions. Paper types can be organized by fiber patterns, method of manufacture, use (or not) of sizing, or by end use. Paper has myriad uses, from the more common ones such as writing, wrapping, boxes, facial tissues, and printed media, to less common uses that include magician’s flash paper, underwater paper, and thermochromic paper (changes color with heat). Some people believe that if the mind can dream it, there’s a paper that might achieve it!
3. **“Why does some paper tear better in one direction than another (e.g., newspaper)?”** As the wood fibers are deposited on a moving belt to form the paper, the long pulp fibers tend to line up in the direction of the belt’s travel. With the fibers mostly aligned in one direction, it gives the completed paper a grain, or direction of orientation. If the paper is torn with the alignment of the pulp fibers, then the paper tears more smoothly and evenly. However, trying to tear the paper perpendicular to that grain will result in a ragged pattern, as the tear goes against the direction of the fibers. Creasing the paper sharply will help the paper tear more evenly because it breaks the pulp fibers. Sometimes lightly dampening the paper crease with water will improve the tearing action because the water interferes with the hydrogen bonding between the fibers.
4. **“Why does paper wrinkle when it gets wet?”** Paper is composed of compressed cellulose fibers held together primarily by hydrogen bonds between the fibers. Water causes the compressed cellulose fibers to expand and breaks the hydrogen bonds between the compressed fibers, allowing them to separate. When the paper is wet, the expansion of the wet fibers shifts their location and places them in a different, wrinkled, arrangement. Also, as the water evaporates and hydrogen bonds reform between the fibers, the wrinkling sets up because the cellulose fibers are no longer compressed. Entropy also plays a role in this behavior, because the wrinkled paper has a lower energy state than a smooth, flat piece of paper.
5. **“Is it true that paper bags are more environmentally friendly than plastic bags?”** This is an excellent, but complex, question. Some localities are considering action regarding single-use plastic (polyethylene) shopping bags. Before the 1970s, most shopping bags were brown paper bags, but concern over cutting forests, plus other environmental factors, led to the development of the plastic bags used today. To fully answer the question requires analysis of multiple factors. Paper bags are a renewable resource and can be recycled like other paper products. Plastic bags are produced from petroleum, a non-renewable resource, but they can also be recycled. Paper bags are strong when manufactured from high virgin fiber content (from new trees), but much weaker when using recycled fibers. Plastic bags are typically produced from ethane, a by-product of natural gas extraction. The manufacture of paper bags requires four times the water and two to four times the energy that is required to produce plastic bags. In a complete life cycle analysis (LCA), most studies agree that plastic bags are more environmentally friendly. An important point lies in reusing either type of bag as many times as possible and then recycling it. Paper bags have a higher recycling rate than plastic bags, which may be why there are so many plastic bags in the environment. Also, the paper bags will break down more readily in the environment when wet and can decompose faster than the plastic bags that can litter the land. Good stewardship of either resource, reduction of littering, conscious reuse, and purposeful recycling efforts can allow either type of bag to fill needs in society. So, which is better? It depends on how the bags are used, reused, recycled, and their method of disposal. Perhaps the ultimate solution might be for consumers to use their own cloth or durable plastic bags for shopping, as many are starting to do. But those bring their own problems, such as bacterial contamination in the bags from the contents, and spills, especially from fresh meats if the bags are not cleansed properly and regularly.

# Activities

**Labs and demos**

**“Paper Making” lab:** In this lab for 9th to 12th graders, students start with used paper and process it to form new, recycled paper. It includes directions, helpful suggestions, and options for varying the paper composition. (<https://www.teachervision.com/print-making/paper-making>)

**“Biofuels: Cellulose Lab”:** This two-day lab uses paper pulp (shredded newspapers) as the starting material for the enzymatic conversion of cellulose into sugar for use as a biofuel. Materials provided include the student lab sheet, teacher guide, and additional teacher resources. (<https://eli.lehigh.edu/energy/instructional-sequence/day-21>)

**Simulations**

“**Hydrogen Bonds: A Special Type of Attraction”:** In this activity students manipulate temperatures while viewing the formation of hydrogen bonds among water molecules. Students can show the hydrogen bonds with dotted lines, show partial charges on the atoms, and use slow-motion animation. (<https://learn.concord.org/resources/769/hydrogen-bonds-a-special-type-of-attraction>)

**“Molecule Polarity”:** This PhET simulation allows students to investigate polarity, electronegativity, bonds, partial charges, and dipoles, which may assist them with comprehending the structure of cellulose and its interactions with water. (<https://phet.colorado.edu/en/simulation/molecule-polarity>)

**Media**

**“Chasing Paper” video (45:10):** This video from National Geographic examines the past, present, and future of paper in our lives. The video includes segments on modern paper manufacturing and toilet paper. (<https://www.youtube.com/watch?v=4K85aiiD_6I>)

**“Intermolecular Forces” video (8:35):** The segment of this Khan Academy video from   
2:54–5:47 explains hydrogen bonding, using the water molecule as an example. (<https://www.khanacademy.org/science/biology/chemistry--of-life/chemical-bonds-and-reactions/v/intermolecular-forces-and-molecular-bonds>)

**Lessons and lesson plans**

**“The Science of Papermaking and Paper Recycling: A Research Experience for Teachers” lessons:** This site, while described as “for teachers”, provides three lab activities: Bleaching of Recycled Pulp, Flotation Deinking of Copy Paper, and Screening Experiment to Determine Yield of a Recycling Process, all with directions, extensions, and questions that may be adapted for classroom use in studying paper and its recycling. (<http://www.shodor.org/ssep/lessons/paperscience/index.html>)

**“Paper Recycling Experiments and Studies” lesson plans:** This Web site provides lesson plans, plus K–12 labs, activities, suggestions for science fair projects, and background information for making paper and recycling paper. (<https://www.juliantrubin.com/encyclopedia/environment/paperrecycling.html>)

**Projects and extension activities**

**“Measuring Paper Strength” activity:** This lab, which could be conducted at home using common items, or done at school, allows students to measure the strength of different papers. The lab also includes suggestions for extension experiments. (<https://cnr.ncsu.edu/fb/wp-content/uploads/sites/2/2014/04/testingpaper.pdf>)

**“Hand Papermaking” project:** Conventional methods of making paper actually recycle old paper, but this Web site provides numerous free articles with helpful advice for hand-making paper from plants. Readers will find the process challenging and will need to read carefully because the articles provide only general information with few details; however, sufficient information is included to inspire adventurous readers to tackle making raw paper. (<https://handpapermaking.org/?page_id=30>)

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***



“Old News, New Paper” provides information on the processes of recycling newspaper, including de-inking, bleaching, and forming the paper. (Borchardt, J. Old News, New Paper. *ChemMatters*. 1993, *11* (2), pp 12–14)

“Sizing Up Paper” explains: controlling how different papers absorb moisture by using sizing, preserving papers, and the historical spread of paper across the world, as well as providing chemical structures for compounds discussed. (Ruth, C. Sizing Up Paper. *ChemMatters*. 1998, *16* (2), pp 10–12)

“The Money Makers” describes how paper currency is made, including the special paper, inks, printing, security measures, and counterfeiting. (Venere, E. The Money Makers. *ChemMatters*. 2003, *21* (1), pp 14–16)

This article includes an activity for using paper chromatography to separate water-based markers into their components. (Brownlee, C. Forensic Chemists: Solving Mysteries with Fascinating Science. *ChemMatters*. 2010, *28* (3), pp 17–19)

This “Open for Discussion” article examines whether paper or plastic bags are better for the environment. (Sitzman, B.; Goode, R. The Big Bag Battle. *ChemMatters*. 2014, *32* (1), p 5)

“It’s Not Easy Being Green—Or Is It?” explains a life cycle analysis (LCA) and explores the life cycles of disposable paper cups, shopping bags, and plastic water bottles. (Tinnesand, M. It’s Not Easy Being Green—Or Is It? *ChemMatters*. 2014, *32* (1), pp 12–13)

“Cellulosic Ethanol: A Fuel of the Future?” looks at the process of producing cellulosic ethanol from corn and other bio-sources. (Sherwood, J. Cellulosic Ethanol: A Fuel of the Future? *ChemMatters*. 2016, *34* (2), pp 16–18)

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“New Paper from Newspaper”, a *J. Chem. Educ.* Classroom Activity, provides a two-part student activity to a) make paper from old newsprint and answer questions about that paper, then b) use the finished paper in an art project. (Gettys, N.; Jacobsen, E First initial. New Paper from Newspaper. *J. Chem. Educ.*, 2001, *78* (11), p 1512A–1512B; <https://pubs.acs.org/doi/pdf/10.1021/ed078p1512A>. Note that this link takes you to a brief abstract only; the full article is available only to American Chemical Society members or subscribers to the journal.)

# Web Resources for More Information

**Paper manufacturing**

“Overview of Pulp and Papermaking Processes” provides an in-depth explanation of paper manufacturing.

(<http://kchbi.chtf.stuba.sk/upload_new/file/Miro/Proc%20problemy%20odovzdane%20zadania/Moln%C3%A1r/10_1002@9780470649657_ch2.pdf>)

This link is a shorter and less technical description of how paper is manufactured.

(<http://www.madehow.com/Volume-2/Paper.html>)

**The history of paper**

Follow this link for excellent information on the origin of, history of, and interesting facts about paper.

(<http://users.stlcc.edu/nfuller/paper/>)

**Products made from paper**

This site provides a list of products made from paper, organized by categories like office and school, household, medicine and technology, and more.

(<https://www.paperonweb.com/A1096.htm>)

This article, “10 Most Bizarre Uses of Paper in History”, might be a slight exaggeration, but the uses *are* unusual.

(<https://www.huffingtonpost.com/nicholas-a-basbanes/post_5940_b_4136654.html>)

**Paper recycling**

“Life-Cycle Assessment for Paper Products” is a report from a 1997 symposium examining the entire process for recycling certain paper products and the environmental impacts of paper use and recycling.

(<https://www.nap.edu/read/5734/chapter/9>)

Read this article for a concise, colorful, and informative overview of recycling paper products and an extensive list of reference links.

(<https://greentumble.com/how-is-paper-recycled-step-by-step/>)

**Types of paper**

This site lists different types of paper with a brief description of their composition, uses, or characteristics.

(<http://www.csun.edu/~pjd77408/DrD/resources/Printing/images03/20024.pdf>)

**Paper versus plastic bags**

The environmental impact of both paper and plastic bags is outlined in this article.

(<https://science.howstuffworks.com/environmental/green-science/paper-plastic1.htm>)

This site provides another discussion of the controversy of whether consumers should use paper or plastic bags in shopping.

(<http://www.yalescientific.org/2015/05/paper-vs-plastic-the-science-behind-the-national-shopping-controversy/>)

**Papermaking**

This web site is a compendium of many aspects of papermaking, but readers will find the categories and multiple links within “Fun and Art”, “Mini-encyclopedia”, and “Links: Paper Chemistry Sites” of particular interest.

(<https://projects.ncsu.edu/project/hubbepaperchem/>)

**Cellulose**

Cellulose was the ACS Molecule of the Week on January 19, 2009, and this link provides both structural and ball-and-stick formulas and a brief description of the compound.

(<https://www.acs.org/content/acs/en/molecule-of-the-week/archive/c/cellulose.html>)

This infographic shows the cellulose in cotton fibers, with their hydrogen bonds, and how water can disrupt the hydrogen bonds between cellulose molecules.

(<https://www.compoundchem.com/wp-content/uploads/2017/03/The-Chemistry-of-Ironing.png>)

**Hydrogen bonding**

Students may refresh their knowledge of hydrogen bonding by reading this article, which includes charts and illustrations.

(<https://www.chemguide.co.uk/atoms/bonding/hbond.html>)

**Hydrophilic and hydrophobic**

This Web site explains the concepts of hydrophilic and hydrophobic compounds with useful pictures.

(<http://news.mit.edu/2013/hydrophobic-and-hydrophilic-explained-0716>)

**Polysaccharides**

This link explains various types of saccharides, including polysaccharides, plus a description of cellulose (with structural formula) and why it is different from amylose, a starch.

(<http://www.edinformatics.com/math_science/what_are_polysaccharides.htm>)

**House made of paper**

A curiosity, this house has typical wood framing, floors, and roof, but the walls and much of the furnishings are made of paper.

(<https://www.paperhouserockport.com/index.html>)