

**April/May 2017 Teacher's Guide**

**for**

***Expresso, Café Latte, Cappuccino… A Complex Brew***

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# About the Guide

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

E-mail: bbleam@verizon.net

Susan Cooper prepared the anticipation and reading guides.

Patrice Pages, *ChemMatters* editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher’s Guide.

E-mail: 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>.

# Student Questions

**Espresso, Café Latte, Cappuccino… A Complex Brew**

* 1. The world’s coffee is provided by what two species of trees?
	2. Where is one possible birthplace of coffee?
	3. What happens during the Maillard reaction?
	4. Explain what happens to coffee beans during pyrolysis.
	5. What are two alkaloid compounds found in the coffee bean and how do they benefit the coffee plant?
	6. How does roasting coffee beans affect the flavor of the coffee beverages?
	7. How does brewing coffee create a solution?
	8. Why should you not use boiling water to make coffee?
	9. Why are espresso drinks much stronger than regular coffee?
	10. What is the purpose of the thick, reddish-brown foam or crema in an espresso drink? How is it formed?
	11. What are the differences between a café latte and a cappuccino?

# Answers to Student Questions

**(taken from the article)**

**Espresso, Café Latte, Cappuccino… A Complex Brew**

* + 1. **The world’s coffee is provided by what two species of trees?**

*The two types of trees that provide most of the world’s coffee are Coffea arabica and Coffea canephora.*

* + 1. **Where is one possible birthplace of coffee?**

*A legend of a goat herder places the birthplace of coffee in Ethiopia.*

* + 1. **What happens during the Maillard reaction?**

*In the Maillard reaction, “carbohydrates react with amino acids at high temperatures, producing chemical compounds that are brown in color.”*

* + 1. **Explain what happens to coffee beans during pyrolysis.**

*During pyrolysis, some compounds decompose at high temperatures in the absence of oxygen. In particular, fats in the coffee beans are converted to aromatic oils, responsible for coffee’s aroma.*

* + 1. **What are two alkaloid compounds found in the coffee bean and how do they benefit the coffee plant?** *The two alkaloid compounds found in coffee beans are trigonelline and caffeine. They are bitter and can be toxic, which is useful in warding of predators.*
		2. **How does roasting coffee beans affect the flavor of the coffee beverages?**

*The coffee bean contains a combination of acids and alkaloids which tend to neutralize each other. As coffee is roasted, the acid compounds break down making darker roasts less acidic and thus more bitter. Chlorogenic acid in coffee beans is broken down into lactones which can further break down into phenylindanes both of which have a very bitter taste.*

* + 1. **How does brewing coffee create a solution?**

*When coffee is brewing, hot water drips through the coffee grounds and soluble components from the grounds are dissolved in the water, producing a solution.*

* + 1. **Why should you not use boiling water to make coffee?**

*Coffee should not be made with boiling water because boiling water drives off too many of the aromatic molecules that give coffee its taste.*

* + 1. **Why are espresso drinks much stronger than regular coffee?**

*Espresso drinks are much stronger than regular coffee due to the higher yield of total dissolved solids, averaging about 12%–10 times greater than normal coffee.*

* + 1. **What is the purpose of the thick reddish-brown foam or crema in an espresso drink? How is it formed?**

*The foam or crema gives a lot of the flavor and aroma to the espresso. It tastes sweet, balancing out the bitterness of the other layers. “The crema is formed due to bubbles of carbon dioxide being outgassed from the grounds as the espresso is made.”*

* + 1. **What are the differences between a café latte and a cappuccino?**

*The differences between a café latte and a cappuccino are that a café latte has more milk and less foam than a cappuccino. Because the air filled foam contributes more to the volume of the drink than to its mass, a cappuccino will be stronger than a latte.*

# Anticipation Guide

Anticipation guides help to engage students by activating prior knowledge and stimulating students' 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.

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

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The world’s coffee comes from more than 20 types of trees.
 |
|  |  | 1. Coffee trees are native to South America.
 |
|  |  | 1. Coffee beans, grilled hamburgers, and toasted bread all brown due to the Maillard reaction.
 |
|  |  | 1. When heated, coffee beans crack due to expansion.
 |
|  |  | 1. Caffeine is a naturally occurring alkaloid with two rings containing nitrogen.
 |
|  |  | 1. Dark roasted coffee is more acidic than lighter roasts.
 |
|  |  | 1. Allowing the coffee to brew longer will create a stronger coffee.
 |
|  |  | 1. The aromatic oils in coffee become gases when heated.
 |
|  |  | 1. Espresso is made at very low pressure.
 |
|  |  | 1. The world’s most expensive coffee has passed through an elephant.
 |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Students’ 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 articles. The use of bullets helps them do this. If you use these reading strategies 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 |

***Teaching Strategies:***

* 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** and **concepts** that are reinforced in this issue:
	+ Chemical reactions
	+ Macro- and micronutrients
	+ Personal and community health
	+ Proteins
	+ Structural formulas
	+ Biochemistry
	+ Consumer choices
	+ Recycling
* Some of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them in their personal lives.
* Consider asking students to read “Open for Discussion” on page 4 to extend the information in “Growing Green on the Red Planet” on pages 5-7.
* The infographic on page 19 provides more information to support the article “Espresso, Café Latte, Cappuccino…A Complex Brew” on pages 10-12.
* 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 Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

**Directions:** As you read the article, complete the graphic organizer below to describe how coffee is produced and prepared.

|  |  |
| --- | --- |
|  | **How chemistry affects the outcome** |
| **Roasting** |  |
| **Brewing** |  |
| **Creating specialty coffee beverages** | **Espresso** |
| **Café Latte** |
| **Cappuccino** |

**Summary:** On the back of this page, write 3 new things you learned about the chemistry of coffee.

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Chemical reactions**—The Maillard reaction, pyrolysis, and caramelization can be used as practical examples of chemical reactions.
2. **Organic chemistry**—While teaching about organic chemistry, the structures of caffeine, chlorogenic acid, and trigonelline can be used to illustrate various functional groups. Classes of compounds such as ketones and aldehydes are also illustrated here.
3. **Acids and bases**—The taste of coffee is due to the presence of acids and their ability to neutralize the bitter taste of the alkaloid compounds also present. This would be an excellent everyday example to use while talking about acid-base reactions.
4. **Solubility**—The amount of dissolved coffee solids in water determines coffee strength. This could be emphasized when teaching the factors that affect solubility.
5. **Bonding and intermolecular forces**—The aroma emitted from brewing coffee is due to volatile oils that readily turn to gas when the coffee is heated. This can be used as an example of heat overcoming the bonding forces in the molecules as they transition into the gaseous state.
6. **States of matter**—Coffee drinks can be used to illustrate the three main states of matter as well as provide examples for different types of mixtures.
7. **Kinetics**—When you are studying kinetics, coffee-making provides an excellent example of the factors that influence reaction rates, such as particle size, and temperature.
8. **Properties of solutions**—Solutions are supposed to be transparent and, most students believe, colorless. Coffee offers a great example of a colored solution.

# Possible Student Misconceptions

**(to aid teacher in addressing misconceptions)**

1. **“Coffee can’t be a solution, because it is brown.”** *Students often think that if a solution is colored, it is not a true solution. They tend to equate clear or transparent and colorless as being the same thing. Coffee that has had any solids filtered out is a solution. When milk is added, the beverage becomes a homogenous mixture that could be classified as a colloid, the same as milk. Transition metal compounds dissolved in water offer another group of examples of colored solutions.*
2. **“Coffee is bad for your health. Research has proven it.”** *Some research has been published revealing deleterious effects of caffeine; however, most recent research has shown that, taken in moderation, coffee actually reduces the risks for heart disease, colon cancer, depression, type II diabetes, Parkinson’s disease, and even death itself.*
3. **“Energy drinks contain more caffeine than coffee.”** *An 8-ounce cup of brewed coffee contains an average of 100 mg of caffeine while the same amount of Red Bull has only 80 mg and a 12-ounce cola soft drink contains between 35 and 55 mg of caffeine. Energy drinks have other substances in them besides caffeine that may also contribute to the drink’s effects.*

# Anticipating Student Questions

**(answers to questions students might ask in class)**

1. **“Who would spend $70 for a cup of coffee that has been in elephant dung?”** *Black Ivory coffee is a luxury item that is sold for its novelty, as well as for the ritual of experiencing it. If you are near Comfort, Texas, you and three friends can try a small cup for $50. Some people would pay this amount just for the experience.*
2. **“Does adding milk to coffee affect the caffeine level in the blood?”** *The short answer is no. This is backed up by a report that appeared in the* Journal of Nutrition*. A summary of those findings is included below:*

*There isn’t a great deal of evidence in the scientific literature exploring the issue of coffee and cow’s milk interactions. By far, the best data currently available can be found in the February 2010 issue of the Journal of Nutrition. There, a pilot trial examined the absorption and retention of coffee-derived antioxidants in 9 healthy subjects. On separate occasions, the study participants were given different coffee preparations:****a)****instant coffee;****b)****instant coffee + 10% whole milk;****c)****instant coffee + nondairy creamer + sugar. All of the coffee beverages contained an identical amount of chlorogenic acid, one of the primary, health promoting phytochemicals contained in coffee.*

* *Blood samples were taken 12 hours after the consumption of each experimental drink.*
* *The testing looked for various, beneficial phytochemicals associated with coffee’s health effects.*

*The findings indicate that the addition of milk did not significantly alter “the overall bioavailability of coffee phenolic acids, whereas sugar and nondairy creamer” did affect the “maximum plasma concentrations or Cmax” and the retention of these select antioxidants or Tmax.*

*These results are largely consistent with several other laboratory studies conducted in animal and in-vitro models. To be clear, some research has shown that dairy protein (casein) does bind to antioxidants such as chlorogenic acid. But this interaction doesn’t appear to negatively affect total antioxidant capacity. This may partially have to do with a decoupling effect that naturally occurs during digestion.*

*(*[*http://www.healthyfellow.com/607/coffee-milk-controversy/*](http://www.healthyfellow.com/607/coffee-milk-controversy/)*)*

1. **“Why does drinking coffee give you more energy and keep you from sleeping?”** *Caffeine has a similar structure to a neurotransmitter in the brain, called adenosine that is responsible for energy level. When it is removed from activity by adenosine receptors in the brain, the response is decreased energy and drowsiness. Caffeine has a similar molecular structure that can block the adenosine receptors, thus maintaining a higher circulatory level of adenosine. With more adenosine circulating, the body remains alert. Also, caffeine initiates some adrenalin release, which helps you feel a surge in energy. Third, caffeine causes the release of dopamine, another neurotransmitter that helps brighten your mood.*
2. **“Why are there two cracks that happen at two different temperatures when coffee is being roasted?”** *The first crack is the result of the moisture in the bean expanding and breaking the shell similar to popcorn. It is caused by the water being converted to steam, and the pressure that builds up finally ruptures its container. The second crack is caused by the second series of chemical reactions that are producing gaseous products. These, too, cause the bean to crack when the pressure builds up deep inside the bean.*
3. **“In the article, why do they say a cappuccino is stronger than a latte, if the two drinks have the same amount of coffee in them?”** *This is really a concentration issue. Though both drinks contain the same amount of coffee in them, the latte has more milk. This dilutes the coffee, making it less concentrated. It’s like when all the ice has melted in your Dr. Pepper, it doesn’t taste as “strong” (now less concentrated) as it did before the ice meltdown.*

# Activities

**Labs and Demos**

1. **Separation of a mixture by distillation lab:** A procedure complete with diagrams, questions, and notes to the instructor on this lab that uses coffee to introduce the techniques involved in using distillation to separate a mixture. Thorough lesson plans and a time line are provided. This would be a good lab to use while teaching solutions and mixtures. (<https://www.researchgate.net/publication/283149887_coffee_distillation_procedure_and_lesson_plan>)
2. **Lab activity to extract fragrances from a variety of substances and classify the smells:** The theme of this lesson is “How does a coffee bean become a cup of java?” This lab activity begins with a discussion about coffee and how coffee tasters judge coffee, based on smell and taste. The experiment guides students to extract fragrances from substances and then describe the smell of what they have extracted. This could be a fun activity performed in small groups, with their results shared out with the entire class. ([www.reachoutMichigan.org/funexperiments/agesubject/lessons/newton/coffee.html](http://www.reachoutMichigan.org/funexperiments/agesubject/lessons/newton/coffee.html))
3. **Lab to determine how origin and roast affect coffee’s acidity:** Students could explore the difference in acidity between coffees of different origins or roasts. They could design their own experiments, making sure to look out for variables to control and safety factors to consider. The pH testing should be done by a pH meter or probe, as the differences in pH between the different varieties may not be distinguishable with pH paper strips. Note that as an open-ended experiment, students may eventually find that their instrumentation is insufficient to show any differences in results. You may want to try this experiment first to see if you get significant results, before you do the lab in class.

An example of a general procedure to measure pH using probes can be found here: (<https://www.wardsci.com/www.wardsci.com/images/Acidic_Drinks_pH.pdf>).

1. **Lab to extract caffeine from coffee:** Caffeine is extracted from coffee using dichloromethane. This lab is geared toward the college student. If you are teaching an advanced chemistry class, you may be interested in doing this. Much of the lab must be performed under a fume hood, with good ventilation throughout the room. (<http://carbon.indstate.edu/inlow/LabManuals/Caffeine.pdf>) This YouTube video might be useful for the students to see the correct way to use a separatory funnel. (<http://carbon.indstate.edu/inlow/LabManuals/Caffeine.pdf>)
2. **A lab demo that answers the question of when to best add cream to coffee:**

To answer the age old question, “Does your coffee cool faster if you add the cream to your coffee right away and drink it later, or if you take the cream along and add it just before you want to drink it?,” you might want to go to the Newton’s Apple video clip, “Coffee and Cream”, here: <http://www.newtonsapple.tv/video_only.php?id=3022> . This is a somewhat light-hearted, yet scientific approach to the experiment. There appears to be a definitive answer here related to kinetic molecular theory. You might want to show the experiment a second time and have students look for uncontrolled variables in the experiment, or ways to improve on the experimental design. Alternatively, you might want to set this up as a student lab, so your students can determine for themselves the answer to this age-old question.

(Teacher’s Guide, p 45, for Haines, G. Brain Booster to Go? *ChemMatters*, 2008, *26* (4), pp 7–9)

**Simulations**

1. **Titration simulation to determine the pH of various liquids:** During a unit on acids and bases, this PHET simulation provides extra practice with determining pH, using titration. Coffee is one of the substances that can be chosen to titrate. (<https://phet.colorado.edu/sims/html/ph-scale/latest/ph-scale_en.html>)

**Media**

 **Videos**

1. **The “Science of Caffeine” and your brain video:** This short (2:26) video produced by the ACS describes the chemical interactions of caffeine and its metabolites on the brain. It could be shown as an introduction to a discussion about student caffeine use. (<http://time.com/64985/how-caffeine-affects-brain>)
2. **Black Ivory coffee videos:** For students who express an interest or curiosity in Black Ivory coffee, these videos will show them the elephants and the processing of the coffee. They will also see the special pot used to brew the coffee. The videos are located at the very bottom of the page. They are (1:48) and (4:20) in length. (<http://the-elephant-story.com/pages/black-ivory-coffee>)
3. **An inside view of coffee roasting using a Go Pro camera:** This short (3:15) video shows the coffee roasting process using a Go Pro camera to get the bean’s perspective. The video is located at the bottom of the Web page. (<http://www.ncausa.org/About-Coffee/Coffee-Roasts-Guide>)
4. **The “Chemistry of Coffee” video:** This (4:45) chemistry-packed video could be shown after reading the article to complement the information about caffeine. (<https://www.coffeechemistry.com/chemistry/alkaloids/the-chemistry-of-coffee-video>)
5. **The Universe in a Cup of Coffee is chemistry combined with physics:** An “ACS Reactions” video (4:38) that packs in multidisciplinary science concepts in describing the science in a cup of coffee can be found here: <https://www.youtube.com/watch?v=xANGsTqxdUw>.
6. **Narrated slide show video about coffee:** Students might appreciate the mild sarcasm in this short (4:20) YouTube narrated slide show. The fast-paced video shows a world map of the areas where coffee is grown, as well as pictures of the tree and cherries. Coffee’s effects on the body are also addressed with high school humor. (<https://www.youtube.com/watch?v=OTVE5iPMKLg>)
7. **Video of a different point of view about drinking coffee:** If your goal is to stimulate some discussion in your classroom as to the pros and cons of drinking coffee, this (6:15) video may be useful, as it supports limited coffee consumption from the Ayurveda perspective. Some pros and cons are discussed by the practitioner, but he comes down on the side of viewing coffee as a medicine and limiting its consumption. You could also use this video to initiate student research into studies on coffee’s effects on the body. (<https://www.youtube.com/watch?v=fnYsrJ5yeco>)
8. **Video, brewing the perfect cup:** This video (6:51) explains the science behind roasting coffee and the science used in brewing the perfect cup of coffee. It reinforces the material in the *ChemMatters* article as to the chemical reactions that are occurring as the coffee is roasting. (<https://oeta.pbslearningmedia.org/resource/0c1c1d56-2209-4049-b505-e69c867cf420/brewing-the-perfect-cup>)

**Slide show**

1. **Black Ivory coffee slide show:** A beautiful 35-frame slide show can be found at this site. This may be a good assignment for the students who were curious about this type of coffee mentioned in the sidebar of the *ChemMatters* article. (<http://www.cbsnews.com/pictures/pricey-elephant-poop-coffee/>)

**Lessons and Lesson Plans**

1. **“Coffee Production: Sustainability, Ecofriendly practices and Social Impact”:** This link is to a zipped folder containing a PowerPoint presentation of the history of coffee, the cultivation, production, and harvesting of coffee, as well as instructions and data sheets for conducting taste tests. ([www.extension.UGA.edu/k12/science-behind-our-food/biology.cfm](http://www.extension.UGA.edu/k12/science-behind-our-food/biology.cfm); scroll down to the title listed above in bold, titles are in alphabetical order)
2. **How caffeine affects the body:** While this set of lessons primarily addresses energy drinks, it does address caffeine and its effect on the body. Four pages of teacher’s notes and two student handouts are included in this packet to help you plan a lesson on this topic. (<http://rsc.org/learn-chemistry/resource/res00000856/the-chemistry-of-sports-and-energy-drinks>)
3. **How long does it take the body to clear caffeine?:** If you are looking for ways to work more math into your lesson plans, this site offers data for students to evaluate in order to determine what is the rate that caffeine is eliminated from the body. Algebra 3 skills are used. It also might be used as an interdisciplinary activity with a math teacher. Scroll down on the page until you find the lesson titled “Cup of Coffee” (<http://www.nuffieldfoundation.org/fsmqs/level-3-algebra>)

**Projects and Extension Activities**

1. **Health related pros and cons of coffee consumption:** Students could be assigned to research the latest findings on the effects of coffee on health. This could culminate in a class discussion or debate on the topic. The Web sites provided in this teachers guide on coffee and health could serve as a starting point. You could include the following video (6:15) to help spark the discussion. You may want to stop the video before the practitioner gives his final judgement. (<https://www.youtube.com/watch?v=fnYsrJ5yeco>)
2. **Caffeine diaries**: Students may want to track their daily caffeine consumption. You could give them a copy of the table of beverages and their caffeine content found at this site. (<https://www.math.utah.edu/~yplee/fun/caffeine.html>)
3. **Economics extension:** Students could research weather patterns in Brazil or Colombia and compare them to the price of coffee. Occasions when there have been killing frosts might affect the coffee price for a year or more.

# References

**(non-Web-based information sources)**

**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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Three processes used to decaffeinate coffee are explained in this 1999 *ChemMatters* article. (Barstow, K. The Case of the Missing Caffeine. *ChemMatters*, 1999, *17* (2), pp 12–13)

The health effects of a few of the 800+ chemicals found in coffee are presented in a way that would make this article an excellent addition to the current article. Some of the same concepts, such as the chemical reactions and roasting of coffee beans, are discussed, but the primary focus of this article is the effect of caffeine on brain chemistry. (Haines, G. Brain Booster to Go? *ChemMatters*, 2008, *26* (4), pp 7–9)

The Teacher’s Guide to the above article contains further historical information, a list of the chemical compounds found in coffee beans, and multiple ideas for projects and class discussions.

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

 Harold McGee discusses the history of coffee brewing, coffee beans and their roasting, always bringing out the chemistry involved in each step. There is a good table on page 446 on methods of brewing coffee. (McGee, H. *On Food and Cooking: The Science and Lore of the Kitchen;* Scribner: New York, NY, 2004; pp 441–447, <http://www.wtf.tw/ref/mcgee.pdf>)

# Web Sites for Additional Information

**(Web-based information sources)**

**History of coffee**

 A history of coffee can be found here as part of a series on the stories behind the foods we eat. The article ends with some recipes for coffee drinks, as well as a flank steak marinated in coffee. (<http://www.pbs.org/food/the-history-kitchen/history-coffee/>)

 More information about the history and development of coffee can be found at this wiki site. Here you will find the words to Bach’s cantata about coffee. (<https://en.wikipedia.org/wiki/Coffee#/media/File:Carte_Coffea_robusta_arabic.svge>)

**Coffee**

 This *National Geographic* site is a treasure trove of information about coffee. There is a good world map that highlights the coffee producing countries. (<http://www.nationalgeographic.com/coffee/ax/frame.html>)

 Another world map that show where the different varieties of coffee are grown can be found at this site: <https://upload.wikimedia.org/wikipedia/commons/3/3c/Carte_Coffea_robusta_arabic.svg>.

 The reference page for Coffee Review has information links provided for every aspect of coffee. For students looking for more information, it would be a good place to start. (<http://www.coffeereview.com/coffee-reference/>)

 The National Coffee Association Web site provides general information about coffee production, from farm to table. ([www.ncausa.org](http://www.ncausa.org))

 At this site you will find a link to four different published academic articles about coffee chemistry. (<https://www.coffeechemistry.com/category/6-published-articles>)

**Coffee roasting reactions**

 The chemistry of roasting reactions, as well as a complete description of the changes occurring in the coffee bean during each minute of roasting are presented at this site. (<https://www.quora.com/What-is-the-science-behind-coffee-roasting>)

Information on the Maillard reaction can be found here: <http://www.scienceofcooking.com/maillard_reaction.htm>.

 A comprehensive flow diagram of the Maillard reactions, using the structural formulas of the compounds, is located at this site: <http://compoundchem.com/wp-content/uploads/2015/01/The-Maillard-Reaction.pdf>.

 The caramelization reaction is discussed at this Wikipedia Web site: <https://en.wikipedia.org/wiki/caramelization>.

 A guide to roasting types can be found at this site. It is an infographic of all 8 roasts of coffee and their respective acidity and roast characteristics. (<https://nationalcoffeeblog.org/2015/11/19/a-guide-to-roasting-types/>)

 A two part article about the science of roasting coffee, and the chemistry that is involved, can be found here.

* (<https://www.coffeechemistry.com/send/6-published-articles/20-alchemy-in-the-roasting-lab-part-1>)
* (<https://www.coffeechemistry.com/send/6-published-articles/21-alchemy-in-the-roasting-lab>)

 Pyrolysis reactions are presented here: <https://en.wikipedia.org/wiki/pyrolysis>.

 Roasting reactions such as pyrolysis and the pyrolytic products of trigonelline are presented in this paper, titled “the antithrombotic effects of pyridinium compounds formed from trigonelline upon coffee roasting.” (<http://pubs.acs.org/doi/ipdf/10.1021/jf5008538>)

**Brewing coffee**

A frothing guide and extensive information about the chemistry of milk in frothing for espresso drinks is available at this coffee geek Web site. (<http://coffeegeek.com/guides/frothingguide/milk>)

 More on the science of producing milk foam used in espresso drinks can be found at this site. Discussion about the differences between lattes, cappuccinos and machiatos is also included. (<http://www.thecoffeebrewers.com/article2.html>)

 “A chemistry teacher’s guide to brewing the perfect cup of coffee” is the title of this article in *The Guardian*. Most chemistry variables related to the brewing process are discussed. (<https://www.theguardian.com/commentisfree/2015/oct/23/a-chemistry-teachers-guide-to-the-perfect-cup-of-coffee>)

 The story of the first espresso machine, complete with a picture of the inventor and his patent sketches, is located here: <http://www.thecoffeebrewers.com/about-demitasse-spoons.html>.

**Caffeine**

A table containing the caffeine content of many popular beverages can be found here: <https://www.math.utah.edu/~yplee/fun/caffeine.html>.

**Compounds in coffee**

 Technical information about chlorogenic acid can be found at this data base site: <https://pubchem.ncbi.nlm.nih.gov/compound/chlorogenic_acid#section=Top>.

A hyperlinked list of many of the acids found in coffee is located at this site. The hyperlinks take you to the structural formulas of the acids. Not all acids on the list are hyperlinked. (<http://www.coffeeresearch.org/science/sourmain.htm>)

 This scientific article about acids in coffee is a good source of diagrams of chlorogenic acid and the quinides. The article describes the reactions occurring during roasting. (<https://www.coffeechemistry.com/send/6-published-articles/19-organic-acids-revisited>)

“The chemistry of Coffee” is the title of this paper. Caffeine, trigonelline, lipids, pyrazines, and pyridines, and Maillard reactions in coffee are all discussed. Structural diagrams of some of the compounds are used. (<https://www.coffeechemistry.com/send/6-published-articles/22-the-chemistry-of-coffee>)

 The aroma compounds like the chlorogenic lactones and the phenylindanes are discussed in this *C&EN* article on coffee aroma, titled “Tweaking Coffee’s Aroma.” (<http://pubs.acs.org/doi/pdf/10.1021.cen-v085n038.p032>)

**Coffee and health**

 **“**Chemistry in Every Cup” is the title of this article that addresses the effects coffee has on each major organ system in the body. (<https://www.chemistryworld.com/feature/chemistry-in-every-cup/1012386.article>)

 Coffee consumption and how it affects bone density is addressed in this article. Also addressed is whether adding milk to coffee influences how compounds in coffee are absorbed by the body. (<http://www.healthyfellow.com/607/coffee-milk-controversy/>)

 This journal article describes a study that correlated coffee consumption and bone loss. (<http://ajcn.nutrition.org/content/74/5/694.full>)

 This *New York Times* article reports on the results of numerous meta-analysis studies about the health effects of coffee consumption. (<https://www.nytimes.com/2015/05/12/upshot/more-consensus-on-coffees-benefits-than-you-might-think.html>)

 An article in *The Atlantic* discusses the results of several studies into the effects of coffee consumption on human health. A study that links coffee to protection from type II diabetes is included in this article. (<https://www.theatlantic.com/health/archive/2012/11/the-case-for-drinking-as-much-coffee-as-you-like/265693/>)

 What are the compounds responsible for the heart-healthy effects of drinking coffee is the focus of this paper, titled “the antithrombotic effects of pyridinium compounds formed from trigonelline upon coffee roasting”. (<http://pubs.acs.org/doi/ipdf/10.1021/jf5008538>)

 Studies that investigated if there was any correlation between cancer and coffee consumption are reported in this article: <http://healthyfellow.com/651/coffee-estrogen-link/>.

 Calcium depletion, spinal osteopenia and coffee intake is the topic of the paper found at this address: <http://www.healthyfellow.com/771/coffee-calcium-controversy/>.

**Black Ivory coffee**

An NPR interview of the entrepreneur who started the Black Ivory coffee business can be found here: <http://www.npr.org/sections/thesalt/2014/08/20/340154271/no-1-most-expensive-coffee-comes-from-elephants-no-2>.

 Links to a variety of articles are located at this site: (<https://www.blackivorycoffee.com/news>. If you go to the home page from this page you will find more videos and information about Black Ivory coffee.