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**December 2014 Teacher's Guide**

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# About the Guide

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Articles from past issues of *ChemMatters* can be accessed from a CD that is available from the American Chemical Society for $30. The CD contains all *ChemMatters* issues from February 1983 to April 2008.

The *ChemMatters CD* includes *an* Index that covers all issues from February 1983 to April 2008.

The *ChemMatters* CD can be purchased by calling 1-800-227-5558.

Purchase information can be found online at [www.acs.org/chemmatters](http://chemistry.org/chemmatters/cd3.html)

# Student Questions (from the articles)

**How Toxic is Toxic?**

* 1. According to the article, what two factors should be considered to determine if a substance is toxic?
  2. Explain why the Paracelsus quote “The dose makes the poison” is important in this article.
  3. In the term LD50, what does the “LD” represent?
  4. And what is the definition of the entire term “LD50”?
  5. What are the units in which LD50 is measured?
  6. The article mentions methods of administering poison other than ingestion. What are they?
  7. How does toxicity vary with LD50 values?
  8. The LD50 value of substance A = 5 mg/kg. The LD50 value of substance B = 23.5 mg/kg. Which substance is more toxic?
  9. What is the LD50 value for caffeine?
  10. What application of the botulinum toxin demonstrates that in very small concentrations a deadly poison can be harmless?
  11. List three concerns about the use of LD50 values to measure toxicity in humans.

**So Tired in the Morning: The Science of Sleep**

1. Why was Jilly Dos Santos concerned about the school board’s pending decision?
2. In what ways did Jilly use technology in her quest for more sleep time?
3. Was Jilly successful in her quest to delay the time for opening school? Explain.
4. How does the chemical melatonin help regulate our sleep cycle?
5. Where is melatonin produced in the body?
6. What is the role of NAT in the production of melatonin?
7. When is NAT activity the greatest?
8. Why does melatonin production often result in teens receiving less than nine hours of sleep per night?
9. Give three examples of positive results reported from school districts that adopted later start times.
10. If your school has an early start time, what is one way that you can help signal your body that it is time to go to sleep?
11. How did understanding the chemistry in this article help Jilly and her friends improve their lives?
12. Circadian rhythms regulate our sleep schedule. Are other life forms controlled by these cycles?

**A Measure of Confusion**

* 1. What was the first indication NASA had that the Mars Climate Orbiter was in trouble?
  2. And what WAS the problem?
  3. Why do societies even have and use units?
  4. Over man’s history, why were there so many different systems of units for measurement?
  5. What factor is responsible for developing the need for international standardization in measurement systems?
  6. Name two measurement units that were based on varying or variable “standards”.
  7. What was the goal of the metric system when it was first developed?
  8. Discuss one major advantage of the metric (or SI) system over all the other conventional systems in existence at the time (1799).
  9. Cite two examples of units of measure used by countries that have adopted the metric system that are not metric-based.
  10. Internationally, how widespread is the adoption of the metric system?
  11. What has prevented the U.S. from adopting the metric system wholesale?
  12. What one consideration is pushing the U.S. to adopt the metric system wholesale?
  13. In the U.S., industries frequently use both U.S. Customary units and metric system units to measure their consumer products. List two examples of this.

**Red, Brown, Black, Orange Hair Today, Bleached Tomorrow**

1. What are the names of the two natural pigments in the hair?
2. What colors does each natural pigment produce?
3. Explain the difference between the pigments in black hair and red hair.
4. Describe what is meant by the term conjugated double bond.
5. Do all molecules with conjugated bonds absorb visible light? Explain your answer.
6. What specifically absorbs electromagnetic energy in a molecule?
7. Explain why a substance appears red if it absorbs green light.
8. What happens to the molecules of eumelanin when bleach is applied? Be specific.
9. In a redox reaction, what substance gains electrons and which substance loses electrons?
10. Why is a base commonly used with hydrogen peroxide to bleach hair?
11. Which hair bleaches more quickly, red or brown hair? Explain why.
12. Why does black hair frequently turn reddish orange when bleached?
13. Occasionally, bleached hair that is later dyed will turn green. Explain why this happens.

**Pheromones: The Chemical Language of Animals**

1. What is the basic chemical composition of pheromones?
2. List the three types of intermolecular forces that attract molecules to each other.
3. How is volatility of a compound related to its intermolecular forces?
4. What is a primary function of pheromones in the animal world?
5. For insects living in colonies, such as ants and bees, what use do they make of pheromones?
6. Since many pheromones are volatile and travel by gaseous diffusion, how does the queen bee’s “queen mandibular pheromone”, QMP, travel through the hive when it is not a very volatile substance?
7. Why is QMP needed in a hive—what purpose does it serve?
8. How are pheromones used by ants in food searches?
9. Can different ant colonies use the same ant trail to find food? Why or why not?
10. What synthetic cat pheromones are available for cat owners and for what are they used?

# Answers to Student Questions (from the articles)

**How Toxic is Toxic?**

* + 1. **According to the article,** what two factors should be considered to determine if a substance is toxic?

*The two factors identified in the article are how much of the substance enters the body and how it enters the body. See “More on the factors affecting how poisonous a substance is” for a more detailed discussion.*

* + 1. **Explain why the Paracelsus quote “The dose makes the poison” is important in this article**.

*The quote stresses the point made in the article that any substance can be a poison if a person is exposed to enough of it.*

* + 1. **In the term LD50, what does the “LD” represent?**

*The “LD” is the abbreviation for the term “lethal dose.”*

* + 1. **And what is the definition of the entire term “LD50”?**

*“LD50” is the amount of a given substance required to kill 50% of a test population (lab rats or other animals).*

* + 1. **What are the units in which LD50 is measured?**

*The units for LD50 are mg substance / kg body mass or mg / kg.*

* + 1. **The article mentions methods of administering poison other than ingestion. What are they?**

*The article lists these variations: administration through the skins (dermal LD50), injection (intravenous LD50) and inhalation (LC50), or lethal concentration.*

* + 1. **How does toxicity vary with LD50 values?**

*They have an inverse relationship. The lower the LD50 value, the greater the toxicity of the substance.*

* + 1. **The LD50 value of substance A = 5 mg/kg. The LD50 value of substance B = 23.5 mg/kg. Which substance is more toxic?**

*Substance A is more toxic because less of it is required to kill 50% of the test subjects.*

* + 1. **What is the LD50 value for caffeine?**

*According to the table on page 7, it is 192 mg/kg for rats.*

* + 1. **What application of the botulinum toxin demonstrates that in very small concentrations a deadly poison can be harmless?**

*It can be used in very small doses to treat cerebral palsy, multiple sclerosis and Parkinson’s disease. And used in even smaller doses, it removes wrinkles in the skin; this product is Botox.*

* + 1. **List three concerns about the use of LD50 values to measure toxicity in humans.**

*Three concerns about the use of LD50 values to measure human toxicity are:*

1. *Citing ethics concerns, animal rights groups object to using lab animals, even rats, in laboratory tests to determine toxicity.*
2. *Despite rats having anatomies similar to humans (making them good test subjects for toxicity tests), their anatomies still differ significantly from those of humans, thus possibly making the results of these LD50 tests far less accurate than we assume them to be.*
3. *LD50 values measure acute toxicity, not chronic effects. This means that these tests only measure immediate effects of doses, not long-term (acute) effects (e.g., lead poisoning has a cumulative effect on the body).*

**So Tired in the Morning: The Science of Sleep**

1. **Why was Jilly Dos Santos concerned about the school board’s pending decision?**

*Jilly’s concern about the school board’s decision centered on her worry about not being able to handle the earlier 7:20 a.m. start time they were suggesting.*

1. **In what ways did Jilly use technology in her quest for more sleep time?**

*Jilly set up a Facebook page and a Twitter account to enlist help from her friends to attend the school board meeting and make a case against an earlier start time.*

1. **Was Jilly successful in her quest to delay the time for opening school? Explain.**

*Yes, Jilly was successful; she and her friends presented their scientific research to the board and in a final decision, the school board decided to begin school at 9:00 a.m.*

1. **How does the chemical melatonin help regulate our sleep cycle?**

*Melatonin is a hormone that builds up during the day and makes us feel sleepy at night. It decreases by morning so that we feel refreshed when we wake up.*

1. **Where is melatonin produced in the body?**

*Melatonin is produced in the pineal gland, a small organ in the brain, shown in Figure 2.*

1. **What is the role of NAT in the production of melatonin?**

*NAT is the enzyme that catalyzes the formation of melatonin from serotonin (see Figure 3).*

1. **When is NAT activity the greatest?**

*NAT is most active at night (in the dark) when its concentration is greatest, thus producing the maximum amount of melatonin.*

1. **Why does melatonin production often result in teens receiving less than nine hours of sleep per night?**

*Teens often get less than nine hours of sleep because their 24-hour cycle differs from the cycle for adults and young children. This is due to the fact that their melatonin production is about three hours later than for others, keeping them up later and making them feel sleepy when they awake early in the morning.*

1. **Give three examples of positive results reported from school districts that adopted later start times.**

*Districts that adopted later start times found*

1. *students got more than five extra hours of sleep per week;*
2. *attendance and enrollment rates improved;*
3. *student alertness increased and rates of depression decreased; and*
4. *the number of car crashes was reduced significantly.*
5. **If your school has an early start time, what is one way that you can help signal your body that it is time to go to sleep?**

*To signal to your body that it is time to sleep, you can reduce the stimulation of artificial light by turning off your TV, computer, and cell phone.*

1. **How did understanding the chemistry in this article help Jilly and her friends improve their lives?**

*Jilly and her friends researched and learned the chemistry required to convince the school board to improve their lives by changing their school’s schedule to a later start time.*

1. **Circadian rhythms regulate our sleep schedule. Are other life forms controlled by these cycles?**

*Research shows that circadian rhythms are present in many forms of life, including plants, animals and bacteria.*

**A Measure of Confusion**

1. **What was the first indication NASA had that the Mars Climate Orbiter was in trouble?**

*The first indication NASA had that there was a problem was when flight controllers couldn’t detect a signal from the Orbiter when it was expected to come out from behind the planet.*

1. **And what WAS the problem?**

*The problem with the orbiter was that engineers had made an error when converting between metric and English units. Pound-force-seconds, a unit of impulse and momentum in the English system of measurement, was used instead of Newton-seconds—the unit of impulse and momentum in the metric system.*

1. **Why do societies even have and use units?**

*Units are used by societies in “… trade and commerce, land division, taxation, and scientific research…”*

1. **Over man’s history, why were there so many different systems of units for measurement?**

*Different systems of measurement units were developed by individual societies for their own purposes, usually involving local trade—long before there was international trade or widespread inter-societal communication.*

1. **What factor is responsible for developing the need for international standardization in measurement systems?**

*According to the article, development of international trade spurred the need for an internationally standardized system of measurement.*

1. **Name and describe two measurement units that were based on varying or variable “standards”.**

*Two units of measurement (and more) that were based on varying “standards” are:*

* + - 1. *The* cubit, which *was based on the length of the forearm from the elbow to the tip of the middle finger.*
      2. *The* yard, *which was the distance from the tip of King Henry I of England’s nose to the end of his outstretched thumb.*
      3. *The* grain *was the mass of one grain of a grain type (very variable).*
      4. *A* span *was three palms.*
      5. *A palm was four digits.*

1. **What was the goal of the metric system when it was first developed?**

*According to the article, “The basic concept of the metric system was to adopt a system of uniform base units that serve as the foundation for decimal-based derived units. The derived units were identified by a standard set of prefixes for larger or smaller divisions of the base unit.”*

1. **Discuss one major advantage of the metric (or International System of Units—SI) system over all the other conventional systems in existence at that time (1799).**

*A primary advantage of the metric system over all other systems in use at the time was that its units reflected all distances, from astronomical distances (e.g., between planets) to sub-microscopic distances (e.g., between atoms. (Most other systems were based solely on measurements on a “human-size scale”.)*

1. **Cite two examples of units of measure used by countries that have adopted the metric system that are not metric-based.**

*Two non-metric-based units (and then some) used by countries that have adopted the metric system are:*

1. *In the United Kingdom, distance is still measured in miles, height in feet and inches (instead of kilometers, meters and centimeters), and units of weight used are stones and pounds (instead of newtons).*
2. *In Argentina, Chile and Australia, tire pressure is still measured in pounds per square inch (psi), the British Imperial System unit for pressure, instead of Pascals (Pa), the SI unit for pressure.*
3. *Some countries in northern Europe still use inches and feet (and hence, “2 by 4s” for construction), instead of meters and centimeters.*
4. *Worldwide, automobile wheel diameters are measured in inches while tire tread depth is measured in millimeters.*
5. *Worldwide, racing bike frames are measured in centimeters, while mountain bike frames are measured in inches.*
6. **Internationally, how widespread is the adoption of the metric system?**

*The metric system has been adopted by all countries worldwide except Burma, Liberia and the United States.*

1. **What has prevented the U.S. from adopting the metric system wholesale?**

*The author says that the reason the metric system hasn’t been adopted in the U.S. is that the federal government hasn’t* mandated *its use, including the ban of the old U.S. Customary system. Of course, inertia also plays a role; we keep using what we are familiar with—few of us embrace change!*

1. **What one consideration is pushing the U.S. to adopt the metric system wholesale?**

*The one factor that might push the U.S. into adopting the metric system is international trade. If every other country uses metric measurements, the U.S. will be (and is being) forced to use metric measurements in its products if it wants to continue trading with other countries.*

1. **In the U.S., industries frequently use both U.S. Customary units and metric system units to measure the same consumer product. List two examples of this.**

*Two examples (plus one more—all shown somewhere in the article) of using both types of units for the same consumer product are:*

* + - 1. *Teaspoons and milliliters for dispensing medicine*
      2. *Liters and quarts to measure volume of liquids (e.g., milk or other drinks).*
      3. *Speedometers show speed in both miles per hour (m/hr) and kilometers per hour (km/hr).*
      4. *Others the student might be familiar with could include:*

1. *Liquids like soups and soaps, juices and energy drinks, all measured both in fluid ounces and milliliters*
2. *Dry goods (e.g., cereals, cake mixes or potato chips) measured both in ounces and grams*
3. *String, rope, dental floss or ribbon measured both in yards or feet and meters*

**Red, Brown, Black, Orange Hair Today, Bleached Tomorrow**

1. **What are the names of the two natural pigments in the hair?**

*The two natural pigments in hair are eumelanin and pheomelanin.*

1. **What colors does each natural pigment produce?**

*Eumelanin is responsible for brown and black colors in hair. Pheomelanin creates the orange and yellow tones.*

1. **Explain the difference between the pigments in black hair and red hair**.

*Black hair contains more eumelanin than pheomelanin. There may be as much as 25 times more eumelanin than pheomelanin in black hair. Red hair contains equal amounts of the color pigments.*

1. **Describe what is meant by the term conjugated double bond.**

*Conjugated double bonds are double bonds alternating with single bonds.*

1. **Do all molecules with conjugated bonds absorb visible light? Explain your answer.**

*No, not all molecules with conjugated bonds absorb visible light. The molecule must have at least eight conjugated bonds to absorb visible light. Only these will appeared colored.*

1. **What specifically absorbs electromagnetic energy in a molecule?**

*Electrons in molecules absorb electromagnetic energy and move from their ground state to a higher energy level.*

1. **Explain why a substance appears red if it absorbs green light.**

*When green light is absorbed by a substance, we see its complementary color on the color wheel, red.*

1. **What happens to the molecules of eumelanin when bleach is applied? Be specific.**

*When hydrogen peroxide is applied to eumelanin it disrupts conjugated double bonds by removing electrons in a reduction-oxidation reaction. Breaking the conjugated double bond system results in shorter conjugate bond systems that cannot absorb visible light [as already established in question 6], thus the new substance appears colorless.*

1. **In a redox reaction, what substance gains electrons and which substance loses electrons?**

*Atoms in the oxidizing agent gain one or more electrons while atoms in the oxidized molecule lose one or more electrons.*

1. **Why is a base commonly used with hydrogen peroxide to bleach hair?**

*The hydroxide ion, OH–*, *from the base reacts with the hydrogen peroxide to form water and a perhydroxyl anion which reacts with the eumelanin and pheomelanin, breaking them into fragments that have too few conjugated double bonds to absorb visible light. The base also opens the outer layer of the hair shaft and allows the bleach to penetrate to the inner layers where it can react with the pigment molecules.*

1. **Which hair bleaches more quickly, red or brown hair? Explain why.**

*Brown hair bleaches more quickly because the perhydroxyl anion reacts with the eumelanin more quickly than the pheomelanin. Pheomelanin is more stable than eumelanin. Since brown or dark hair has more eumelanin than pheomelanin it will bleach more quickly.*

1. **Why does black hair frequently turn reddish orange when bleached?**

*Since eumelanin is bleached quicker than pheomelanin***,** *when black hair is bleached the amount of eumelanin is decreased significantly, changing the color balance. Pheomelanin, which causes hair to be reddish, becomes predominant making the hair reddish orange.*

1. **Occasionally, bleached hair that is later dyed will turn green. Explain why this happens.**

*Hair dyes are formulated assuming that the hair contains a certain amount of pheomelanin. Manufacturers add blue pigments that, when combined with the pheomelanin, look brown. If there is not enough orange from pheomelanin to balance out the blue, the blue dye combines with the residual bleached yellow color to produce hair with a green color.*

**Pheromones: The Chemical Language of Animals**

1. **What is the basic chemical composition of pheromones?**

*Pheromones are hydrocarbons—a carbon backbone to which hydrogen is attached; sometimes oxygen juts off the sides of the carbon backbone as well.*

1. **According to the article, what are the two types of intermolecular forces that attract molecules to each other?**

*The two types of intermolecular forces are:*

1. *dipole-dipole interactions of polar molecules and*
2. *dispersion forces of attraction between non-polar molecules*
3. **How is volatility of a compound related to its intermolecular forces? Explain your answer.**

*The stronger the intermolecular forces, the lower the volatility of a substance. Stronger intermolecular forces (e.g., dipole-dipole interactions) stick molecules together for longer periods of time, so it’s harder to separate them, so they’re not as likely to evaporate.*

1. **What is a primary function of pheromones in the animal world?**

*A primary function of pheromones is to help animals recognize each other and other animals.*

1. **For insects living in colonies, such as ants and bees, what use do they make of pheromones?**

*Their pheromones help them to recognize each other, to detect foreign invaders, and to identify their role in the colony.*

1. **Since many pheromones are volatile and travel by gaseous diffusion, how does the queen bee’s “queen mandibular pheromone”, QMP, travel through the hive when it is not a very volatile substance?**

*The QMP produced by the queen is carried by bees attending the queen, as they move around the hive.*

1. **Why is QMP needed in a hive—what purpose does it serve?**

*The QMP is used to inform the hive residents that the queen bee is alive and continues to reign. It helps maintain reproductive exclusivity for the queen.*

1. **How are pheromones used by ants in food searches?**

*When ants go out in search of food, they leave a chemical pheromone trail. When a desirable food source is located, the ant returns to the colony, reinforcing that particular trail through the deposition of more pheromone which other ants can then follow to the food.*

1. **Can different ant colonies use the same ant trail to find food? Why or why not?**

*Members of one colony cannot detect another colony’s chemical marker. The markers left by the ants of one colony are very specific in chemical structure so that only the ants of that colony can detect them. Even though the molecules might only differ by one methyl (CH3–) group, that is enough difference to prevent a second colony from detecting that colony’s “scent”.*

1. **What synthetic cat pheromones are available for cat owners and for what are they used?**

*Synthetic feline facial pheromones (FFPs) are now available for cat owners. These synthetic pheromones are used to make cats in a new home feel or sense that the environment is familiar.*

# *ChemMatters* Puzzle: Chemical Ken-Ken Puzzle

Like its big brother SUDOKU, KEN-KEN is a logic game from Japan. In 4x4 grid on the left, your objective is to fill the digits 1–4 so that each appears **exactly once** in each row and each column.

Notice that most boxes are part of a cluster. In the upper-left corner of each multibox cluster is a value that is the SUM of its numbers. For example, if that value is 3 for a two-box cluster, you know that only 1 and 2 can go in there. But it is your job to determine which number goes where! A few clusters may have just one box, and that is the number that fills that box.

We will help you solve this warm-up puzzle or you can cover up our completed version to try it on your own!

**WARM-UP PUZZLE SOLUTION**

A B C D

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 5+ |  | 7+ | 8+ |  | 5+  **2** | **3** | 7+  **4** | 8+  **1** |
| 2 | 3+ |  |  |  | 3+  **1** | **2** | **3** | **4** |
| 3 | 11+ | 1 | 3+ |  | 11+  **4** | 1  **1** | 3+  **2** | **3** |
| 4 |  |  |  | 2 | **3** | **4** | **1** | 2 |

1. The single-box cluster at D4 contains a 2. Where is the other single cluster, and what digit goes there?
2. The three boxes in the upper-right corner total 8. There are just three ways to achieve that: 1+3+4, 2+2+4, and 3+3+2 (in any order). But since you *cannot* repeat a number in column four, two ways are eliminated!
3. Such number logic will also let you set the bottom left-hand corner cluster of three boxes. Try it!
4. Once three digits are in place in any row or column, the fourth must follow.

It likely will not take you long to complete the puzzle. More difficult puzzles use a 5x5 grid filled with the digits 1,2,3,4, and 5, or 6x6 with 1, 2, 3, 4, 5, and 6, etc. They may also use more than one kind of math operation.

On the next page we show you a variant called CHEMICAL KEN-KEN. It is played on a 5x5 grid and uses multiplication rather than addition, along with some knowledge of the elements and the periodic table. Have fun in solving it!

The **Chemical Ken-Ken** is a 5x5 grid so the digits are 1, 2, 3, 4, and 5. And the values are obtained by multiplying them instead of adding them. For example, a three-box cluster containing 3, 3, and 5 would show a value of 45. Note that *that* set of factors is the *only* way for a three-box cluster to have a value of 45. Any cluster containing the number 5 must yield a product that ends in either 5 or 0.

In this blank grid, we represent the value with a letter. Below the grid is a group of clues about chemical elements. As you decipher each clue, transfer that atomic number to the grid and then proceed as you did on the first page. For example, if you think the element labeled (a) is oxygen (which it isn't…), you would put 8 beside “a” in the grid. The more clues you can decipher the first time, the more easily you can determine the values of the other numbers. You can also work backward to deduce a missing atomic number, knowing the numbers at play.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **a** |  | **b** | **c** |  |
| **d** |  | **e** |  |  |
| **f** | **g** |  | **h** |  |
|  |  | **i** |  | **j** |
| ***k*** |  | ***l*** |  |  |

CLUES

Identify the **atomic numbers** of the following 12 elements as best you can. A few appear more than once. Then transfer it to the corner of the box in the grid holding that letter.

a A not-too-dense but tough metal, sometimes used in flares.

b The most common element in a star.

c The first metal to have both its *3d* and *4s* subshells filled in its ground state.

d The second-most common element in a star.

e This group-2 metal is predominant in quick lime, lime water, and limestone.

f Besides oxygen and carbon, a key element in the spiral ”backbone” of DNA

(but not the nucleic acids that make up the “rungs”).

g In a periodic table, this element occupies period 5, group 4.

h This alkali metal has the strongest drive to be oxidized, measured by Eox values.

i Its boiling point is a very cold 4.1 K.

j This metal’s carbonate salt has a molar mass of 100.

k The one element in the alkaline-earth group that is *not* a true metal.

l Graphite is one of the allotropes of this element.

# Answers to the *ChemMatters* Puzzle

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **a 12 4** | **3** | b **1**  **1** | **c** 30 **5** | **2** |
| d 2  **2** | **1** | 20 **e**  **5** | **4** | **3** |
| **f 15**  **5** | **g 40**  **2** | **4** | **h 3 3** | **1** |
| **3** | **5** | **i 2**  **2** | **1** | **j 20**  **4** |
| ***k*** 4  **1** | **4** | ***l 6***  **3** | **2** | **5** |

The numbers in the upper-right corner of each cluster match the clues given on the previous page.

Here are the **atomic numbers** and **symbols** and clues for the 12 entries.

a 12 Mg A not-too-dense but tough metal, sometimes used in flares.

b 1 H The most common element in a star.

c 30 Zn The first metal to have both its *3d* and *4s* subshells filled in its ground state.

d 2 He The second-most common element in a star.

e 20 Ca This group-2 metal is predominant in quick lime, lime water, and limestone.

f 15 P Besides oxygen and carbon, a key element in the backbone spirals of DNA.

g 40 Zr In a periodic table, this element occupies period 5, group 4

h 3 Li This alkali metal has the strongest drive to be oxidized, measured by Eox values.

i 2 He Its boiling point is a very cold 4.1 K.

j 20 Ca This metal’s carbonate salt has a molar mass of 100.

k 4 Be The one element in the alkaline-earth group that is *not* a true metal.

l 6 C Graphite is one of the allotropes of this element.

# Next-Generation Science Standards (NGSS) Correlations

|  |  |
| --- | --- |
| **Article** | **NGSS** |
| **How Toxic is Toxic?** | |  | | --- | | **HS-PS1-5**  Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. |   **Crosscutting Concepts:**   * Scale, proportion, and quantity   **Science and Engineering Practices:**   * Developing and using models * Using mathematics and computational thinking * Obtaining, evaluating, and communicating information   **Nature of Science:**   * Scientific knowledge assumes an order and consistency in natural systems. |
| **So Tired in the Morning . . . The Science of Sleep** | |  | | --- | | **HS-PS1-6**  Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.  **Crosscutting Concepts:**   * Cause and effect: Mechanism and explanation * Structure and Function   **Science and Engineering Practices**:   * Constructing explanations and designing solutions   **Nature of Science**:   * Science models, laws, mechanisms and theories explain natural phenomena. * Science addresses questions about the natural and material world. | |
| **A Measure of confusion** | |  | | --- | | **HS-ETS1-3**  Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. |   **Crosscutting Concepts:**   * Cause and Effect   **Science and Engineering Practices:**   * Analyzing and interpreting data * Obtaining, evaluating, and communicating information   **Nature of Science:**   * Science is a human endeavor. |
| **Red, Brown, Black, Orange Hair Today, Bleached Tomorrow** | |  | | --- | | **HS-PS3-2**  Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).  **Crosscutting Concepts:**   * Cause and Effect * Structure and Function   **Science and Engineering Practices:**   * Constructing evidence and designing solutions   **Nature of Science**:   * Science addresses questions about the natural and material world. | |
| **Pheromones: The Chemical Language of Animals** | |  | | --- | | **HS-PS1-3**  Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. | | **Crosscutting Concepts:**   * Structure & Function * Systems and System Models   **Science and Engineering Practices**:   * Asking questions and defining problems * Obtaining, evaluating, and communicating information   **Nature of Science**:   * Science models, laws, mechanisms, and theories explain natural phenomena. * Scientific knowledge assumes an order and consistency in natural systems. | |

# 

# Common Core State Standards (CCSS) Connections

**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.

**RST.9-10.2:** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

**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.

**RST.11-12.2:** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

***In addition***, the teacher could assign writing to include the following **Common Core State Standards**:

**WHST.9-10.2** Develop the topic with well-chosen, relevant, and sufficient facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience’s knowledge of the topic.

**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).

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

**WHST.11-12.2**  Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience’s knowledge of the topic.

# Anticipation Guides

Anticipation guides help 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.

**Directions for all Anticipation Guides: *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.

## How Toxic Is Toxic?

**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. All chemicals are toxic. |
|  |  | 1. How a substance enters your body affects its toxicity. |
|  |  | 1. You should be more concerned about inhaling mercury vapors than touching metallic mercury. |
|  |  | 1. Lethal doses (LD50)of chemicals are determined using hamsters. |
|  |  | 1. The lethal dose (LD50) of a substance is less for children than adults. |
|  |  | 1. The higher the LD50 of a substance, the more toxic it is. |
|  |  | 1. Vitamin D is added to milk sold in U. S. stores to help prevent cataracts. |
|  |  | 1. Theobromine (found in chocolate) is more toxic than caffeine. |
|  |  | 1. The most toxic substance known (botulinum toxin) is used in small amounts to treat the symptoms of certain diseases. |
|  |  | 1. LD50 values can be used to measure chronic effects of a toxin. |

## So Tired in the Morning… The Science of Sleep

**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. Light exposure affects release of melatonin, a chemical that signals our bodies to sleep. |
|  |  | 1. Melatonin production occurs at the same time in the sleep cycle for everyone, including children, teens, and adults. |
|  |  | 1. The pineal gland is found in the brain. |
|  |  | 1. High schools that have switched to later start times have seen measurable benefits. |
|  |  | 1. Melatonin is an amino acid. |
|  |  | 1. The only elements found in melatonin are carbon, hydrogen, oxygen, and nitrogen. |
|  |  | 1. Artificial sources of light interfere with melatonin production. |
|  |  | 1. Circadian rhythms are found only in humans. |
|  |  | 1. Caffeine affects melatonin production. |
|  |  | 1. Sleeping late on the weekends is a good idea if you want to catch up on sleep lost during the week. |

## A Measure of Confusion

**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. In 1999, a $193-million spacecraft crashed into the surface of Mars because the wrong units were used in the computer program calculations. |
|  |  | 1. Some older cars need wrenches to measure in both old English and metric units in the same car. |
|  |  | 1. King Henry I of England based the length of a yard on his courtyard. |
|  |  | 1. Measurement systems are only a few hundred years old. |
|  |  | 1. The International System of units (SI) was introduced in France in 1799. |
|  |  | 1. Some countries that have officially adopted the metric system have made exceptions to it. |
|  |  | 1. Racing bicycle frames and mountain bike frames are measured in inches. |
|  |  | 1. The metric system is much more convenient than other systems for measuring both huge and very small distances. |
|  |  | 1. By the late 19th century, half the world’s population lived in countries that had officially adopted the metric system. |
|  |  | 1. It was not legal to use the metric system in the United States before 1960. |

## Red, Brown, Black, Orange Hair Today, Bleached Tomorrow

**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. Hair colors depend on at least ten different natural pigments. |
|  |  | 1. Double bonds alternating with single bonds in a molecule are referred to as conjugated double bonds. |
|  |  | 1. The colors we see depend on the energy released by electrons when they move from the excited to the ground state. |
|  |  | 1. If a molecule absorbs red light, it appears green. |
|  |  | 1. The shortest wavelength of light we can see is red. |
|  |  | 1. Many hair bleaching agents remove electrons from the pigments that give hair its color. |
|  |  | 1. Baking soda solution is basic. |
|  |  | 1. Hydrogen peroxide bleaches red hair more quickly than brown hair. |
|  |  | 1. Red hair fades more quickly than brown hair. |
|  |  | 1. Hair dyes are formulated on the assumption that hair contains some of the pigment that causes hair to appear red. |

## Pheromones: The Chemical Language of Animals

**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. Pheromones are used by animals to communicate. |
|  |  | 1. All pheromones are organic compounds. |
|  |  | 1. Volatility depends on intermolecular forces. |
|  |  | 1. Polar molecules evaporate more readily than nonpolar molecules. |
|  |  | 1. Water molecules evaporate more readily than most pheromone molecules. |
|  |  | 1. Each individual in a colony of bees has pheromones to specifically identify itself, including its job. |
|  |  | 1. The shape of a molecule can change the pheromone signal. |
|  |  | 1. Pheromones are used to locate food. |
|  |  | 1. All species of ants respond to the same pheromones. |
|  |  | 1. Scientists have synthesized human pheromones. |

Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. 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 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:***

1. 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.
2. **Vocabulary** and **concepts** that are reinforced in this issue:
   * Lethal dose (LD)
   * Amino acid
   * Enzyme
   * Organic molecular structure
   * Metric system
   * Electromagnetic radiation
   * Redox reaction
   * Pheromones
   * Volatility
3. 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.

## How Toxic Is Toxic?

As you read, complete the graphic organizer below to describe evidence for the scientific or engineering practices required to determine toxicity of substances.

|  |  |
| --- | --- |
| **Scientific and Engineering Practices** | **Evidence** |
| Asking questions or defining problems |  |
| Developing and using models |  |
| Planning and carrying out investigations |  |
| Analyzing and interpreting data |  |
| Using mathematics and computational thinking |  |
| Obtaining, evaluating, and communicating information |  |

## So Tired in the Morning… The Science of Sleep

As you read the article, complete the graphic organizer below to describe the structure and role for each molecule in governing your sleep schedule.

|  |  |  |
| --- | --- | --- |
| **Molecule** | **Structure** | **Role** |
| **Melatonin** |  |  |
| **Tryptophan** |  |  |
| **Serotonin** |  |  |
| **Caffeine** |  |  |
| **Adenosine** |  |  |

## A Measure of Confusion

**Directions:** As you read the article, complete the graphic organizer using information from the article to answer the question: **Should the United States have a law to mandate conversion to the metric system?**

Find reasons to support both sides in the article and then state your conclusion in the space below.

State your conclusion, with an explanation based on information in the article:

## Red, Brown, Black, Orange Hair Today, Bleached Tomorrow

**Directions:** As you read the article, complete the graphic organizer below to compare how you might get different colors of hair, including unintended results.

|  |  |
| --- | --- |
| **Hair color** | **Reason** |
| Brown |  |
| Red |  |
| White |  |
| Yellow |  |
| Orange |  |
| Green |  |

## Pheromones: The Chemical Language of Animals

**Directions**: As you read the article, complete the graphic organizer below describing your learning about pheromones.

|  |  |
| --- | --- |
| 3 | Write **three new things** you learned about pheromones from reading this article that you would like to share with your friends.  1.  2.  3. |
| 2 | Share **two things** you learned about chemistry from the reading the article.  1.  2. |
| 1 | Did this article change your views about the importance of pheromones? Explain in **one sentence**. |
| **Contact!** | Describe a **personal experience** about pheromones that connects to something you read in the article—something that your personal experience validates. |

# How Toxic is Toxic?

## Background Information (teacher information)

**More on toxicity**

Poisonous. Hazardous. Toxic. Dangerous. All are adjectives we use, often interchangeably, to describe chemicals that may cause harm to living organisms by reacting chemically with substances in the organisms so as to do some degree of harm, including death. Do the terms all mean the same thing? By explaining the concept of toxicity the article suggests that the terms have different meanings. The question involving the terms mentioned above is, “Is this substance poisonous?” The Merck Index provides some basics:

*Poisoning is contact with a substance that results in toxicity. Symptoms vary, but certain common syndromes may suggest particular classes of poisons. Diagnosis is primarily clinical, but for some poisonings, blood and urine tests can help. Treatment is supportive for most poisonings; specific antidotes are necessary for a few. Prevention includes labeling drug containers clearly and keeping poisons out of the reach of children.*

Most poisonings are dose-related. Dose is determined by concentration over time. Toxicity may result from exposure to excess amounts of normally nontoxic substances. Some poisonings result from exposure to substances that are poisonous at all doses. Poisoning is distinguished from hypersensitivity and idiosyncratic reactions, which are unpredictable and not dose-related, and from intolerance, which is a toxic reaction to a usually nontoxic dose of a substance.

Poisoning is commonly due to ingestion but can result from injection, inhalation, or exposure of body surfaces (eg, skin, eye, mucous membranes). Many commonly ingested nonfood substances are generally nontoxic (see Table 1: [Substances Usually Not Dangerous When Ingested\*](http://www.merckmanuals.com/professional/injuries_poisoning/poisoning/general_principles_of_poisoning.html#v1117965)); however, almost any substance can be toxic if ingested in excessive amounts.



(<http://www.merckmanuals.com/professional/injuries_poisoning/poisoning/general_principles_of_poisoning.html>) (Note that Table 1 referred to in this quote can be accessed by using the Merck Index link in “More on poisons”, below)

Another way to answer the “Is it poisonous?” question is to consider two things—the toxicity of the substance and the health hazard of the substance. And if we decide that the substance is toxic or hazardous, or both, we may simply tell our students that the substance is dangerous, a non-technical term that warns students to be cautious around the substance in question.

The context for these ideas is the process of analyzing the risks and benefits involved with chemicals. Risk analysis is an important function of many endeavors, no more so than in our everyday interaction with chemicals. The risk assessment for human health has grown in importance in recent years due to new understandings about how chemicals affect human health.

The World Health Organization (WHO) estimates that more than 25% of the global burden of disease is linked to environmental factors, including exposures to toxic chemicals. Lead exposure, for example, accounts for 3% of the cerebrovascular disease burden and 2% of the ischaemic heart disease burden worldwide. Some 9% of the global burden of lung cancer is attributed to occupational exposure to toxic substances, and 5% to outdoor air pollution. Lung cancer and mesothelioma are caused by exposure to asbestos, which remains in use in some countries. Unintentional poisonings kill an estimated 355 000 people each year, two thirds of them in developing countries, where such poisonings are strongly associated with excessive exposure to, and inappropriate use of, toxic chemicals, including pesticides.

(<http://www.inchem.org/documents/harmproj/harmproj/harmproj8.pdf>)

The ubiquitous nature of chemicals in our lives and the potential risks they may cause, as well as the potential benefits they may produce, requires a careful analysis of those risks and benefits. Again, according to the World Health Organization:

Human health risk assessment is a process intended to estimate the risk to a given target organism, system or (sub)population, including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system (IPCS, 2004).

It is the first component in a risk analysis process that also includes risk management and risk communication. Human health risk assessment of chemicals refers to methods and techniques that apply to the evaluation of hazards, exposure and harm posed by chemicals, which in some cases may differ from approaches used to assess risks associated with biological and physical agents.

The risk assessment process begins with problem formulation and includes four additional steps: 1) hazard identification, 2) hazard characterization, 3) exposure assessment and 4) risk characterization (IPCS, 2004).

(<http://www.inchem.org/documents/harmproj/harmproj/harmproj8.pdf>)

We should consider toxicity, then, as one key factor in the more general risk-benefit analysis of chemicals in our lives.

As the article describes, the toxicity of a substance is a property that can be measured in a laboratory and is a fixed number for a given substance. It is commonly measured by determining the 50% lethal dose, LD50, of the substance, using lab animals as test subjects. It is a direct measure of how poisonous a substance is. (See below for “More on LD50”). However, the degree to which a substance is a *hazard* can vary. Whether the substance is a hazard depends on circumstances—how the substance is stored, how it is transported or how it is used. This is where you can inject lab safety into the discussion because hazards can be controlled. Lab safety rules are often designed to minimize hazards. See below for “More on lab safety”.

An important note of context for the article—the article discusses only those substances that react *chemically* to cause potential harm to people. It is the chemical mechanism that distinguishes this group of substances from other substances that are dangerous. For example, an explosion is dangerous and can injure or kill a person, but the cause of the injury is not chemical. In this case the injury is caused by physical pressure of shock waves that result from the explosion or by being struck by foreign objects propelled by the blast. There is no LD50 in this situation. This article does not deal with these kinds of physical trauma.

Chemical and biological changes in the body can also be the result of exposure to ionizing radiation like the kind that residents of Hiroshima and Nagasaki experienced during World War II. This kind of nuclear radiation has multiple effects: breaking and forming of chemical bonds, and damage to biomolecules (like DNA) that have essential body functions. There are known LD50 values for exposure to ionizing radiation from nuclear sources, but the article does not include a discussion of these either. For example, for acute exposure to higher doses of radiation, a person might experience changes in blood components, fatigue, diarrhea, nausea and death. These effects will develop within hours,   
days or weeks, depending on the size of the dose. The LD50 for whole-body acute radiation is 320–60 rem, provided there is no medical treatment administered. If there is medical treatment the LD50 rises to 480–540 rem. For a longer discussion of these radiations, see <http://www.nrc.gov/reading-rm/basic-ref/teachers/09.pdf>.

**More on the factors affecting how poisonous a substance is**

The issue of “poisonous” is not always “cut-and-dried.” There are factors that influence whether a substance, even one normally considered poisonous, is actually so. The factors are a) route of entry into the body, b) dose entering the body, c) toxicity of the chemical, d) the natural processes that remove the substance from the body and e) the natural physiological variation among and within individuals.

As the article notes, the toxicity of a substance may depend on the route of entry into the body. The article uses mercury as an example. If swallowed as a liquid it likely will simply pass through without harm, but if the vapor emitted from the liquid is inhaled, the resulting symptoms include mood swings, nervousness, irritability, insomnia, headache, muscle atrophy and decreased cognitive function. In addition, if organic mercury in the form of methylmercury is eaten it can cause neurological disorders, especially in fetuses. Methylmercury is an organo-metal ion with the formula CH3Hg+ and is present in varieties of seafood. You may have to explain to your students that mercury was once the most common liquid in a thermometer since many high school students may remember only digital or strip (liquid crystal) thermometers from home or alcohol or digital thermometers from your lab.

The dose taken in will also affect toxicity. It is the most important factor, as the article describes. The article makes the point that every substance is toxic if enough of it is taken. The introduction to the article reminds us that water can be toxic, even though it is essential for life. The article describes the toxicity of vitamin D, which is a milk additive. The LD50 for vitamin D is 10 mg/kg, well within the definition of a poison (less than 50 mg/kg, according to the article). But a cup of milk contains only 2.5 µg (*micro*grams) of vitamin D, well less than the LD50 level. So too, oxygen, a substance essential for life, can be toxic in sufficient concentrations. We know that air is only about 20% oxygen, and that a body’s physiological processes are calibrated to process oxygen for respiration at that concentration. In much higher oxygen concentrations these processes break down. Mucus-like fluid fills the lungs, total gas flow decreases, chest pains occur and the total oxygen exchange in the lungs actually decreases. Cells are deprived of needed oxygen and cell death can occur. Under these circumstances oxygen acts as a poison. The condition is called hyperoxia.

The emphasis of this article is on toxicity and how it is measured. According to the article, “The toxicity of any substance is measured by a value known as its LD50. (LD stands for “lethal dose.”)This quantity refers to thedose required to kill 50% of a test population, usually lab rats.” Clearly LD50 is a major factor in any discussion of poisonous substances. The article indicates that the lower the LD50, the more toxic the substance. For a more detailed discussion of LD50 issues, see the next section of this Teacher’s Guide.

Yet another factor affecting whether a substance is poisonous is how the body eliminates the substance or its metabolic products. In some cases a substance may pass through the body unchanged and can be eliminated in the urine, feces, sweat or exhaled breath. Most substances, however, react chemically with other substances in the body and are, therefore, broken down as they pass through. The situation is improved if the products of the metabolic breakdown are less toxic than the original substance. If the products are more toxic, the person is in greater danger than before. Another consideration is how quickly substances are broken down. Rapid changes mean less exposure over time. Other substances are stored in the body for long time periods, causing longer-term damage. And there are other personal characteristics like age and sex that can also affect how poisonous a given substance is.

The article also mentions the difference between acute toxicity and chronic toxicity, and to clarify, the main emphasis of the article is on acute toxicity. Refer to the line in the article, “Because LD50 measures acute—or short-term—toxicity, the substance being tested must be given to the test animals all at once.” Acute toxicity is the result of a one-time, short-term, significant-dose exposure to a substance. So, for example, we sometimes hear about railroad tank cars containing a poisonous substance (like chlorine) overturning as the result of a derailment or other accident. If the chlorine leaks out, residents in the vicinity of the accident will be exposed suddenly to potentially dangerous chlorine concentrations. This would be a case of acute toxicity.

On the other hand, some exposures are well below LD50 levels, but the exposures occur repeatedly over a longer time period. Exposure to lead and to asbestos are well-known examples. Other examples include chronic exposure to second-hand smoke from tobacco products, environmental pollutants, pesticides, ionizing radiation and specific chemicals like tetrachloroethylene (TCE) or benzene.

**More on** **LD50**

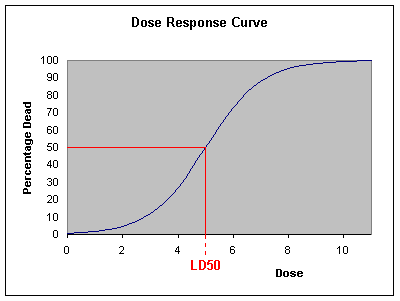
As noted above,the toxicity of a substance—its effect on an organism, tissue or cell—is a property that can be measured in a laboratory and is a fixed number for a given substance. It is commonly measured by determining the 50% lethal dose, LD50, of the substance, using lab animals as test subjects. It is a direct measure of how poisonous a substance is.

Since individuals vary in their reaction to a specific substance, scientists use what is called a population-level measure of a substance’s toxicity. LD50 is a population-level measure of toxicity in that it is the dose required to kill 50 per cent of *a given population*, most often a population of lab animals. It is measured in units that relate the dose to body weight as in “mg/kg” and often includes the route of entry (ingestion, inhalation, etc.) and the animals used to test it. For example, this is the LD50 for aniline, C6H5NH2: Aniline LD50 oral-rat: 250mg/kg. Other methods of expressing toxicity data include dose per area of skin surface and dose per volume of inhaled air (often given in parts per million)

How toxic is toxic? According to the Flinn “Science Department Safety Training Notes”, “In general, chemicals with LD50 values less than 300mg/kg are considered highly toxic, those with LD50 values between 300 and 1,000 mg/kg are considered moderately toxic, and those with LD50 values between 1,000 and 5,000 mg/kg are considered slightly toxic.” (<http://www.flinnsci.com/media/460940/safety_notes_vol_12-9.pdf>) Note that these values and categories differ from those given in the article.

When toxicologists set up toxicity tests they first determine a test organism. They can choose from a range of possibilities—from strains of bacteria through higher order animals. Ideally the species provides a good model for humans. They also choose the response they are testing for. The response should be an objective one and one that can be determined over and over. This can be something as simple as a change in heart rate or as complex as death in the case of LD50 testing. An exposure period must also be determined and, finally, the dose or series of doses.

Although the article does not discuss this, LD50 values are part of a broader concept called the dose-response relationship. There is typically a measureable relationship between the exposure (dose) to a potentially harmful chemical and the adverse response by the exposed organism. In most cases, as the dose increases the response increases once a threshold value is passed. That is, there are some doses that elicit no response. The lowest dose to elicit a response is called the threshold dose.



*<http://environmentalet.hypermart.net/env1100/atmos&ap.htm>*

As applied to toxicity testing, the response values are measured and plotted against the measured dose values. The shape of these curves may vary, but the curve at right is a typical dose-response curve. Once the threshold value is exceeded the response increases with increasing dose up to a maximum value beyond which there is no added response. On the curve at right the LD50 value would be a dose of 5 mg/kg.

In addition to measuring lethal dose (LD) toxicologists may measure effective dose (ED) in cases where they are looking for a positive effect. Other standard doses include LDLo, the lowest dose that produces death in a population; TDLo, the lowest dose that produces any specific toxic effect; and the corresponding TC, or toxic concentrations in the case of administration by inhalation.

**More on** **lab safety**

This article has serious implications for chemistry teachers and their students. By its very nature, your classroom contains potentially toxic substances. And every good chemistry course should include instruction for students on handling potentially hazardous materials. In addition every chemistry teacher should practice chemical safety—from storage to disposal and every step in between, as this statement from the American Chemical Society indicates in their publication “Chemical Safety for Teachers and Their Supervisors, Grades 7-12:”

All chemicals are hazardous, but they all can be used safely if we know how to control their hazardous characteristics while we use them. The suppliers of chemicals used in our schools are aware of and fulfill their responsibilities to inform their customers of the hazardous characteristics of the chemicals they provide.

Suppliers provide this information both by labels on the containers and by Material Safety Data Sheets (MSDSs) (provided separately). According to the U.S. Occupational Safety and Health Administration (OSHA) and, in some cases, corresponding state regulations, it is the employer’s responsibility to ensure that this important precautionary information is conveyed to teachers. Typically, a supervisor informs teachers on behalf of the principal.

(<http://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/chemical-safety-manual-teachers.pdf>)

This ACS safety guide outlines areas of knowledge and practice that should be part of every chemistry classroom:

Knowledge entails in turn understanding the particular hazardous characteristics of a chemical that will be used. Is it flammable? Is it toxic? Knowledge also means knowing what to do and what to avoid when a chemical is flammable or corrosive. Moreover, knowledge includes knowing what to do in case no precautions or inadequate precautions were taken and an accident occurs. For example, how to use a fire extinguisher or what to do if a corrosive chemical is splashed on the skin. To gain this necessary information before using these chemicals, ask the chemical hygiene officer for your school system and other local resource persons for their help, read the labels, study the MSDSs; use all these sources for necessary information.

(<http://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/chemical-safety-manual-teachers.pdf>; p3)

The guide discusses hazardous chemicals specifically. It notes that each chemical presents its own potential hazards, making the task of knowing the risks involved in using any given chemical in the classroom a formidable task. However, the guide suggests that there only four categories of hazard—flammability, toxicity, reactivity and corrosivity. In describing toxicity, the guide says:

Broadly speaking, there are two different toxic effects, chronic and acute. A chronic toxic effect is noted only after repeated exposures or after a single, long exposure. Commonly known chronic toxic effects include cancer and reproductive malfunctions. Acute toxic effects occur promptly upon exposure, or within a short time—a few hours at most. Methyl and ethyl alcohol are examples. Both exhibit the same acute toxic effect: inebriation. Ethyl alcohol exhibits a chronic effect: cirrhosis of the liver.

Methyl alcohol exhibits two additional acute toxic effects: blindness and death. To understand this, consider the “dose-response” phenomenon, a characteristic of all toxins, both acute and chronic: the greater the dose, the more severe the response to the toxin. Thus, a very small amount of methyl alcohol inebriates, a bit more causes blindness, yet a bit more is fatal. All toxic substances share this characteristic; exposure to a larger amount of the toxin is worse than exposure to a smaller amount. An exposure of a longer duration has a greater toxic effect than an exposure of a shorter duration.

One precautionary measure for toxins is now obvious: Minimize the exposure. Use the smallest amount of toxin that is suitable for the purposes of an experiment. Minimize the time an experimenter will work with a toxin. Work with toxins only in a fume hood that is known to be working properly.

(<http://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/chemical-safety-manual-teachers.pdf>)

Other recommended steps to ensure safety are to: require use of certified eye protection, read MSDS documentation, take special steps to prevent fires, limit use of chemicals that are corrosive to tissue and be aware of especially reactive chemicals. The guide also provides advice for teaching students about safety and about developing an overall safety plan for your classroom. Other important precautions include: 1) always wear personal protective equipment, 2) work with volatile substances only in a properly functioning hood or well-ventilated lab, 3) immediately clean up all spills and 4) do not eat food, drink beverages or chew gum in the laboratory.

Standard Safety Data Sheets (formerly Material Safety Data Sheets) contain information about LD50 values. This is a requirement of the U.S. Department of Labor Occupational Safety and Health Administration (OSHA). Their brief on Safety Data Sheets says:

The Hazard Communication Standard (HCS) (29 CFR 1910.1200(g)), revised in 2012, requires that the chemical manufacturer, distributor, or importer provide Safety Data Sheets (SDSs) (formerly MSDSs or Material Safety Data Sheets) for each hazardous chemical to downstream users to communicate information on these hazards. The information contained in the SDS is largely the same as the MSDS, except now the SDSs are required to be presented in a consistent user-friendly, 16-section format. This brief provides guidance to help workers who handle hazardous chemicals to become familiar with the format and understand the contents of the SDSs.

The SDS includes information such as the properties of each chemical; the physical, health, and environmental health hazards; protective measures; and safety precautions for handling, storing, and transporting the chemical. The information contained in the SDS must be in English (although it may be in other languages as well). In addition, OSHA requires that SDS preparers provide specific minimum information as detailed in Appendix D of 29 CFR 1910.1200. The SDS preparers may also include additional information in various section(s).

Sections 1 through 8 contain general information about the chemical, identification, hazards, composition, safe handling practices, and emergency control measures (e.g., firefighting). This information should be helpful to those that need to get the information quickly. Sections 9 through 11 and 16 contain other technical and scientific information, such as physical and chemical properties, stability and reactivity information, toxicological information, exposure control information, and other information including the date of preparation or last revision. The SDS must also state that no applicable information was found when the preparer does not find relevant information for any required element.

(<https://www.osha.gov/Publications/OSHA3514.html>)

Section 11 of the SDS contains the information about LD50 for the substance. The OSHA brief describes Section 11 this way:

This section identifies toxicological and health effects information or indicates that such data are not available. The required information consists of:

* Information on the likely routes of exposure (inhalation, ingestion, skin and eye contact). The SDS should indicate if the information is unknown.
* Description of the delayed, immediate, or chronic effects from short- and long-term exposure.
* The numerical measures of toxicity (e.g., acute toxicity estimates such as the LD50 (median lethal dose)) - the estimated amount [of a substance] expected to kill 50% of test animals in a single dose.
* Description of the symptoms. This description includes the symptoms associated with exposure to the chemical including symptoms from the lowest to the most severe exposure.
* Indication of whether the chemical is listed in the National Toxicology Program (NTP) Report on Carcinogens (latest edition) or has been found to be a potential carcinogen in the International Agency for Research on Cancer (IARC) Monographs (latest editions) or found to be a potential carcinogen by OSHA

(<https://www.osha.gov/Publications/OSHA3514.html>)

The Safety Data Sheets are consistent with the *United Nations Globally Harmonized System of Classification and Labelling of Chemicals* (GHS), which provides a non-mandatory set of guidelines for describing the “health, physical and environmental hazards of chemicals;

creating classification processes that use available data on chemicals for comparison with the defined hazard criteria; and communicating hazard information, as well as protective measures, on labels and Safety Data Sheets (SDS).” (<https://www.osha.gov/dsg/hazcom/ghs.html>) In section 3.2.1 of GHS, acute toxicity is described using LD50 data. The complete GHS text can be accessed at <http://www.unece.org/trans/danger/publi/ghs/ghs_rev00/00files_e.html>.

**More on poisons**

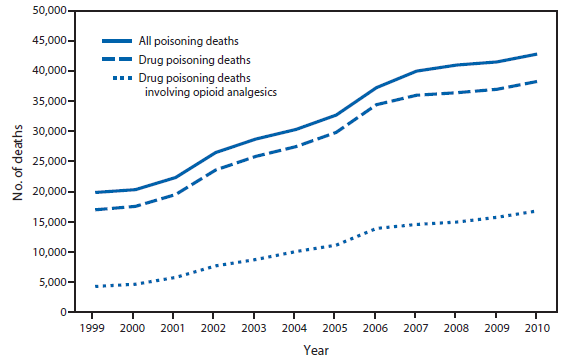
According to the U.S. Centers for Disease Control and Prevention:

Poisoning is the leading cause of injury death in the United States. Drugs—both illicit and pharmaceutical—are the major cause of poisoning deaths, accounting for 90% of poisoning deaths in 2011. Misuse or abuse of prescription drugs, including opioid-analgesic pain relievers, is responsible for much of the recent increase in drug-poisoning deaths . . .

Poisons are substances that cause harm to organisms when sufficient quantities are absorbed, inhaled or ingested. Some poisons make an organism sick, others may cause it to die and yet others may lead to subtle changes in health that may not be noticed for years. [Toxicology](http://www.sciencelearn.org.nz/About-this-site/Glossary/toxicology) is the science of poisons. It is the study of harmful effects   
of chemicals on living organisms.

(<http://www.cdc.gov/nchs/data/databriefs/db166.htm>)

Also according the Centers for Disease Control and Prevention, U.S. poison centers handled 2.3 million human poison exposures in 2011. However, there were likely many more cases of poisonings since many cases are never reported. Poisonings also are unreported when people do not realize they have been exposed, choose not to seek medical treatment or advice, do not have access to medical care, or do not know about poison center services. The graph below provides data about the number of poisoning deaths in the United States between 1999 and 2010.



*(*[*http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6212a7.htm*](http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6212a7.htm)*)*

Potentially poisonous chemicals or toxins can be natural or synthetic. Dioxin, pesticides and nerve gas are all synthetic, but belladonna, snake venoms and botulinum are natural products. Naturally-occurring toxins are sometimes referred to as biotoxins. For a list of poisons categorized by their mode of operation, see <http://emergency.cdc.gov/agent/agentlistchem-category.asp>.

**More on** **toxicology**

Your students might be interested in pursuing a career in toxicology. You can introduce this topic by noting that it is toxicologists who do the research that leads to the LD50 information described in the article. According to the Society of Toxicology (SOT) Web site: “Toxicology is the study of the adverse effects of chemical, physical, or biological agents on living organisms and the ecosystem, including the prevention and amelioration of such adverse effects.”

Further, SOT describes the work of toxicologists:

Hardly a week goes by without hearing that a chemical may potentially threaten our health—pesticides in the food we eat, pollutants in the air we breathe, chemicals in the water we drink, toxic dump sites near our homes. Chemicals make up everything around us. Which chemicals are really dangerous? How much does it take to cause harm? What are the effects of a particular chemical? Cancer? Nervous system damage? Birth defects?

Finding scientifically sound answers to these very important questions is what toxicologists do, using the most modern molecular, genetic, and analytical techniques available. Toxicology combines the elements of many scientific disciplines to help us understand the harmful effects of chemicals on living organisms.

An additional, important aspect of toxicology is determining the likelihood that harmful effects will occur under certain exposure circumstances, sometimes called “risk assessment.” If the risks are real, then we must be able to deal with them effectively. If the risks are trivial, then we must ensure that valuable public resources are not spent ineffectively.

**The responsibility of the toxicologist is to:**

1. develop new and better ways to determine the potential harmful effects of chemical and physical agents and the amount (dosage) that will cause these effects. An essential part of this is to learn more about the basic molecular, biochemical and cellular processes responsible for diseases caused by exposure to chemical or physical substances;
2. design and carry out carefully controlled studies of specific chemicals of social and economic importance to determine the conditions under which they can be used safely (that is, conditions that have little or no negative impact on human health, other organisms, or the environment);
3. assess the probability, or likelihood, that particular chemicals, processes or situations present a significant risk to human health and/or the environment, and assist in the establishment of rules and regulations aimed at protecting and preserving human health and the environment.

(<http://www.toxicology.org/ai/apt/careerguide.asp#What is Toxicology?>)

Among the basic tasks performed by toxicologists are: isolating, identifying and measuring toxic substances or radiation and any harmful effect they have on humans or animals; planning and carrying out a wide range of experiments in the field or laboratories; analyzing and evaluating statistical data and researching scientific literature; writing reports and scientific papers; presenting findings and, in the case of forensic work, giving evidence in court; advising on the safe handling of toxic substances and radiation, in production or in the event of an accident; and studying the effects of harmful chemicals and biological agents on people and advising on the treatment of affected patients.

Two of the more popular specialties in this field are forensic toxicology and medical toxicology.

Forensic toxicologists isolate and identify substances in the body that are part of evidence of a crime—substances like alcohol, drugs, poisons, metals and gases like carbon monoxide. Often they are performing analyses on body tissues and fluids. For the most part forensic toxicologists work in the lab using crime scene samples provided by investigators like on the TV shows like CSI. This field has grown in recent years to include drug testing for employers and traffic enforcement officials and testing for performing-enhancing drug substances banned from sporting events.

Medical toxicologists focus on the diagnosis, management and prevention of poisoning and other adverse health effects due to medications, occupational and environmental toxins, and biological agents. These specialists encounter cases of drug overdoses for both prescription and over-the-counter medications, exposure to industrial and environmental hazards like pesticides, toxic gases and household products and ingestion of food-borne toxins.

To work as a toxicologist requires a degree in toxicology or a related degree like biology, chemistry or biochemistry. Bachelor's degree programs in toxicology cover the chemical makeup of toxins and their effects on biochemistry, physiology and ecology.

**More on animal testing**

Your students may raise the issue of using laboratory animals for testing of factors like LD50—or it may be one of your concerns. The article does not mention the controversy directly, so this section of the Teacher’s Guide will be limited. There are other resources listed in the “More sites” section of the Teacher’s Guide, below.

If you choose to raise this issue in connection with this article, it is a good opportunity for students to research two sides of a very controversial issue and present arguments and supporting facts in a classroom setting. This kind of critical thinking research and presentation is important if students are to develop these skills during their time in school.

The web site “Pro-Con.Org” presents all sides of many controversial issues, including animal testing, and is a good place for students to begin. The site notes:

An estimated 26 million animals are used every year in the United States for scientific and commercial testing. Animals are used to develop medical treatments, determine the toxicity of medications, check the safety of products destined for human use, and other biomedical, commercial, and health care uses. Research on living animals has been practiced since at least 500 BC.

Proponents of animal testing say that it has enabled the development of many life-saving treatments for both humans and animals, that there is no alternative method for researching a complete living organism, and that strict regulations prevent the mistreatment of animals in laboratories.

Opponents of animal testing say that it is cruel and inhumane to experiment on animals, that alternative methods available to researchers can replace animal testing, and that animals are so different from human beings that research on animals often yields irrelevant results.

(<http://animal-testing.procon.org/#background>)

The site presents equivalent opinion and facts on both sides of this issue:

**PRO - Animal testing has contributed to many life-saving cures and treatments.**

The California Biomedical Research Association states that nearly every medical breakthrough in the last 100 years has resulted directly from research using animals. Experiments in which dogs had their pancreases removed led directly to the discovery of insulin, critical to saving the lives of diabetics. The polio vaccine, tested on animals, reduced the global occurrence of the disease from 350,000 cases in 1988 to 223 cases in 2012. Animal research has also contributed to major advances in understanding and treating conditions such as breast cancer, brain injury, childhood leukemia, cystic fibrosis, malaria, multiple sclerosis, tuberculosis, and many others, and was instrumental in the development of pacemakers, cardiac valve substitutes, and anesthetics. Chris Abee, Director of the University of Texas M.D. Anderson Cancer Center's animal research facility, states that "we wouldn't have a vaccine for hepatitis B without chimpanzees," and says that the use of chimps is "our best hope" for finding a vaccine for Hepatitis C, a disease that kills 15,000 people every year in the United States.

(<http://animal-testing.procon.org/#background>)

**CON - Animal testing is cruel and inhumane.**

According to Humane Society International, animals used in experiments are commonly subjected to force feeding, forced inhalation, food and water deprivation, prolonged periods of physical restraint, the infliction of burns and other wounds to study the healing process, the infliction of pain to study its effects and remedies, and "killing by carbon dioxide asphyxiation, neck-breaking, decapitation, or other means." The Draize eye test, used by cosmetics companies to evaluate irritation caused by shampoos and other products, involves rabbits being incapacitated in stocks with their eyelids held open by clips, sometimes for multiple days, so they cannot blink away the products being tested. The commonly used LD50 (lethal dose 50) test involves finding out which dose of a chemical will kill 50% of the animals being used in the experiment. The US Department of Agriculture (USDA) reported in 2010 that 97,123 animals suffered pain during experiments while being given no anesthesia for relief, including 1,395 primates, 5,996 rabbits, 33,652 guinea pigs, and 48,015 hamsters.

(<http://animal-testing.procon.org/#background>)

You can refer to this site and others presented below to get more information on animal testing and ideas for including this topic in your classroom.

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Lab Safety—**The contents of this article relate directly to safety in the lab. You can easily apply the article to hazardous materials, toxicity and procedures that students must follow in order to maintain a safe environment in the classroom.
2. **Properties of elements and compounds—**There are a variety of properties discussed in the article, all, of course, relating to the toxicity of a substance. As you discuss chemical properties, for example, you may wish to include toxicity as well.
3. Biochemistry—In general for this article the mechanisms that make a substance toxic are biochemical in nature. You can illustrate to students the variety of biochemical reactions that are important in discussing how the body functions, both in a safe environment and in a hazardous one.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“All chemicals are hazardous.”** *Strictly speaking, this is not true. As noted earlier in this Teacher’s Guide, the hazard of a chemical lies in the way it is stored, handled or used. In other words, “hazard” describes behavior and not properties inherent in a substance. It might be appropriate to say that a substance is poisonous or toxic, but it only become hazardous if it is not handled correctly.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“If all substances are potentially toxic, why aren’t there warning labels on everything?”** *While it is true that all substances are toxic depending on doses, many substances are categorized as “practically non-toxic” or “relatively harmless.” The chances of anyone being poisoned by these substances are so small that warning labels would only be a distraction—or cause unnecessary worry.*
2. **“Does LD50 mean that scientists actually kill lab animals?”** *Yes, they do. Federal laws and other regulations permit these practices. Many people believe that animals should not be used for product testing while others believe that such testing is critical to testing drugs and other products that are safe for humans. [Note to teacher: Answer this question in whatever depth you are comfortable. See “More on animal testing”, above, and “More sites on animal testing”, below.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. Students can learn about toxicology and what toxicologists do in this series of class activities from the University of Georgia, including a lab in which students produce a dose-response curve for radish plants subject to potentially toxic substances. (<http://extension.uga.edu/k12/science-behind-our-food/lesson-plans/IntrotoToxicology.pdf>)
2. This lab activity from Penn State University gives students experiences about how the body processes toxins: <http://vbs.psu.edu/etoxic/educators/lesson-plan-four-entry-exit-and-everything-in-between>.
3. This lab activity from the National Science Teachers Association (NSTA) teaches students how to use SDS (formerly MSDS) and also has a section on toxicity using daphnia. (<http://www.gaaged.org/Browseable_Folders/Curriculum/Lesson%20Plans/Supplemental_Lesson_Plans/Agricultural%20Chemistry%20Selectivity%20and%20Toxicity.htm>)
4. This lab activity examines the effect of several potentially toxic solutions on the behavior of California blackworms by varying the concentration of each solution. (<http://kennedyapes.weebly.com/uploads/4/5/3/0/4530459/lc50_toxicity_lab.doc>)
5. The University of Arizona gives us a lab featuring multiple lab stations. Concepts examined include threshold limits, body size, dose-response and response variability. (<http://coep.pharmacy.arizona.edu/curriculum/basictoxlab/Basic_Toxicology_Lab_Stations.pdf>)
6. The Society of Toxicologists provides links to other classroom activities related to toxicology. (<http://www.toxicology.org/teachers/curriculum.asp>)
7. The National Institutes of Health Office of Science Education offers a free curriculum supplement that has activities on chemicals, risk, dose-response, among other topics. (<http://science.education.nih.gov/customers.nsf/MSEnvironment.htm>)
8. The PBS series “American Experience” explores case studies of poisonings and provides classroom activities on poisons for students. (<http://www.pbs.org/wgbh/americanexperience/films/poisoners/player/>)
9. High school chemistry students can do this lab on measuring the toxicity on brine shrimp of common household products. (<http://www.juliantrubin.com/encyclopedia/environment/brine_shrimp.html>)
10. Flinn Scientific offers a kit for testing toxicity in brine shrimp. (<http://www.flinnsci.com/store/Scripts/prodView.asp?idproduct=19056>)
11. You might use this Web site to begin a discussion with students about toxic substances and under what circumstances they’re toxic. The site seeks to ban dihydrogen monoxide: <http://descy.50megs.com/descy/webcred/webcred/dhmo.html>.

Here is the official Web site of Dihydrogen Monoxide: <http://www.dhmo.org/>.

And here is an article in the newspaper reporting about a student’s science fair project investigating students’ reactions to the call to ban dihydrogen monoxide: <http://articles.orlandosentinel.com/1997-10-28/news/9710280246_1_dihydrogen-monoxide-ban-dihydrogen-dhmo>.

## Out-of-class Activities and Projects (student research, class projects)

Students can make their own simple candies at home (with parent approval/supervision).

1. Beginning with clear and explicit warnings about handling materials, you could assign each student in a class to identify five (or any number) common materials around their house and research the LD50 for each. Be sure to require that students document their sources. The class can then compile one class list and discuss results. A more detailed version of this activity can be found on the Cornell University Web site: <http://cwmi.css.cornell.edu/TrashGoesToSchool/Toxics.html>. Although it is designed for students in grades 7-8, it can be adapted for high school use.
2. If there are organizations in your community that might employ toxicologists, you can assign students to interview them to find out their skill set, academic background and their normal work routine. If any of the toxicologists are willing to come speak to your class, this can be turned into an in-class activity.
3. The Society of Toxicologists has a series of enrichment topics (e.g., thalidomide and DDT) that could be assigned as out-of-class work. See <http://www.toxicology.org/teachers/enrichtopics.asp>.

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). 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)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

Buchman, D. The Mystery of the Poisoned Boy. *ChemMatters* **1994**, *12* (1), pp 9–11. The search for the substance that poisoned a young boy is the focus of this article. [*Spoiler alert!*] Organic phosphates from mosquito spraying were found to be the eventual cause.

Black, H. The Poison that Heals. *ChemMatters*. **1994,** *12* (4), pp 7–9. This article describes how the highly poisonous botulinum toxin was developed as a treatment for a variety of muscle disorders. The story precedes botulinum’s use as Botox.

Goldfarb, B. CO Control: On the Street, In the House, Where You Live. *ChemMatters* **1997,** *15* (3), pp 10–12. The mechanism of carbon monoxide poisoning and methods of prevention are examined. Current (2014) data for LC50 inhalation in rats is 1350 mg/m3.

Stone, C. The Case of Napoleon Bonaparte. *ChemMatters* **1998**, *16* (4), pp 4–6. Several poisoning theories about the death of Napoleon Bonaparte are explored.

Graham, T. Poisoned! *ChemMatters* **2005**, *23* (4), pp 17–19. This article is about the mystery surrounding arsenic poisoning in a small town in Maine. It discusses acute vs. chronic poisoning, lethal dose (without mentioning LD50) and chelating agents as treatments.

Tinnesand, M. Material Safety Data Sheets. *ChemMatters* **2006**, *24* (3), pp 18–19. The author describes some of the history and uses for MSDS and highlights some of the problems with their accuracy.

Brownlee, C. Bling Zinger: The Lead Content in Jewelry. *ChemMatters* **2006**, *24* (4), pp 11–13. This article provides an example of chronic toxicity. It describes lead and lead compound poisons especially in gasoline, paint and jewelry.

Keown, A. The Death of Alexander Litvinenko. *ChemMatters* **2007,** *25* (2), pp 18–19. Another example of a method of poisoning is outlined in this article on the death of a Russian spy by polonium-210 poisoning. (Note: polonium-210 does not poison by chemically interacting with body tissue. It emits radiation that interacts with the tissue. Its 30-day LD50 is less than 1 microgram in an adult male.)

Becker, B, “Question from the Classroom: ‘What is the most deadly poison in the world?’” *ChemMatters* **2010,** *28* (1), p 2. This edition of the continuing series focuses on the most deadly poison in the world and includes acute and chronic poisons, information about LD50 and its limitations. (The answer to the question depends on the meaning of the terms in the question.)

## Web Sites for Additional Information (Web-based information sources)

**More sites on** **poisons**

The Merck Index provides extensive background on poisons and poisoning, along with a list of common non-food substances that are not dangerous when consumed and a list of common toxic syndromes. (<http://www.merckmanuals.com/professional/injuries_poisoning/poisoning/general_principles_of_poisoning.html>)

Profiles of thousands of toxic substances are listed on the Agency for Toxic Substances and Disease Registry page. The registry is part of the U.S. Department of Health and Human Services. (<http://www.atsdr.cdc.gov/>)

The Canadian Center for Occupational Health and Safety is an excellent resource on poisons. (<http://www.ccohs.ca/oshanswers/chemicals/poisonou.html>)

**More sites on** **LD50**

Dose-responseand measuring exposure (e.g., LD50) is explained on this Cornell University Extension Service site: <http://pmep.cce.cornell.edu/profiles/extoxnet/TIB/dose-response.html>.

Technical aspects of measuring toxicity are described on this site from the State University of New York: <http://life.bio.sunysb.edu/marinebio/fc.6.toxicity.measures.html>.

Risk assessment and acute and chronic toxicity are outlined on this Analysis Online site: <http://www.analysisonline.org/site/aoarticle_display.asp?sec_id=140002434&issue_id=5&news_id=140002554&pg=22>.

This is a very brief page from the University of Oregon that explains the use of LD50 data in MSDS: <http://chemlabs.uoregon.edu/Safety/toxicity.html> .

The Physicians Committee for Responsible Medicine shares this criticism of using LD50 data to measure toxicity: <http://www.pcrm.org/good-medicine/1999/summer/the-ld50-cruel-archaic-and-still-used-in>.

This site from Utah State University lays out some basic principles of toxicology <http://toxicology.usu.edu/660/html/principles.html>

**More sites on toxic substances**

The United Nations World Health Organization publishes a “Human Health Risk Assessment Tool Kit”: <http://www.inchem.org/documents/harmproj/harmproj/harmproj8.pdf>.

The World Health Organization also publishes a document called “Principles and Methods for Evaluating the Toxicity of Chemicals”: <http://www.inchem.org/documents/ehc/ehc/ehc006.htm>.

The state of California issues an “Introduction to Hazardous Chemicals in the Workplace”, which is a basic but complete guide to dangerous chemicals, as part of their “Understanding Toxic Substances” program: <http://www.cdph.ca.gov/programs/hesis/Documents/introtoxsubstances.pdf>.

**More sites on toxicology**

The Society of Toxicologists is a professional organization for working toxicologists and the site offers information about careers in this field. (<http://www.toxicology.org/>)

Flinn Scientific provides this primer on toxicology: <http://www.flinnsci.com/media/460940/safety_notes_vol_12-9.pdf>.

A very detailed examination of the field of toxicology is provided here by The National Library of Medicine: <http://toxlearn.nlm.nih.gov/htmlversion/module1.html>.

**More sites on lab safety**

The American Chemical Society publishes a complete guide to “Chemical Safety for Teachers and Their Supervisors, Grades 7-12” that includes a section on the safe handling of hazardous chemicals: <http://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/chemical-safety-manual-teachers.pdf>.

From Flinn Scientific, here’s a searchable series of safety sheets that identify hazards and responses: <http://www.flinnsci.com/msds-search.aspx>.

The Lab Safety Institute provides many resources promoting lab safety: <http://www.labsafetyinstitute.org/>.

The U.S. Centers for Disease Control and Prevention (the CDC) publishes a comprehensive “School Chemistry Safety Guide” that outlines steps to control hazardous chemicals along with other important safety concepts. (<http://www.cdc.gov/niosh/docs/2007-107/pdfs/2007-107.pdf>)

The National Science Teachers Association lists on their Web site multiple resources for lab safety. (<http://www.nsta.org/safety/>)

**More sites on animal testing**

**Sites with a balanced approach to animal testing**

This site, ProCon.org, offers opposing points of view on many topics of interest, including animal testing: <http://animal-testing.procon.org/>.

The Markkula Center for applied Ethics has an essay that incorporates both pro and con on animal testing. (<http://www.scu.edu/ethics/publications/iie/v1n3/cures.html>)

The U.S. Food and Drug Administration has a position on animal testing that is provided on its Web site. The site also contains links to other federal laws or rules governing use of animals. (<http://www.fda.gov/Cosmetics/ScienceResearch/ProductTesting/ucm072268.htm>)

**Sites that are pro-testing**

This site, funded by firms that use animals in their testing programs, has a positive view of testing: <http://www.understandinganimalresearch.org.uk/>.

Pharmaceutical company Johnson & Johnson gives their position on animal testing and provides a link to their guidelines for the use of animals. (<http://www.jnj.com/caring/citizenship-sustainability/strategic-framework/animal-testing>)

**Sites that are anti-testing**

People for the Ethical Treatment of Animals presents the arguments against using lab animals as test subjects. (<http://www.peta.org/issues/animals-used-for-experimentation/animal-testing-101/>)

The Humane Society International also presents the case against animal testing. (<http://www.hsi.org/campaigns/end_animal_testing/qa/about.html>)

# So Tired in the Morning: The Science of Sleep

## Background Information (teacher information)

On average, humans spend about one third of their lives sleeping. From early times, scientists have asked:

* **Why do we need so much sleep?**
* **In what ways is sleep beneficial to our health?**
* **What happens when we are sleep deprived?**

**More on scientific theories on the need for sleep**

The first reported evidence of brain activity during sleep was based on animal observations and studies. With current technology, neural scientists are able to use human brain scans to accurately determine the areas of the brain where activity occurs. Further, these studies identify the periods during human sleep when brain wave activity is the most robust (see later sections on REM and NREM sleep). Several theories have been proposed to explain our need for so much sleep. Harvard Medical School groups them as:

* Inactivity Theory─One of the earliest hypotheses was based on safety. While animals are quiet during the night, they are less likely to be attacked by predators.
* Energy Conservation─While awake, the body is frequently very active, the metabolic rate is high and the demand for body energy is at its peak. During sleep, the body has the opportunity to restore the energy that it has lost during waking hours. In addition, the metabolic rate is lower during sleep so less energy is used.
* Restoration Theory─During sleep the brain remains active, directing body functions. (See section below: “More on the biochemistry of sleep”.) This is the time for most muscle growth, tissue repair, protein synthesis, and growth hormone release. While awake, adenosine builds up in the brain causing sleepiness. A cup of coffee may trigger alertness because caffeine blocks the action of adenosine. For further information on caffeine and the effect of adenosine, see *ChemMatters* article “Caffeine” in the “References” section of this Teachers’ Guide.
* Brain Plasticity Theory─Changes in how the brain organizes memories and the relationship between memory and decision making occur during REM sleep. Current brain studies at the University of California, San Francisco (UCSF) and the Massachusetts Institute of Technology (MIT) show sharp-wave ripples (SWRs) that link memory and decisions occur only during sleeping, under anesthesia or during periods of immobility. (For more information see *Quanta Magazine* on neurological research:

<http://www.quantamagazine.org/20141022-mental-leaps-cued-by-memorys-ripples/>.

(from <http://healthysleep.med.harvard.edu/healthy/matters/benefits-of-sleep/why-do-we-sleep>)

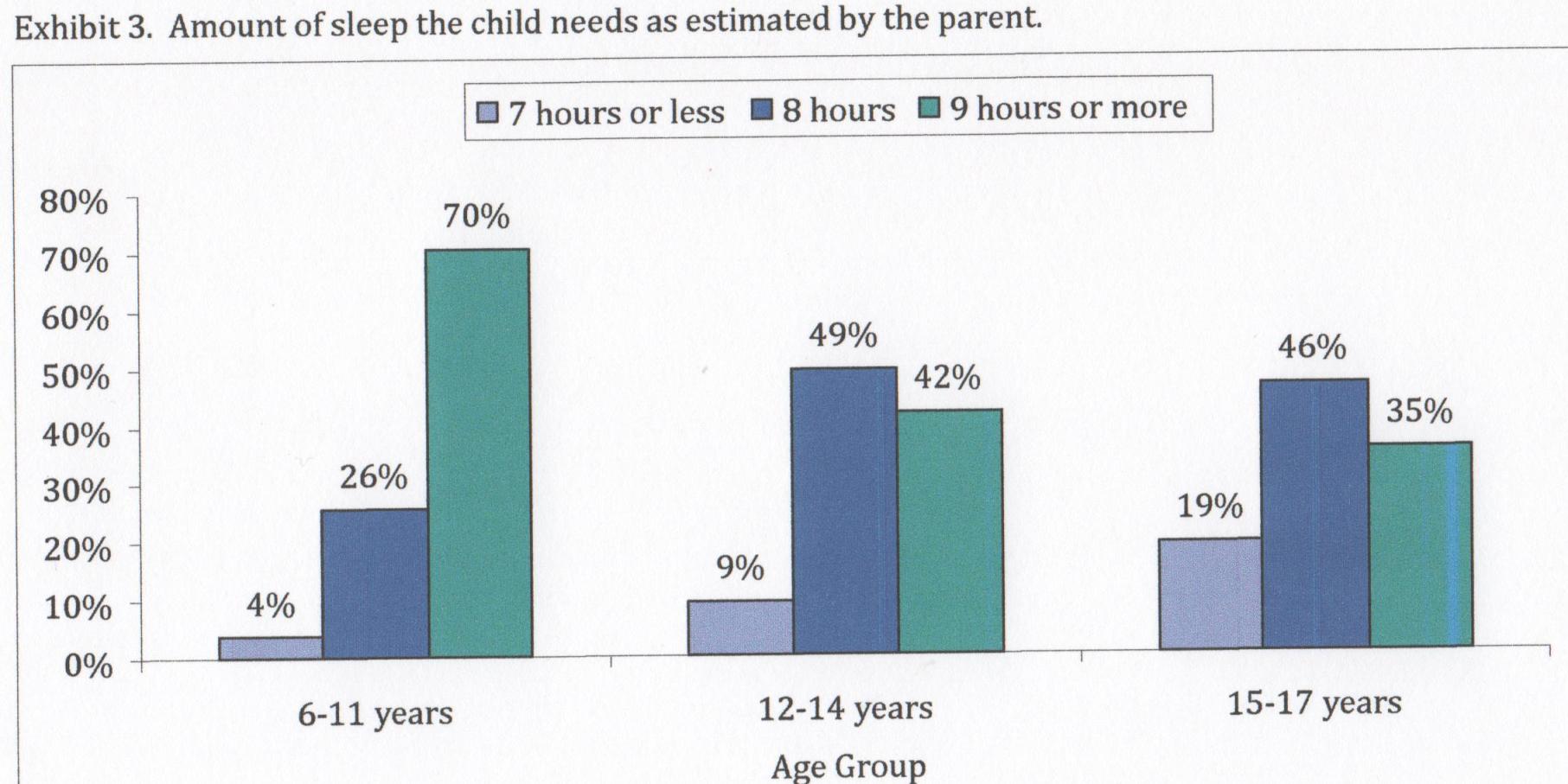
**More on teen sleep research**

Research done by the University of California, Los Angeles (UCLA) Sleep Disorders Center (<http://sleepcenter.ucla.edu/body.cfm?id=63>) shows that “Most teenagers do not get the sleep that they need on a daily basis.” When lifestyles, early class start times, and obligations conflict with their ability to obtain the recommended nine hours of sleep, teens show signs of sleep deprivation. It is often difficult for them to learn to manage their out-of-class time. There may be excessive homework, exhausting and time-consuming sports and other activity obligations coupled with social demands from friends and families. In addition, some teens have to cope with work schedules and caring for younger siblings after school.

Daily schedules need to be finely tuned to accommodate all these demands and leave at least nine hours for sleep. To alleviate some of the student stress, school districts and teachers are discussing limits on homework and, as demonstrated in this article, later times for the beginning of classes.

**More on sleep requirements for adolescents**

The National Sleep Association 2014 “Sleep in American Poll” shows that only 42% of 12–14 year olds and even less—35%—of teens 15–17 years old, are sleeping for nine hours or more according to their parents. Their research states that this is the amount of sleep that teens require to remain “healthy, focused and productive”.



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*<http://sleepfoundation.org/sites/default/files/2014-NSF-Sleep-in-America-poll-summary-of-findings---FINAL-Updated-3-26-14-.pdf)>*

**More on the 2014 “*Sleep in America Poll”***

The full 2014 “Sleep in America Poll” results contain information in the following sections:

* [Learn about why your family's sleep suffers when technology invades the bedroom](http://sleepfoundation.org/ask-the-expert/electronics-the-bedroom)─ Even small electronics like cell phones and computers involve mental activity and alert the retina to sense that it is daytime. Using electronic devices may keep teens awake far into the night, thus disrupting the natural sleep cycle and depriving them of the hours of sleep needed to function optimally.
* [Understand the importance of designing a healthy sleep environment](http://sleepfoundation.org/ask-the-expert/three-things-you-need-know-about-your-child%E2%80%99s-sleep-environment)─An environment that promotes healthy sleep should go beyond powering down electronic devices. While clinical studies on temperature, noise, and light have been focused on adults, this data may also have implications for teen health. Optimal temperature is cool, but not cold. Studies recognize that some families may not have the option of air conditioning and sufficient heating. In high crime areas, leaving an open window for cooling may be a dangerous option. Household noise and light caused by work schedules and food preparation may retard the beginning of sleep as well as disrupting later sleep. Outside noise and light from traffic, industry, commerce, or neighbors may disturb sleep.
* [Explore why children and teens need sleep rules](http://sleepfoundation.org/ask-the-expert/what-happens-when-my-child-or-teen-doesn%E2%80%99t-get-enough-sleep)─Sleep rules monitored by parents are necessary for the health, focus and productivity of teens. Teens need consistent routines for sleep including a set time for bed that provides nine hours of sleep plus half an hour away from cell phones, TVs, and computers. This section also discusses some teen health problems such as anxiety and depression created by lack of sufficient sleep.
* Data from prior years of the *Sleep in America Polls* is given under: [Catch up on past Sleep In America® polls](http://sleepfoundation.org/sleep-polls-data)

(<http://sleepfoundation.org/sites/default/files/2014-NSF-Sleep-in-America-poll-summary-of-findings---FINAL-Updated-3-26-14-.pdf>)

**More on consequences of teen sleep deprivation—behavior problems**

Teens who are not receiving sufficient sleep each night will begin to show signs of sleep deprivation. In the classroom, they fall asleep, become irritable by afternoon, and their grades may drop due to lack of ability to concentrate on lessons. Lack of sleep may also impair teen athletic ability and cause drowsiness when driving. At home, teens who need more sleep may find it difficult to wake up in the morning and sleep for long periods on the weekend.

The UCLA Sleep Center has found that signs of lack of sleep in teens may be confused with those of ADHD (attention-deficit/hyperactivity disorder). ADHD may be characterized by trouble concentrating, mood swings, hyperactivity, nervousness, and aggressive behavior.

To promote good sleep habits, UCLA stresses the importance of a regular, relaxing routine that includes exercise and a healthy diet. An atmosphere conducive to a good night’s sleep for teens should be quiet. Caffeine and video games before bedtime should be avoided. Their studies also suggest that short naps (less than one hour) are beneficial, longer ones simply leave the teen groggy and may make it harder to fall asleep at night. (<http://sleepcenter.ucla.edu/body.cfm?id=63>)

**More on the politics of later start times for schools**

On August 25, 2014, the American Academy of Pediatrics issued a new policy statement, “School Start Times for Adolescents”, that “urges high schools and middle schools to aim for start times that allow students the opportunity to achieve optimal levels of sleep (8.5–9.5 hours).” See the full policy statement at: (<http://pediatrics.aappublications.org/content/early/2014/08/19/peds.2014-1697>)

Political advocacy for delaying the time of the first period bell was spear-headed by New Jersey State Senator Richard Codey. He supports the recommendation of the American Academy of Pediatrics that school start times be delayed. Codey introduced a bill asking the state Department of Education to study how following this recommendation will benefit students. Codey said, “This is more than a matter of teenagers dozing at their desks. This is about their health and ability to learn, retain information and succeed.” (<http://www.app.com/story/news/education/education-trends/2014/10/15/state-senator-richard-codey-calls-later-school-start-times/17337981/>)

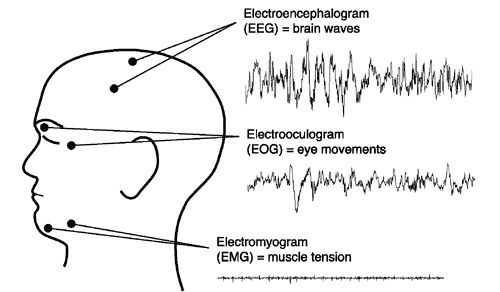
To date, only seventy school districts throughout the United States have developed plans to delay the beginning of high schools until 8:30 a.m. or later. Both the logistics and politics of this type of change prove to be severe stumbling blocks. There are school budgets, bus schedules, and athletic programs. In addition, the needs of parents on fixed work schedules to transport children to classes each morning must be considered.

Successful school start delays have usually occurred within small districts where task forces composed of the various stakeholders discuss both the data supporting the need for additional/later sleep for teens and the logistics of accomplishing this change. There are two large districts, Seattle and Fairfax County (Virginia), in the planning stages. (<http://blogs.seattletimes.com/educationlab/2014/09/30/be-heard-on-school-start-times-for-teens-seattle-forms-task-force/>)

**More on the biochemistry of sleep**

Sleeping is an active, endothermic process. While sleeping, the body uses energy to maintain metabolic processes such as breathing, digestion, and pumping blood. In addition, energy is being used to keep the brain active. Scientists use electroencephalograms (EEGs) to measure electrical changes in the brain; electrooculograms (EOG) to measure eye movements; and electromyograms (EMG) to measure muscle tension. These activities during sleep lead to the identification of two basic patterns of brain waves, characterized by different sleep patterns:

* REM—Rapid Eye Movement
* NREM—Non Rapid Eye Movement



**Figure 2.** *Placement of electrodes to determine EEG, EOG, and EMG.*

*(*<https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>)

During sleep, the body cycles between NREM (non-rapid eye movement) and REM (rapid eye movement) sleep. As you fall asleep, NREM begins the cycle. For approximately 75% of the night the body is in the NREM mode. The body switches into the REM portion of the cycle about 90 minutes after you fall asleep. The table below summarizes the difference in the processes that occur during the sleep cycle.

| **Table 1. Comparison of Physiological Changes During NREM and REM Sleep** | | |
| --- | --- | --- |
| **Physiological Process** | **During NREM** | **During REM** |
| brain activity | decreases from wakefulness | increases in motor and sensory areas, while other areas are similar to NREM |
| heart rate | slows from wakefulness | increases and varies compared with NREM |
| blood pressure | decreases from wakefulness | increases (up to 30 percent) and varies from NREM |
| blood flow to brain | does not change from wakefulness in most regions | increases by 50 to 200 percent from NREM, depending on brain region |
| respiration | decreases from wakefulness | increases and varies from NREM, but may show brief stoppages (apnea); coughing suppressed |
| airway resistance | increases from wakefulness | increases and varies from wakefulness |
| body temperature | is regulated at lower set point than wakefulness; shivering initiated at lower temperature than during wakefulness | is not regulated; no shivering or sweating; temperature drifts toward that of the local environment |
| sexual arousal | occurs infrequently | increases from NREM (in both males and females) |

*(*[*https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm*](https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm)*)*

Additional information on details of the function of the endocrine and renal systems and alimentary activity can be found at the National Institutes of Health Teacher’s Guide (see the URL above).

Studies on rats show that their normal life spans of two to three years have been shortened to five months when they are deprived of REM (see section below on sleep). When deprived of all sleep, they may die in as little as three weeks. Some scientists consider lack of sleep as injurious to health as lack of food. (<https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>)

**More on the quality of sleep and the NREM/REM cycles**

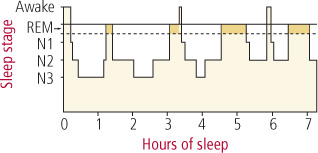
It is not only the nine hours of sleep before the alarm that are important for teens, but it is also the adequate quality of this sleep time that is required to produce a refreshed and alert morning wake up. There are four main stages of sleep:

**The Stages of Sleep**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| |  | | --- | | **Non-REM sleep** | | **Stage N1 (Transition to sleep)** – This stage lasts about five minutes. Your eyes move slowly under the eyelids, muscle activity slows down, and you are easily awakened. | | **Stage N2 (Light sleep)** – This is the first stage of true sleep, lasting from 10 to 25 minutes. Your eye movement stops, heart rate slows, and body temperature decreases. | | **Stage N3 (Deep sleep)** – You’re difficult to awaken, and if you are awakened, you do not adjust immediately and often feel groggy and disoriented for several minutes. In this deepest stage of sleep, your brain waves are extremely slow. Blood flow is directed away from your brain and towards your muscles, restoring physical energy. | | **REM sleep** | | **REM sleep (Dream sleep)** – About 70 to 90 minutes after falling asleep, you enter REM sleep, where dreaming occurs. Your eyes move rapidly, your breathing shallows, and your heart rate and blood pressure increase. Also during this stage, your arm and leg muscles are paralyzed. | |

*(*[*http://www.helpguide.org/articles/sleep/how-much-sleep-do-you-need.htm*](http://www.helpguide.org/articles/sleep/how-much-sleep-do-you-need.htm)*)*

During deep sleep (NREM), the body restores the physical energy burned during the day, repairs muscles and tissues, and strengthens the immune system. A disruption during this time can be very damaging. The REM period is the time when the brain’s neural connections are renewed. In quality sleep, the NREM/REM sleep patterns cycle throughout the night. A quiet, stress free environment is necessary to maintain this pattern. Sleep disorders may occur when sleep is repeatedly interrupted. For example, when noise inside or outside the home, lights turned on and off, or other disturbances, repeatedly wake a person, the body cannot cycle normally through the NREM and REM patterns seen in the graph below:



When you chart the sleep stages over the course of the night, the result looks like a city skyline—  
which is why it is called "sleep architecture".

*(*[*http://www.helpguide.org/articles/sleep/how-much-sleep-do-you-need.htm*](http://www.helpguide.org/articles/sleep/how-much-sleep-do-you-need.htm)*)*

Both disruption in the sleep cycles shown above and/or the lack of sufficient hours of sleep may lead to problems related to sleep deprivation. The National Sleep Foundation published an article written directly for teenagers. Sleep is described as “food for the brain”. Below are lists of the “Facts” about sleep and the “Consequences” of inadequate sleep:

**FACTS:**

* Sleep is vital to your well-being, as important as the air you breathe, the water you drink and the food you eat. It can even help you to eat better and manage the stress of being a teen.
* Biological sleep patterns shift toward later times for both sleeping and waking during adolescence -- meaning it is natural to not be able to fall asleep before 11:00 pm.
* Teens need about 9 1/4 hours of sleep each night to function best (for some, 8 1/2 hours is enough). Most teens do not get enough sleep — one study found that only 15% reported sleeping 8 1/2 hours on school nights.
* Teens tend to have irregular sleep patterns across the week — they typically stay up late and sleep in late on the weekends, which can affect their biological clocks and hurt the quality of their sleep.
* Many teens suffer from treatable sleep disorders, such as [narcolepsy](http://www.sleepfoundation.org/sleep-disorders-problems/excessive-daytime-sleepiness-disorders/narcolepsy), insomnia, [restless legs syndrome](http://www.sleepfoundation.org/content/restless-legs-syndrome-rls-and-sleep) or sleep apnea.

**CONSEQUENCES:**

Not getting enough sleep or having sleep difficulties can:

* Limit your ability to learn, listen, concentrate and solve problems. You may even forget important information like names, numbers, your homework or a date with a special person in your life;
* Make you more prone to pimples. Lack of sleep can contribute to acne and other skin problems;
* Lead to aggressive or inappropriate behavior such as yelling at your friends or being impatient with your teachers or family members;
* Cause you to eat too much or eat unhealthy foods like sweets and fried foods that lead to weight gain;
* Heighten the effects of alcohol and possibly increase use of caffeine and nicotine; and
* Contribute to illness, not using equipment safely or [driving drowsy.](file:///\\acs.org\AppData\Local\Microsoft\ACS%20CHEMMATTERS%20Mag\Teachers%20Guide\Dec.%202014.Sleep\driving%20drowsy)

(<http://sleepfoundation.org/sleep-topics/teens-and-sleep>)

**More on the biological clock of teens**

During adolescence, the circadian rhythm of the body changes. A teen’s clock signals a later time for sleep. Actually this is only about one hour later but, in addition, many teens postpone bedtime for an additional two hours to keep up with the demands of academics, extracurricular activities, work schedules, social pressures and the tempting technology of video games and social media. Teens find it difficult to balance the needs of their bodies for sleep with outside time commitments. Life styles and biology combine to create a three hour sleep deficit for many teens, leaving them feeling groggy and tired when the morning alarm sounds. (<http://sleepcenter.ucla.edu/body.cfm?id=63>)

The National Sleep Foundation refers to the changes in the circadian rhythms that occur during adolescence as “sleep phase delay”. The Cleveland Clinic defines “sleep phase delay” as a condition where a person’s sleep is delayed two or more hours beyond their usual bedtime. (<http://my.clevelandclinic.org/services/neurological_institute/sleep-disorders-center/disorders-conditions/hic-delayed-sleep-phase-syndrome>)

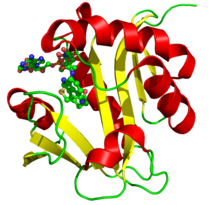
Research done at the National Sleep Foundation shows:

This shift (sleep phase delay) in teens' circadian rhythm causes them to naturally feel alert later at night, making it difficult for them to fall asleep before 11:00 pm. Since most teens have early school start times along with other commitments, this sleep phase delay can make it difficult to get the sleep teens need—an average of 9-1/4 hours, but at least 8-1/2 hours. This sleep deprivation can influence the circadian rhythm; for teens the strongest circadian “dips” tend to occur between 3:00–7:00 am and 2:00–5:00 pm, but the morning dip (3:00–7:00 am) can be even longer if teens haven’t had enough sleep, and can even last until 9:00 or 10:00 am.

(<http://sleepfoundation.org/sleep-topics/sleep-drive-and-your-body-clock>)

**More on the enzymatic production of melatonin from serotonin and the use of melatonin supplements**

The production of melatonin is catalyzed by the hormone, serotonin N-acetyltransferase.



*Crystallographic structure of serotonin N-acetyltransferase*

*(*[*http://upload.wikimedia.org/wikipedia/commons/thumb/b/ba/SNAT\_PDB-code\_1KUX.png/220px-SNAT\_PDB-code\_1KUX.png*](http://upload.wikimedia.org/wikipedia/commons/thumb/b/ba/SNAT_PDB-code_1KUX.png/220px-SNAT_PDB-code_1KUX.png)

As described in the Harper sleep article, light detection by the eye’s retina signals the pineal gland in the brain to produce melatonin. According to the abstract for “Melatonin Biosynthesis” published in the journal *Molecular Cell* the structure of serotonin-N-acetyltransferase (SNAT) shown above and in the third structure of Figure 3 of the Harper sleep article suggests a catalytic mechanism for this biosynthesis as follows:

Conversion of serotonin to N-acetylserotonin, the precursor of the circadian neurohormone melatonin, is catalyzed by serotonin N-acetyltransferase (AANAT) in a reaction requiring acetyl coenzyme A (AcCoA). AANAT is a globular protein consisting of an eight-stranded beta sheet flanked by five alpha helices; a conserved motif in the center of the beta sheet forms the cofactor binding site. Three polypeptide loops converge above the AcCoA binding site, creating a hydrophobic funnel leading toward the cofactor and serotonin binding sites in the protein interior. Two conserved histidines not found in other NATs are located at the bottom of the funnel in the active site, suggesting a catalytic mechanism for acetylation involving imidazole groups acting as general acid/base catalysts.

(<http://www.ncbi.nlm.nih.gov/pubmed/10024876>)

Scientific research shows that melatonin is the hormone that helps control our sleep-wake cycle. Some studies suggest that melatonin supplements may be useful in treating severe sleep disorders and jet lag by helping people fall asleep. Common side effects associated with the use of melatonin supplements include dizziness, headaches, and sleepiness in the daytime; and, less commonly, short-term feelings of depression, stomach cramps, and irritability. Additional information about the use and warnings associated with the use of melatonin supplements can be found on the Mayo Clinic website below. (<http://www.mayoclinic.org/healthy-living/adult-health/expert-answers/melatonin-side-effects/faq-20057874>)

The circadian rhythm of people who are totally blind is permanently disrupted because the retina cannot detect light. Melatonin supplements may help regulate the biological clocks of the blind, thus improving their ability to follow normal sleep patterns. The National Institutes of Health warns: “Since the high doses of melatonin found in most supplements can build up in the body, long-term use of this substance may create new problems. Because the potential side effects of melatonin supplements are still largely unknown, most experts discourage melatonin use by the general public.” (<http://www.ninds.nih.gov/disorders/brain_basics/understanding_sleep.htm>)

Melatonin is sold as an over-the-counter supplement and considered safe for most adults when taken by mouth for a short period of time. Labels warn about the use for children. Due to its effects on other hormones, melatonin supplements may interfere with development during adolescence. (<http://www.rxlist.com/melatonin/supplements.htm>)

**More on jet lag, body clocks, and coping with jet lag**

Sports competitions, visits to grandparents, vacations, and school field trips that cross time zones often deliver tired and fatigued teens to their final destinations. In addition to the expected changes in eating habits and the effect of being squashed into small, dry airplane spaces, circadian rhythms are disrupted. Traveling from west to east creates more sleep problems because the body clock has to advance rather than delay the time to sleep. The medical journal *The Lancet* published a list comparing normal travel fatigue and jet lag:

**Differences between travel fatigue and jet lag**

* Travel fatigue is associated with any long journey; jet lag generally needs three or more time zones to be crossed rapidly.
* Travel fatigue abates by the next day, the traveler having had a good night’s sleep; jet lag after eastward flights lasts for several days, roughly equal to two-thirds of the number of time zones crossed, and about half the number of time zones crossed after westward flights. Again, there are obvious differences between individuals.

To reduce the effects of jet lag it is recommended that you:

* Begin resetting the biological clock a few days before leaving by gradually changing bedtimes to adapt to adapt to the new time zone.
* Upon arrival, set your watch to the new time.
* Stay hydrated, drink plenty of water.
* If tired, take just a short nap, then get up, go for a walk, or talk to others staying awake until dark.
* Get up and be active as soon as the sun shines in the morning.

(*The Lancet*. *369* (9567), pp 1117–1129, 31 March 2007 doi: 10.1016/S0140-6736(07)60529-7. Available online at: <http://www.v2020la.org/pub/PUBLICATIONS_BY_TOPICS/VARIOUS/Jet%20lag.....pdf>)

**More on the effects of daylight saving time on the circadian rhythm**

It has been shown that sleep deprivation and the change of circadian rhythm can trigger mental illness and cause higher accident rates. While daylight saving time affects millions of people annually, the impacts of dealing with only a one hour change are still widely unknown. While the transitions into and out of daylight saving time change the circadian rhythm, daylight saving time results in a very small loss of sleep.

The major study on the effects of the one hour transitions for daylight saving time was based on data from the Finish Hospital Discharge Register. Nationwide, during a time period including two weeks after and two weeks before daylight saving time for the years 1987-2003, there was no significant increase in hospital cases involving accidents, manic episodes, or signs of major sleep deprivation. The following website contains the abstract and free access to the full report: (<http://www.ncbi.nlm.nih.gov/pubmed/18302734>).

In 2007, Till Roenneberg published the results of a study of 55,000 people in central Europe in the journal, *Cell Biology*. Roenneberg’s data came from surveys completed by the subjects in his study. His group concluded: “For both morning larks and night owls, their timing for sleep and peak activity easily adjusted when daylight saving time ended in the fall. However, it never adjusted to the return to daylight saving time in spring. This was especially true for night owls -- those who stay up late and sleep late.”

(<http://consumer.healthday.com/mental-health-information-25/behavior-health-news-56/body-s-clock-never-adjusts-to-daylight-saving-time-609394.html>)

**More on teen sleep deprivation behaviors**

Sleep disorders may occur when there is insufficient time for sleep and/or when sleep is repeatedly interrupted and the body cannot cycle normally through the NREM and REM patterns. The Cleveland Clinic lists the following three signs that may indicate teen sleep deprivation:

* Excessive daytime sleepiness─Falling asleep in class may not indicate boredom or disrespect for the teacher. This may be the result of inadequate sleep.
* Irritability, hyperactivity, depression, impatience, mood swings, low self-confidence, low tolerance for frustration and other impulse control problems─These behaviors may also indicate attention deficit hyperactivity disorder (ADHD) discussed below.
* Falling grades and reports of drowsy driving─Sleep deprived teens have difficulty focusing on their learning. Their low grades may be indicative of this. Sleep deprivation can seriously impair the ability to drive safely.

(<https://my.clevelandclinic.org/ccf/media/files/Sleep_Disorders_Center/09_Adolescent_factsheet.pdf>)

The behaviors above are similar to those found in students diagnosed with ADHD. According to Dr. Thakkar, professor of psychiatry at the New York University Langone Medical Center, many of the symptoms of ADHD are indistinguishable from those seen in sleep deprivation. Unfortunately, this frequently leads to a misdiagnosis of ADHD.

In the article “ADHD or Sleep Disorder: Are We Getting it Wrong?” *(Psychology Today*, May 1, 2013) the author cites “lack of focus, agitated, excitable, and impulsive” as behaviors common to both sleep disorders and ADHS. This article continues to state: “These behaviors associated with A.D.H.D. interfere with a child’s social and intellectual development, causing problems with relationships with peers and adults, at school and at home. But what if A.D.H.D. isn’t always the underlying cause of these symptoms? Signs of poor quality and insufficient sleep in children can look remarkably like symptoms of A.D.H.D., as a number of recent studies show.”

(<http://www.psychologytoday.com/blog/sleep-newzzz/201305/adhd-or-sleep-disorder-are-we-getting-it-wrong>)

**More on some severe sleep disorders and medical diagnosis**

The American Association of Pediatrics (AAP) has expressed concern regarding the lack of screening children for sleep problems by pediatricians. This is necessary to reduce the incidence of misdiagnosis of behaviors and subsequent unnecessary treatment for ADHD. A 2012 study of sleep screening practices, *Screening for Sleep Disorders in Pediatric Primary Care Are We There Yet?,* published in *CLIN PEDIATR* (December 2012 vol. 51 no. 121125-1129) showed inadequate patient screening for sleep problems that might account for behaviors similar to sleep deprivation. It was found that less than 20% of the pediatricians surveyed had received training in the diagnosis of sleep-disorders. The study demonstrates the need for better training for physicians and more effective screening for sleep disorders to be certain that a medical diagnosis is accurate. Results and conclusions of the study show:

Although guidelines were published by the American Academy of Pediatrics (AAP) a decade ago recommending routine screening of sleep-disordered breathing (SDB) in primary care settings, it remains unclear to what extent such guidelines have been implemented and resulted in effective SDB screening. The aim of this study was to determine if AAP guidelines are adhered to in pediatric primary care.

Of the children screened for sleep-related issues, 34.1% (n = 86) snored, but the majority of them (61.6%, n = 53) received no further evaluation. In the present sample, 0.5% (n = 5) had a diagnosis of OSA. The low prevalence of obsessive sleep apnea (OSA) may be explained by the relatively low frequency of sleep-related problem screening by pediatricians and thus the inordinately low adherence to the AAP guidelines. Modification and transition to electronic medical records as well as expanded efforts to educate health care providers and caregivers may improve detection and timely treatment of children at risk for SDB.

(<http://cpj.sagepub.com/content/51/12/1125.abstract>)

The Mayo Clinic, the National Institutes of Health, and the UCLA Sleep Disorders Center provide similar lists of severe health effects attributed to sleep deprivation caused by both the number of sleep time hours (sleep quantity) and the disruptions during sleep (sleep quality). Excessive daytime sleepiness may be a sign of serious medical problems such as:

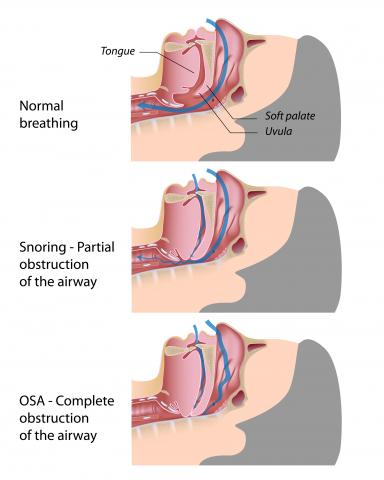
* Side effects─Medications used to treat hyperactivity may cause daytime sleepiness, insomnia, and aggressive behavior. These side effects mimic sleep deprivation behaviors as well as lead to increased sleep deprivation. (<http://www.nimh.nih.gov/health/topics/attention-deficit-hyperactivity-disorder-adhd/index.shtml>)
* Insomnia─The inability of teens to fall asleep at night or difficulty falling back to sleep after waking up at night may be caused by stress, environmental noise, physical discomfort, excessive sleeping during the day, or a reaction to medication or excessive caffeine. (<http://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>)
* Obstructive sleep apnea (OSA)─OSA is a potentially life-threatening sleep disorder that affects as many as 25% of the adult population. OSA is characterized by snoring and numerous brief pauses in breathing that can seriously disrupt the sleep cycle. During normal breathing, air goes passes down the throat, through the windpipe, and continues into the lungs. The back of the throat is the narrowest part of this pathway. While awake, the muscles actively keep the air passage open. During sleep, muscles relax and this path narrows. Clinical research describes what happens during OSA. As the air passes through, the narrow passage may become partially blocked. There are pauses in breathing and throat vibrations that produce a snoring sound. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3021364/>)
* Restless legs syndrome (RLS)─Approximately 10 to 15% of the population experiences leg sensations and movements that disrupt sleep. This uncomfortable and even painful urge to move the legs usually occurs in the late evening or during the night. Sitting for long time periods of time such as on an airplane may initiate symptoms; movement such as walking may alleviate them. This is a neurological disorder that can sometimes be successfully treated by exercise, leg massages, and elimination of caffeine and alcohol from the diet. Studies find low levels of iron and dopamine in the brain of RLS patients. Scientists also suspect that the genes that manage iron concentrations in the brain may play a role in RLS, but according to the John Hopkins report, there remain, “gaps in our knowledge”. (<http://www.hopkinsmedicine.org/neurology_neurosurgery/centers_clinics/restless-legs-syndrome/what-is-rls/>)
* Narcolepsy─The on-set of narcolepsy often occurs between the ages of 15 and 25 years. In narcolepsy, the brain is unable to control the sleep-wake cycles. This chronic sleep disorder is characterized by sleep attacks in the middle of the day. The person may suddenly feel overwhelmingly tired and fall asleep for a short period of time (a few seconds to a few minutes) even while eating or holding a conversation. Sometimes there is an emotional trigger such as a response to laughter, anger or surprise. The National Institutes of Health (NIH) “Teacher’s Guide” suggests that narcolepsy may be linked to an immune system attack on the nervous system as described below:

REM sleep in people with narcolepsy frequently occurs at sleep onset instead of after a period of NREM sleep. Consequently, researchers believe that the symptoms of narcolepsy result from a malfunction in some aspect of REM sleep initiation. Some scientists believe that the immune system causes narcolepsy by attacking the nervous system (that is, an autoimmune response). In this view, exposure to an unknown environmental factor results in an immune response against nerve cells in the brain circuits that control arousal and muscle tone.

(<https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>)

**More on sleep apnea (OSA) and obesity’s role in OSA**

The illustration below compares normal breathing with partial obstruction and complete blockage during OSA.



*(*[*http://stanford.edu/~pdjones/sleepapnea/sleep-apnea/causes.html*](http://stanford.edu/~pdjones/sleepapnea/sleep-apnea/causes.html)*)*

OSA occurs when the soft tissue in narrow back of the throat collapses and physically blocks the airway preventing the air from reaching the lungs. Excessive body weight may exacerbate this condition due to the additional soft tissue present in the nasal area. These obstructions can occur frequently and may last from 10 to 30 seconds, severely disrupting the sleep cycles and the oxygen levels throughout the night. When breathing resumes, it is often accompanied by gasps or body jerks. These pauses in breathing severely disturb the quality of sleep resulting in fatigue and sleepiness in the morning. The reduction and irregularity of oxygen flow may cause heart arrhythmias. Swollen tonsils or adenoids or enlargement of soft tissue from excessive weight can further obstruct the air pathway. (<http://www.aasmnet.org/resources/factsheets/sleepapnea.pdf>)

The Mayo Clinic produced a short video for YouTube to show the mechanics of OSA. (<http://www.mayoclinic.org/diseases-conditions/sleep-apnea/multimedia/obstructive-sleep-apnea/vid-20084717>)

Various treatment methods include changing sleeping positions and diet; using mechanical devices that force air through the nasal passages and dental appliances designed to lower the jaw and tongue; and undergoing surgery to remove tonsils or to widen the pathway. (<http://www.sleepapnea.org/treat/childrens-sleep-apnea.html>)

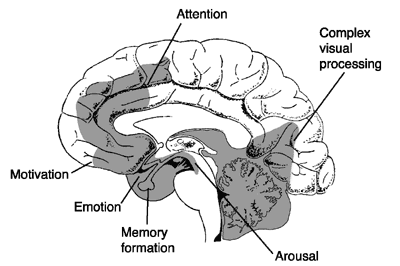
Sleep deprivation is often accompanied by weight gain. When sleep deprived, people frequently crave calorie-rich, sugary food to provide a quick boost of energy. In addition, those who stay awake late into the night are more prone to snacking in the long hours following dinner. The helpguide.org discussion, “How sleep deprivation can add to your waistline”, discusses the hormonal regulation of hunger:

There are two hormones in your body that regulate normal feelings of hunger and fullness. Ghrelin stimulates appetite, while leptin sends signals to the brain when you are full. However, when don’t get the sleep you need, your ghrelin levels go up, stimulating your appetite so you want more food than normal, and your leptin levels go down, meaning you don’t feel satisfied and want to keep eating. So, the more sleep you lose, the more food your body will crave.

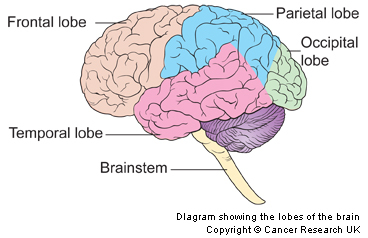
(<http://www.helpguide.org/articles/sleep/how-much-sleep-do-you-need.htm>)

**More on dreams and nightmares**

Dreaming usually takes place during REM sleep, but it may also occur during NREM, usually soon after sleep begins. Most people spend about two hours dreaming during the night. Dreams may vary from fairly ordinary experiences to the very bizarre, but they rarely portray realistic experiences. (<http://www.ninds.nih.gov/disorders/brain_basics/understanding_sleep.htm#dreaming>)

 Scanning studies of the brain show the areas that are active during REM dreaming. The active areas are shown shaded in the image to the right. The areas responsible for higher level thinking skills such as planning, organizing, and problem solving reside in the frontal lobe of the brain (see diagram below). The frontal lobe is not active during dreaming. Many people speculate, but scientists have not determined, the meaning of dreams or the reasons for dreaming.

*(*[*https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm*](https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm))



*(*[*http://www.cancerresearchuk.org/prod\_consump/groups/cr\_common/@cah/@gen/documents/image/cr\_116646.jpg*](http://www.cancerresearchuk.org/prod_consump/groups/cr_common/@cah/@gen/documents/image/cr_116646.jpg)*)*

Nightmares are often considered within a collection of sleep disorders designated as parasomnias. This group also includes walking and/or talking during sleep and bed-wetting. Nightmares usually occur during the REM stage, but extreme nightmares may occur during NREM sleep. Nightmares may be vivid and disturbing; often involve an instant wake-up and recall of the content; and result in feelings of stress, anxiety, and fear. Quality sleep is often disrupted during nightmares, thus leading to sleep deprivation. Nightmares usually relate to a traumatic event that involved emotions similar to those experienced at the time of wakeup.

**More on risky teen behaviors when coping with lack of sleep**

Teen sleep disorders, both mild and severe, may lead to behavioral problems, poor athletic and academic performance, and emotional problems. The United States Center for Disease Control and Prevention (CDC) study found that the probability of risky behaviors increased, when teens were sleep deprived. These behaviors include substance abuse, lack of physical exercise, excess computer use, consumption of excess caffeine, and suicide attempts. (<http://www.cdc.gov/media/releases/2011/a0926_insufficient_sleep.html>)

In a study published in the *American Journal of Health Behavior*, the weekday and weekend sleep patterns of 242 teens (average age, 16.4 years) were compared to their risky behaviors. It was found that adequate weekday sleep was directly related to fewer incidents of substance abuse, depression, and school truancy. In contrast, those teens that lacked sufficient quality sleep during the week and/or whose weekly sleep schedule was erratic, displayed a larger percentage of risky behaviors. The study summary, published in the *American Journal of Health Behavior,* shows:

In conclusion, adequate sleep during the school week appears to be associated with lower risk behaviors and lower levels of depression in youth. However, this research suggests that parents need to pay attention not only to sleep patterns and amount of sleep that their teens get during the school week, but they also need to be alert that late bedtimes and rising times on weekends may be signaling risk-taking behaviors. Setting weekend curfews may help reduce a variety of risk behaviors. Given the demands of adolescence and the importance of this developmental period, it is critical that we better understand how lack of sleep, in addition to changing sleep patterns, may influence risk behaviors and the health of adolescents.

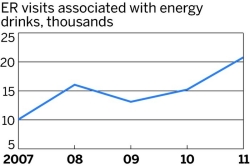
(<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3086400/>)

To cope with lack of sleep, teens frequently turn to coffee or other caffeine-laden energy drinks or products. The Mayo Clinic suggests that teens should limit themselves to 100 mg of caffeine per day, which is equivalent to one 5-oz cup of coffee. (<http://www.mayoclinic.org/healthy-living/nutrition-and-healthy-eating/in-depth/caffeine/art-20045678>)

The cover story of the February 4, 2013 issue of *Chemical and Engineering News*

(*C&E N*) is “Caffeine Jitters”. (<http://cen.acs.org/articles/91/i5/Caffeine-Jitters.html>)

As the title infers, there are serious side effects associated with the consumption of too much caffeine. The symptoms are similar to those produced by amphetamines: nervousness, headache, rapid heartbeat, and possible death. The graph below shows the rapid increase in emergency room (ER) visits associated with the overconsumption of caffeine from foods and energy drinks from the year 2007 to 2011.



*(*<http://cen.acs.org/articles/91/i5/Caffeine-Jitters.html>*)*

The article “Caffeine” in *ChemMatters*, October 2013 introduces the multitude of caffeine laden products on supermarket shelves; discusses how caffeine is metabolized in the body; and describes the dangers involved in the consumption of excess caffeine. This article is cited in the “References” section of this Teacher’s Guide.

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Rates of Reaction: Catalysis**—In the brain’s pineal gland, the hormone NAT catalyzes the production of melatonin from serotonin. Figure 3 in the Harper sleep article shows the chemical reaction. Concentration of the hormone NAT increases when it is dark, thus increasing the rate of catalysis to form melatonin.
2. **Biochemistry: Cycles**—This article provides a basis for studying cycles in the human body that directly reference teen interests and concerns. The biochemistry of circadian rhythms and the triggers involved are explained and illustrated.
3. **Biochemistry: Neural Pathways**—During study of the brain, students can trace the process from the retinal trigger to the pineal gland where the hormone melatonin is produced.
4. **Organic Chemistry: nomenclature, structure**—The production of melatonin from serotonin shown in Figure 3 of the Harper article, can be used to reinforce student understanding of organic nomenclature, structure, and functional groups.
5. **Chemical Kinetics: Reaction mechanisms**—The process shown in Figure 3 in the Harper article shows the four step mechanism involved in the organic synthesis of melatonin from serotonin.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. “**I can catch up on lost sleep during the weekend.”** *This is not the way to change your biological clock. Sleeping late all weekend tends to confuse your internal diurnal rhythm and may make it even more difficult to fall asleep during the week.*
2. **“During sleep, the body and the brain shut down to rest*.”*** *Actually, sleep is an active process. The average teenager burns one calorie per minute while sleeping. In addition to metabolic functions of the body, studies of brain waves show various stages of brain activity during sleep.*
3. **“I can cheat a bit on the amount of sleep each night.”** *Even if you just cut 20 minutes off the amount of sleep time that you require each night, sleep debt will gradually accumulate and can’t be easily repaid. This may affect your daytime performance in school, sports, and even your mood.*
4. **“My young body is very adjustable and can quickly adapt to different sleep schedules*.”*** *One’s biological clock is set to familiar day and night schedules. Trying to quickly change this by working, studying, or playing all night, and sleeping during the day leaves one with decreased ability to solve mental problems and may reduce athletic skills***.**
5. **“If I just pay attention to my body and go to bed when I feel sleepy I’ll get enough sleep!”** *For active teenagers, feeling sleepy may be**at 10:00 p.m. This would be fine except when school begins at 8:00 a.m. (or earlier!) The teen body needs nine hours of sleep, so count backwards and allow an extra hour to get ready for school. This is a total of ten hours so if this is your schedule, you will have to go to sleep by 9:00 p.m.*
6. **“Teens need about the same amount of sleep as adults.”** *Teens actually* *need more sleep than adults, at least nine hours or more per night. So, they must carefully plan their sleep schedule to be certain that they are fully functioning and not sleepy during the day*.
7. **“Caffeine will take care of everything.”** *While drinking a cup of coffee or an “energy shot” may wake up a sleepy teen, this is a temporary situation, and too much caffeine can send you to the emergency room.*
8. **“If I feel sleepy while driving, I can just turn up the music loudly, open the windows, and lower the air conditioner setting, then I’ll be fine*.”*** *False, this will only temporarily reduce sleepiness and lull one into a false sense of security. The solution is to take a thirty minute nap, or better yet, get a good night’s sleep before a long road trip.*
9. **“Teens who fall asleep in class are lazy!”** *Sleeping in the morning is usually a sign that teens have not had enough sleep the night before*.
10. **“Counting sheep will help me fall asleep.”** *Relaxing thoughts or images better induce sleep than the activity involved in counting sheep. If you are still awake after 15-20 minutes, go into another room if possible to read or listen to music until you are relaxed and sleepy, then return to bed.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“My little brother wakes up naturally before 7 a.m., so why am I still half asleep when the alarm rings?”** *Melatonin, the sleep inducing hormone, is produced about three hours earlier in children than in teens. While the melatonin concentration in your brother’s system has diminished, concentration in your system is still high enough to keep you asleep at 7 a.m.*
2. **“What can I do to fall asleep more quickly at night?”** *The most important thing you can do to help you fall asleep at night is to create a quiet, light free environment for sleeping. Turn off your phone and television at least half an hour before bedtime and find something quiet like reading to help you relax and fall asleep quickly.*
3. **“Why do I feel groggy and still sleepy after a long nap?”** *After about 20 minutes of sleep, your brain goes into a deep sleep phase. Waking from deep sleep during a long nap may leave you feeling disoriented and groggy. Short naps, 10-20 minutes, are best.*
4. **“What happens to your biological clock if you are totally blind?”** *Since the retina in a blind eye cannot respond to light, the production of the sleep producing hormone, melatonin, is not initiated, so there will be no signal to regulate the biological clock. Melatonin supplements are available to help blind people maintain normal sleep/wake cycles.*
5. **“Will dreaming upset my sleep cycle?”** *Dreaming is normal and usually will not affect your sleep cycle and the quality of your sleep. Even if you don’t remember your dreams, studies show that most**people dream for about two hours every night. On the other hand, violent nightmares may disrupt your sleep cycle, leaving you feeling tense and tired.*
6. **“How can I reduce my jet lag when I go to visit my grandparents in Asia?”** *Jet lag is the extreme tiredness that you feel after flying across several time zones. Before traveling to Asia, you can begin to reset your biological clock by changing your bed time by one or two hours each night to correspond more closely to Asian time.*
7. **“Why does my uncle suddenly fall asleep in the middle of dinner?”** *Your uncle may have a condition called narcolepsy. If so, he has no control over when he falls asleep because his brain is unable to control his sleep-wake cycles.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. Students could debate the “pros” and “cons” of delaying start times for schools. The student “pro” team can research the Internet and use scientific data to advocate for later school start times. The “con” team can gather community information regarding the societal effects and problems associated with later start times. This site provides a format for high school student mini-debates: <http://www.proquestk12.com/productinfo/pdfs/MiniDebate_Teachers.pdf>.

Additional details for debates are located at: <http://www.educationworld.com/a_lesson/lesson/lesson304b.shtml>.

1. Ask students to carefully examine the structures shown in Figure 3 in the Harper sleep article and identify the organic functional groups. The molecules shown contain benzene rings, cyclohexene, amino groups, organic (carboxylic) acids, aldehydes and hydroxyl groups. This Purdue University site provides a list of organic functional groups and their structural formulas: <http://chemed.chem.purdue.edu/genchem/topicreview/bp/2organic/2org_frame.html>.
2. The “Iodine Clock Reaction” lab can be used to give students hands-on laboratory experience with multi-step reactions: <https://www.flinnsci.com/media/621293/91549.pdf>.

## Out-of-class Activities and Projects (student research, class projects)

1. Before reading the Harper sleep article, students could watch this YouTube video at home, “Matt’s Story Rethinking School Start Times” (<https://www.youtube.com/watch?v=9aqopRzY2MA>) by Kelley Ditzenberger, and complete a questionnaire similar to the one that Matt used in the video, such as:

Answer the following questions based on your sleep schedule last week.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Question** | **Sunday**  **night** | **Monday**  **night** | **Tuesday**  **night** | **Wednesday**  **night** | **Thursday**  **night** |
| What time did you go to sleep? |  |  |  |  |  |
| What time get up? |  |  |  |  |  |
| How many hours did you sleep? |  |  |  |  |  |
| Did you feel awake and rested when the alarm went off? |  |  |  |  |  |

Collate the class results and discuss, or use this survey as a springboard for the next activity.

1. This activity is based on results from a class survey similar to the one above.

* Students construct a histogram or bar graph to organize class answers to the third question, “How many hours did you sleep?
* Students answer the question: “Do you see a correlation between the numbers of sleep hours shown in the histogram and the feeling of being rested?”
* Add a horizontal line above the bars on their graph to show the area where the numbers of hours of sleep match where students felt rested.

1. An extension to the previous activity: Ask students to share the reasons that prevented them from sleeping for nine hours each night and to answer the following questions as they reflect on this activity.

* Based on your own experience, are you receiving enough sleep each night?
* What can you do to alter your personal schedule to be certain that you allow enough time for sleep?

1. Ask students to investigate and collect Internet research on the myths surrounding the importance of sleep. One place to begin is the Sleep Foundation web site: “Myths—Facts—About Sleep” (<http://sleepfoundation.org/how-sleep-works/myths-and-facts-about-sleep>). If students work as groups in class, assign each group a different myth to investigate, such as these listed on the above web site:

* Snoring is a common problem, especially in men, but it isn’t harmful.
* You can “cheat” on the amount of sleep you get.
* Turning up the radio, opening the window, or turning on the air conditioner are effect ways to stay awake when driving.
* Teens that fall asleep in class have bad habits and/or are lazy.
* Insomnia is characterized by difficulty falling asleep.
* Daytime sleepiness always means a person isn’t getting enough sleep.
* Health problems such as obesity, diabetes, hypertension, and depression are unrelated to the amount and quality of a person’s sleep.
* The older you get, the fewer hours of sleep you need.
* During sleep, your brain rests.

1. Students could prepare creative posters that explain and use scientific facts to dispel these myths. Additional information on myths can be found in the National Institutes of Health (NIH) Teacher’s Guide on “Information about Sleep”: (<http://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>).

## References (non-Web-based information sources)

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). 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)**. Scroll to the bottom of the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**



**30 Years of *ChemMatters***

Available Now!

Vandeborght, C. You’re getting Sleepy. *ChemMatters* **2004,** *22* (1), pp 4–6. This article describes the body’s reaction to anesthesia including the gradual “shut down” of some brain areas during sedation.

Hersey, J. and Heltzel, C. Your Colorful Food. *ChemMatters* **2007,** *25* (1), pp 12–15. Hersey and Heltzel discuss the suspected relationship between food dye and children’s behavior. The symptoms related to food dyes resemble those linked to sleep deprivation and ADHD: difficulty going to sleep, poor concentration, disturbing others, and temper tantrums.

Haines, J. Coffee: Brain Booster to Go? *ChemMatters* **2008,** *26* (4), pp 7–9. Haines describes how coffee works in the brain to release adrenaline into body. The effects of and withdrawal symptoms of caffeine are compared to those of heroin and cocaine.

Tinnesand, M. Your Body under Construction *ChemMatters* **2011,** *29* (4), pp 14–16. Tinnesand’s discussion of the endocrine system includes the effect of hormones on the brain. The Teacher’s Guide, Background Information section: “More on hormones and the endocrine system”, p 78, discusses the pineal gland secretion of melatonin.

Sitzman, B. and Goode, R. Caffeine *ChemMatters* **2013,** *31* (3), p 5. The authors show the multitude of caffeine laden products on supermarket shelves, their caffeine content, and safe limits for teens. Caffeine metabolism, the side effects, and the danger involved in the consumption of excess caffeine are described.

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Wolf, L. Caffeine Jitters *C&E N* **2013,** *91* (5), pp 9–12. In this article, Wolf uses real events to illustrate the dangers of caffeine “overdose”. A graph given in the Background Information section of this Teacher’s Guide shows the rapid increase in emergency room visits associated with the overconsumption of caffeinated products. Structural formulas are used in a discussion of caffeine metabolism. Free download is available at (<http://cen.acs.org/articles/91/i5/Caffeine-Jitters.html>).

## Web Sites for Additional Information (Web-based information sources)

**More sites on sleep requirements for humans**

This site from the Harvard Medical School covers age related stages of sleep requirements for people from infants to adults. Videos are included to illustrate the stages. REM and NREM patterns are discussed as well as sleep disorders. (<http://healthysleep.med.harvard.edu/healthy/science/variations/changes-in-sleep-with-age>)

*The Sleepy Teenager* is a health publication of Harvard Medical School. This article explains why teenage schedules don’t allow time for sufficient sleep and well describes the possible consequences of sleep deprivation. This article might be considered as a reading or research assignment for chemistry students. (<http://www.health.harvard.edu/newsweek/The_Sleepy_Teenager.htm>)

**More sites on advocacy for later start times for high schools**

The American Academy of Pediatrics (AAP) released a policy statement on August 25, 2014: “AAP recommends middle and high schools delay the start of class until 8:30 a.m. or later.” AAP rationale for the statement is discussed on this site: <http://www.aap.org/en-us/about-the-aap/aap-press-room/Pages/Let-Them-Sleep-AAP-Recommends-Delaying-Start-Times-of-Middle-and-High-Schools-to-Combat-Teen-Sleep-Deprivation.aspx>.

A good YouTube video, “Matt’s Story Rethinking School Start Times”, by Kelley Ditzenberger shows a story similar to Jilly’s experience in the Harper sleep article. Matt, an advocate for later school start times, takes data from student polls to his high school principal. (<https://www.youtube.com/watch?v=9aqopRzY2MA>)

The *Seattle Times* “Education Lab Blog”, reports that even though it is logistically challenging to change school start time, nationwide 70 school districts have accomplished this.

(<http://blogs.seattletimes.com/educationlab/2014/09/30/be-heard-on-school-start-times-for-teens-seattle-forms-task-force/>)

**More sites on myths about sleep**

“Nine Sleep Myths that Make You Tired” in*Prevention Magazine* describes nine myths about sleep that will make you feel tired. The article suggests: “Ignore these myths and get more energy, sleep better and longer, and wake up happier.” Find the list at <http://www.prevention.com/health/sleep-energy/9-sleep-myths-make-you-tired/1-many-people-are-short-sleepers>.

**More sites on consequences of teen sleep deprivation**

Detailed information on sleep disorders is available from the Mayo Clinic and National Institutes of Health (NIH) at <http://www.mayoclinic.org/healthy-living/tween-and-teen-health/in-depth/teens-health/art-20046157> and <https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>.

**More sites on the biochemistry of sleep**

The chemistry of the synthesis of melatonin from serotonin is discussed on the web page for the chemistry department of Imperial College, UK. Structural formulas for this multi-step process are shown. (<http://www.ch.ic.ac.uk/local/projects/s_thipayang/synth.html>)

The *International Journal of Endocrinology* paper, “Sleep and Metabolism: An Overview”, provides a comprehensive review of the links between sleep and metabolism. (<http://www.hindawi.com/journals/ije/2010/270832/>)

**More sites on the NREM/REM cycles of sleep**

University of California, Berkeley (UCB) describes “short-term euphoria” as a lesser known side effect of sleep deprivation leading to “poor judgment and addictive behavior”. This may occur as a result of NREM/REM sleep disruption. (<http://newscenter.berkeley.edu/2011/03/22/pulling-an-all-nighter/>)

**More sites on jet lag**

The journal *Current Biology* contains the article *“*Social Jetlag and Obesity” that describes the relationship between adult social jetlag and potential obesity. This can easily be compared to teen social jetlag. (*Current Biology* 22: 939–943, 10 May 2012; <http://www.sciencedirect.com/science/article/pii/S0960982212003259>)

You can find a 4:56 abstract of the article about jetlag cited above, “Social Jetlag and its Consequences”, on YouTube: <https://www.youtube.com/watch?v=iZ_VH2Zh1lU>. The video describes human life controlled by three clocks: alarm, social, and body (internal). The difference between the social and body clocks lead to sleep deprivation behaviors.

**More sites on severe sleep disorders: insomnia, restless leg syndrome, narcolepsy**

A comprehensive presentation of insomnia can be found on this Mayo Clinic website. Following a definition, causes, risk factors, and complications that are similar to those of other sleep disorders are listed.

(<http://www.mayoclinic.org/diseases-conditions/insomnia/basics/definition/con-20024293>)

An in depth discussion of the symptoms and known causes of Restless Leg Syndrome (RLS) leaves the reader with the understanding that there are still gaps in our knowledge of gene function in the brain. This website shows an overview; the left margin contains links for other sections of the report. (<http://www.hopkinsmedicine.org/neurology_neurosurgery/centers_clinics/restless-legs-syndrome/what-is-rls/>)

A “Narcolepsy Fact Sheet” is located at the *National Institute of Neurological Disorders and Stroke (NINDS)*. In narcolepsy, the brain fails to control the sleep cycle. Interference with normal NREM and REM patterns affects daily activities such as concentrating on studies, driving safely, and interacting socially.

(<http://www.ninds.nih.gov/disorders/narcolepsy/detail_narcolepsy.htm>)

**More sites on obstructive sleep apnea (OSA), misdiagnosis, and obesity**

To show your students exactly how OSA occurs, visit this site, scroll down to the illustration of the sleeping man, and click on the start button. An excellent animation with audio description shows the normal breathing process, snoring, and complete obstruction of the air passage. Written text of the audio portion is shown on the right of the screen.

(<http://www.nhlbi.nih.gov/health/health-topics/topics/sleepapnea/>)

There are also two good videos that show OSA in action. The first, a Mayo Clinic site video, is a one-minute video clip with the script written under the video, creating a very nice teaching tool. (<http://www.mayoclinic.org/diseases-conditions/sleep-apnea/multimedia/obstructive-sleep-apnea/vid-20084717>)

The second YouTube video on OSA, produced by Nuclear Medical Media, is more detailed and includes the causes and prevention. (<https://www.youtube.com/watch?v=i6lxO6W2-m8>)

This site from the Sleep Apnea Association discusses the symptoms of OSA in children and how those symptoms are frequently confused with similar behavioral patterns of children with attention-deficit hyperactivity disorder (ADHD). (<http://www.sleepapnea.org/treat/childrens-sleep-apnea.html>)

The American Academy of Sleep Medicine page, “Obstructive Sleep Apnea (OSA)”, describes treatments for the OSA. (<http://www.aasmnet.org/resources/factsheets/sleepapnea.pdf>)

Some of the “overabundance” of ADHD cases may be explained by the misdiagnosis of OSA due to symptoms caused by swollen tonsils. This article from the *Columbia Chronicle* (Columbia College, Chicago) provides a good explanation of the effect on NREM/REM sleep patterns by OSA and the resulting sleep deprivation. (<http://www.columbiachronicle.com/arts_and_culture/article_f05d529a-525a-11e4-ac54-001a4bcf6878.html>)

Material in this web site looks at the interactions between body weight and OSA and the implications for treatment. The authors conclude that due to the complex nature of OSA symptoms and their causes, treatment requires a multidisciplinary approach. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3021364/>)

**More sites on dreams and nightmares**

The following site suggests that taking a closer look at dreams may help the understanding of nightmares. The two website articles discuss sleep walking and acting out while dreaming or during a nightmare. (<http://www.psychologytoday.com/conditions/nightmares>) and (<http://sleepfoundation.org/sleep-disorders-problems/abnormal-sleep-behaviors/nightmares-and-sleep>)

**More sites on teen at-risk behaviors as a consequence of sleep deprivation**

On the Florida International University (FIU) site, sleep deprivation is linked to risky behavior in teens such as substance abuse, drunk driving, suicidal tendencies, and obesity. (<http://news.fiu.edu/2014/04/research-links-extreme-sleep-deprivation-to-health-and-behavior-problems-in-teens/76986>)

The United States Center for Disease Control and Prevention (CDC) states that almost 70 percent of high school students do not sleep long enough each night. Listed are the risky behaviors associated with teen sleep deprivation.

(<http://www.cdc.gov/media/releases/2011/a0926_insufficient_sleep.html>)

The National Institutes for Health (NIH) provides additional details on risky behavior caused by sleep deprivation, specifically due to disruption of the NREM/REM cycle. The publication also states: “In addition, sleep deficiency has played a role in human errors linked to tragic accidents, such as nuclear reactor meltdowns, grounding of large ships, and aviation accidents.”

(<http://www.nhlbi.nih.gov/health/health-topics/topics/sdd/>)

**More sites on general references for sleep**

Section 3.9, “Evolution of sleep”, found in the National Institutes of Health (NIH) *Teacher’s Guide, Information about Sleep*, compares the patterns, habits, postures, and places of sleep for various animals. Mammals usually follow NREM/REM cycles, but the time spent in each pattern is different (brown rats average 19.9 hours per day, while giraffes average only 1.9 hours) than that required for quality human sleep. Birds spend only 2.5 minutes in NREM and 9 seconds in REM; lizards have not demonstrated REM patterns in current studies.

(<https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>)

Sleep deprivation in teens may lead to risky behaviors such as drug use, especially performance enhancing drugs such as steroids. The following references provide details on the increase in drug abuse visits to emergency rooms, the effects of steroid abuse, and what is being done to identify and reduce drug use at high schools and colleges.

Another interesting topic is the connection between lack of sleep and impaired memory. Since sleep deprivation is one of the tools used in the interrogation of prisoners, one could question the reliability of testimony obtained from a sleep deprived individual. The next sites provide information on memory loss or distortion due to lack of sleep.

Sleep deprivation may lead to loss or clouding of memory. A University of California, Irvine (UCI) study led by Steven Frenda and published in *Scientific American* found that after hours of interrogation by the police, people who average less than 5 hours of sleep a night frequently mixed facts with imagination and even reported things that never happened. See more at <http://www.scientificamerican.com/article/all-nighters-could-alter-your-memories/>.

Frenda’s work on false memories is also discussed in “Let the Body Rest, for the Sake of the Brain”, published in *The Atlantic Monthly****,*** 2014. (<http://www.theatlantic.com/health/archive/2014/10/let-the-body-rest-for-the-sake-of-the-brain/381582/>)

Frenda’s research was also published in the *Journal of the Association for Psychological Science*. (<http://www.psychologicalscience.org/index.php/news/releases/sleep-deprivation-may-increase-susceptibility-to-false-memories.html>)

Sleep Medicine at Harvard Medical School links types of memory with stages of sleep. (<http://healthysleep.med.harvard.edu/healthy/matters/benefits-of-sleep/learning-memory>)

*Quanta Magazine*, published an article, “Mental Leaps Cued by Memory’s Ripples”, that reports on studies of how the brain organizes memories. The studies show links between memory and decision making that involve sharp-wave ripples (SWRs). Studies on rats show that SWRs occur only during sleeping, under anesthesia, or periods of immobility. (<http://www.quantamagazine.org/20141022-mental-leaps-cued-by-memorys-ripples/>)

## General Web References (Web information not solely related to topic of article)

The Drug Abuse Warning Network (DAWN) is a public health surveillance system that monitors drug-related visits to hospital emergency departments (ED). From 2005 to 2011, there was a 51 percent increase in drug related ED visits involving suicide attempts among people 12 and older. Data is charted and discussed here:

<http://www.samhsa.gov/data/sites/default/files/DAWN-SR154-SuicideAttempts2014/DAWN-SR154-SuicideAttempts2014.htm>.

This Cleveland Clinic article details many of the health effects of steroid abuse: <http://my.clevelandclinic.org/health/drugs_devices_supplements/hic_Steroids_Anabolic-Androgenic>.

The next three sites discuss banned substances and drug testing in schools:

This article from *The School Administrator* (online) highlights the effort of several school districts to test for steroids: <http://www.aasa.org/SchoolAdministratorArticle.aspx?id=8104>.

The National Institute of Drug Abuse frequently asked questions about drug testing schools can be found at <http://www.drugabuse.gov/related-topics/drug-testing/faq-drug-testing-in-schools>.

The National Collegiate Athletic Association (NCAA) site on banned and restricted substances is found here: <http://www.ncaa.org/health-and-safety/policy/drug-testing>.

Another interesting topic relates to the circadian rhythms of people who live at the far north and far south latitudes. They experience 24 hour days when the sun either shines or doesn’t shine. Researchers have found “evidence of clock gene alleles along latitudinal/photoperiod clines in humans”. The report of the study “Genetic Differences in Human Circadian Clock Genes among Worldwide Populations” can be found at <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2579796/>.

## More Web Sites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

The National Institutes for Health (NIH) has posted a very comprehensive, well organized, and easy to read teacher’s guide, “Information about Sleep”: <https://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm#content>. This publication begins with, “Sleep is not just something to fill time when a person is inactive. Sleep is a required activity, not an option.” The guide, designed for teacher use, proceeds to provide details on the physiology of sleep and the consequences of sleep deprivation.

An almost-companion guide, published by the National Heart, Lung, and Blood Institute of the National Institutes of Health (NIH) places additional emphasis on the problems associated with lack of sleep, “What are Sleep Deprivation and Deficiency?” (<http://www.nhibi.nih.gov/health/health-topics/add/printall-index.html>)

The Oregon Health Science University (OHSU) has designed training programs (ATLAS and ATHENA) for coaches that are specifically designed to discourage steroid use among student-athletes. The home page of the ATLAS program provides a basic description, research findings, and program materials. Further information on these programs can be found at

<http://www.ohsu.edu/xd/education/schools/school-of-medicine/departments/clinical-departments/medicine/divisions/hpsm/research/atlas-and-athena-program.cfm>.

# A Measure of Confusion

## Background Information (teacher information)

To truly understand the problems NASA had with the Mars Climate Orbiter (we’ll come back to that later), one needs to understand the two different systems of measurement in effect at the time of the mishap (and still in effect today).

**More on the history of SI and the metric system**

*ChemMatters* Teacher’s Guides frequently begin with “More on the history of…” the topic. In the case of measurement, SI and the metric system, the history is interwoven in their development, as well as in their “final”, or present status. You will find much history on SI throughout this “Background Information” section.

**More on** **metrology (no, not meteorology—that’s weather)**

Maybe some of your students will choose to become metrologists. Scientists who study units and measurement work with the science of metrology.

Metrologists are scientists who work to define and refine the units and techniques of measurement. Nearly every nation in the world has an institute or national laboratory devoted to metrology. Governments are committed to metrology because it is important for trade, as well as for science, to have a consistent set of units for measurement. In the United States, metrology is part of the mission of the National Institute for Standards and Technology (NIST), formerly known as the National Bureau of Standards, a division of the U.S. Department of Commerce.

The goal of metrologists has been to develop units that are based only on atomic properties or universal constants. So far, this goal has been achieved for length, time, electric current, temperature, amount of substance, and light intensity—six of the seven base units in the System Internationale (SI). The only unit that is still based on a “prototype”, or physical example of the quantity, is the standard for mass, the *kilogram.*

(*ChemMatters* Teacher’s Guide, Oct 1999, p 14; accompanies the article “The Weighty Matter of the Kilogram Standard”; Powers, A. The Weighty Matter of the Kilogram Standard. *ChemMatters* **1999**, *17* (3), pp 14–15)

**More on Le Système International d’Unités**

The goals of Le Système International d'Unités (SI), or The International System of Units, are to:

* Have units of measurement be neutral and (therefore) universal. This would avoid any political or national bias or dependency (e.g., base unit of length [foot] changing with revolution or death of local king), with the result that all nations would be more likely to adopt it.
* Allow any laboratory to replicate the units by making copies of prototypes of the base units (that all nations could duplicate). (While this goal might seem to conflict with the first goal because adopting countries would be dependent on the original prototype base units, these units were also established using common quantities or materials (e.g., volume of water of specific mass and cubic units of length, or distance along a meridian of the Earth) that most laboratories could use to produce their own “copies” of the unit, thereby ensuring consistency of the unit worldwide.
* Provide decimal multiples and submultiples to make computations easier (based on man’s possessing 10 fingers).
* Use common prefixes across the various base and derived units, thus making the entire system more universal and more “user-friendly”.
* Be practical, in the sense that the base units should be close in size to customary units (again, more “user-friendly”), making adoption by nations and individuals more likely to succeed.

(adapted from <http://www.sciencemadesimple.com/metric_system.html>)

**More on SI base units**

The SI system has only seven base units to measure length, mass, time, electric current, temperature, amount and luminous intensity. All other measurable quantities are derived from these seven base units. Because of this minimalist approach, SI is a much simpler system of measurement than any that has preceded it.

The table below lists the seven SI base units, the quantity they measure, their symbol, and the original (historical) and most recent (scientific) basis for the size of that unit:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantity Measured** | **Unit** | **Symbol** | **Original Basis** | **Newest Basis** |
| Length | meter | m | (1793) 1/10,000,000 of length of a quadrant of Earth (North Pole to Equator);  Later (1960), length of platinum-iridium alloy prototype meter | (interim) Various measurements involving wave-lengths of visible emission of light from various elements (first, 1960, Kr-86);  Now (1983), distance light travels in a vacuum in  1 / 299,792,458  of a second |
| Mass | kilogram | kg | (1793) Unit of “grave” (now obsolete), mass of 1 decimeter3 of water | (1901) Mass of  platinum-iridium alloy prototype kilogram |
| Time | second | s | (ancient) 1/86,400  of one day;  Later (1956) 1/31,556,925.9747 of tropical year for January 1900 | (1997) Duration of  9,192,631,770 periods of radiation corresponding to transition between two hyperfine levels of ground state of the Cs-133 atom |
| Electric Current | ampere | A | (1881) One-tenth of current flowing in an arc 1 cm long of a circle 1 cm in radius that creates a field of one oersted at the center | (1948) Current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed  1 m apart in vacuum, would produce between these conductors a force equal to  2×10−7 newtons per meter of length |
| Temperature | kelvin | K | (1743) Centigrade scale, based on water freezing at 0 oC and boiling at 100 oC (later changed to Celsius) | (1967) (now Kelvin)  1 / 273.16 of temperature of triple point of water (0.01 oC) |
| Amount | mole | mol | (1900) Molecular weight of substance in grams | (1971) Amount of material in a substance that contains as many particles as are contained in 0.012 kg of carbon-12 |
| Luminous Intensity | candela | cd | (1948) Value of new candle is such that brightness of full radiator at temperature of solidification of platinum is 60 new candles per square centimeter | (1979) Luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×1012 hertz and that has a radiant intensity in that direction of 1/683 watt  per [steradian](http://en.wikipedia.org/wiki/Steradian). |

(This table was crafted from various sources; primary source is the National Institute of Standards and Technology, NIST, at <http://physics.nist.gov/cuu/Units/current.html>).

**More on SI derived units**

The SI system of units was established so that all measurable quantities could be expressed in the seven base units or in units derived from the seven base units (or in units derived from units derived from the base units). Derived units are created by mathematical relationships ​ (multiplication or division) among **other** base units and are expressed in a combination of fundamental and base quantities. The base units and derived units together comprise the “coherent system of SI units”. The SI also includes the prefixes to form decimal multiples and submultiples of SI units. (<http://physics.nist.gov/cuu/pdf/sp811.pdf>)

According to NIST (URL above, p 3, footnote 2), “A system of units is coherent with respect to a system of quantities and equations if the system of units is chosen in such a way that the equations between numerical values have exactly the same form (including the numerical factors) as the corresponding equations between the quantities…. In such a coherent system, of which the SI is an example, no numerical factor other than the number 1 ever occurs in the expressions for the derived units in terms of the base units.” Thus, a unit with a prefix (e.g., a milliliter) cannot be a coherent unit in the SI system because it requires the use of a number other than one (one thousand) to convert it to an SI base unit (the liter). Note that the milliliter is still an *accepted* SI unit, but it is not a *coherent* unit, because it uses a prefix.

This table shows a few simple, coherent derived units in SI. Note that in these units, there are no special names—the name is expressed in the SI unit symbols appropriate for that measurement.

|  |  |  |
| --- | --- | --- |
| **DERIVED QUANTITY** | **NAME** | **SYMBOL** |
| Area | Square Meter | m2 |
| Volume | Cubic Meter | m3 |
| Mass Density | Kilogram Per Cubic Meter | kg / m3 |
| Specific Volume | Cubic Meter Per Kilogram | m3 / kg |
| Speed, Velocity | Meter Per Second | m / s |
| Acceleration | Meter Per Second Squared | m / s2 |
| Wavenumber | Reciprocal Meter | m–1 or 1 / m |
| Amount concentration | Mole Per Cubic Meter | mol / m3 |

(<http://physics.nist.gov/cuu/pdf/sp811.pdf>)

The unit’s name does not always match its symbol, however; many SI derived units, even though they are derived from the base units, are given special names, often for their discoverer(s), as indicated in the examples in this table.

|  |  |  |  |
| --- | --- | --- | --- |
| **DERIVED QUANTITY** | **NAME** | **SYMBOL (and Non-SI Expression)** | **EXPRESSION IN TERMS OF BASE UNITS** |
| Force | Newton | N | m • kg/ s2 |
| Pressure | Pascal | Pa (N / m2) | kg / m / s2 |
| Energy | **Joule** | J (N • m) | kg • m2 / s2 |
| Power | Watt | W (J / s) | kg • m2 / s3 |
| Electric Charge | Coulomb | C | A • s |
| Electric Potential | Volt | V (W / A) | kg • m2 / s3 / A |
| Celsius Temperature | Degree Celsius | oC | K |

(<http://physics.nist.gov/cuu/pdf/sp811.pdf>)

And the table below shows examples of slightly more complex, coherent derived units expressed with the aid of other SI derived units that themselves have special names and symbols.

|  |  |  |  |
| --- | --- | --- | --- |
| **DERIVED QUANTITY** | **NAME** | **SYMBOL** | **EXPRESSION IN TERMS OF BASE UNITS** |
| Moment of Force | Newton Meter | N • m | kg • m2 / s2 |
| Surface Tension | Newton Per Meter | N / m | kg / s2 |
| Heat Capacity, Entropy | **Joule** Per Kelvin | J / K | kg • m2 / s2 / K |
| Specific Heat, Specific Energy | Joule Per Kilogram | J / kg | m2 / s2 |
| Specific Heat Capacity,  Specific Entropy | **Joule** Per Kilogram Kelvin | J / (kg • K) | m2  / s2 / K |
| Thermal Conductivity | Watt Per Meter Kelvin | W / (m • K) | kg • m/ s3 / K |
| Energy Density | Joule Per Cubic Meter | J / m3 | kg / m / s2 |
| Electric Charge Density | Coulomb Per Cubic Meter | C / m3 | A • s/ m3 |
| Molar Energy | Joule Per Mole | J / mol | kg • m2 / s2 / mol |
| Molar Entropy | Joule Per Mole Kelvin | J / (mol • K) | kg • m2 / s2 / mol / K |

(<http://physics.nist.gov/cuu/pdf/sp811.pdf>)

This table shows the accepted prefixes that precede the base- or derived units in the SI system, their names, symbols and number.

|  |  |  |  |
| --- | --- | --- | --- |
| **Power  of Ten** | **Unit  Name** | **Symbol** | **Actual  Number** |
| 1024 | yotta | Y | 1,000,000,000,000,000,000,000,000 |
| 1021 | zetta | Z | 1,000,000,000,000,000,000,000 |
| 1018 | exa | E | 1,000,000,000,000,000,000 |
| 1015 | peta | P | 1,000,000,000,000,000 |
| 1012 | tera | T | 1,000,000,000,000 |
| 109 | giga | G | 1,000,000,000 |
| 106 | mega | M | 1,000,000 |
| 103 | kilo | k | 1,000 |
| 102 | hecto | h | 100 |
| 101 | deka | da | 10 |
| 100 |  |  | 1 |
| 10–1 | deci | d | .1 |
| 10–2 | centi | c | .01 |
| 10–3 | milli | m | .001 |
| 10–6 | micro | μ | .000 001 |
| 10–9 | nano | n | .000 000 001 |
| 10–12 | pico | p | .000 000 000 001 |
| 10–15 | femto | f | .000 000 000 000 001 |
| 10–18 | atto | a | .000 000 000 000 000 001 |
| 10–21 | zepto | z | .000 000 000 000 000 000 001 |
| 10–24 | yocto | y | .000 000 000 000 000 000 000 001 |

*(ChemMatters* Teacher’s Guide [October 2009, pp 84–5] to accompany: Halim, N. Nanotechnology’s Big Impact, *ChemMatters* **2009**, *27* (3), pp 14–17.

**More on the SI base unit for mass—the kilogram**



*Housed in Sèvres, France, at the Bureau International des Poids et Mesures (BIPM), under three vacuum-sealed bell jars, inside a vault two stories below the ground, there is a carefully tended metal cylinder, and six copies—each one about the size of a film canister. To the French, this is “le grand K”. We know it as the kilogram.*

As mentioned previously, the standard unit of mass, the kilogram, unlike all other base units in the International System of Units (Le Système International d'Unités, or SI), is still an actual object—a cylinder of a platinum-iridium alloy, polished to a mirror-like finish, that is housed in Sèvres, France. It has resided there since 1889.

It is protected from oxidation by the atmosphere under a triple vacuum system using three bell jars. It is only rarely brought out from under that vacuum system, usually for comparison to other standard prototypes that have been distributed in various countries around the world. Those prototypes are themselves protected under a vacuum system to protect them from atmospheric oxidation.

*(both images above from Powers, A. The Weighty Matter of the Kilogram Standard.* ChemMatters***1999****, 17 (3), pp 14–15)*

*The United States stores its copy of the kilogram prototype at the National Institute for Standards and Technology (NIST).*



**More on teaching the metric system**



(<http://lamar.colostate.edu/~hillger/whyteach.htm>)

The National Science Teachers Association publishes position statements on many topics specific to science and science education. In 1999, the organization published their position statement on teaching the metric system:

**NSTA Position Statement: Use of the Metric System**

**Rationale**

The efficiency and effectiveness of the metric system has long been evident to scientists, engineers, and educators. Because the metric system is used in all industrial nations except the United States, it is the position of the National Science Teachers Association that the International System of Units (SI) and its language be incorporated as an integral part of the education of children at all levels of their schooling. Therefore, we recommend that the following actions be taken:

**Declarations**

* We assume responsibility for leadership in teaching the metric system.
* We urge that use of the metric system be integrated into all curriculum subjects and at every grade level.
* We recognize that the use of the customary units will persist for some time, especially in the early grades, but will encourage the use of the metric system whenever possible.
* We urge the re-establishment of the U.S. Metric Board to support and encourage the use of the metric system nationwide.

—Adopted by the Board of Directors, January 1999

(<http://www.nsta.org/about/positions/metric.aspx>)

The National Council of Teachers of Mathematics (NCTM) also issued a position statement, in 2011, on the teaching of the metric system, as well as learning goals for students:

**NCTM Position**

Because the metric system is an effective, efficient base-ten measurement system used throughout the world, students need to develop an understanding of its units and their relationships, as well as fluency in applying it to real-world situations. At the same time, since some non-metric units of measure are still widely used in day-to-day life in the United States, American students also need to develop familiarity with these units of measure.

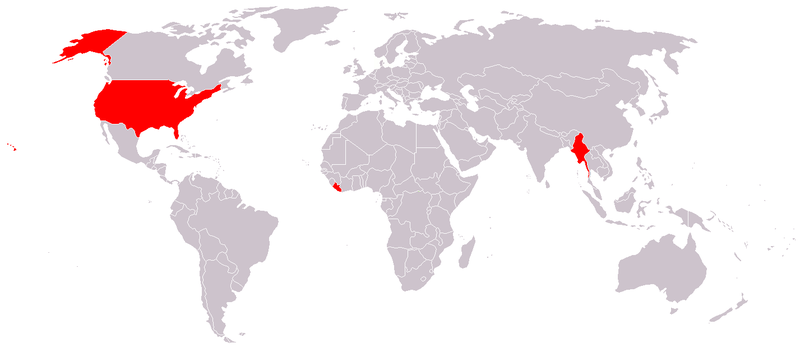
The learning goals for students include—

* knowledge of and ability to use referents, or benchmarks, in estimation;
* ability to make a reasonably accurate measurements of an attribute by using standard tools;
* ability to assess and select an appropriate unit for the type and size of the attribute being measured;
* ability to convert flexibly and fluently among commonly used units *within* a measurement system;
* knowledge of the role and implications of accuracy and precision in measurement; and
* ability to apply and operate on units of measure flexibly and fluently in the solution to problems.

(<http://www.nctm.org/uploadedFiles/About_NCTM/Position_Statements/Metric_System_Positions_Statement_20113.pdf>)

This probably is not a problem for chemistry teachers or science teachers in general, but just in case you aren’t sure why you should teach metric units, visit this U.S. Metric Association page “Why Teach the Metric System?” at <http://lamar.colostate.edu/~hillger/whyteach.htm>.

And if you need a graphic to show your students how “Metric” the world is, or why the U.S. should “go metric”, show them this illustration.

[](http://upload.wikimedia.org/wikipedia/commons/1/17/Metric_system.png)

*Map of the world where red represents countries that do not use the metric system (*[*Liberia*](http://commons.wikimedia.org/wiki/Liberia)*,* [*Myanmar*](http://commons.wikimedia.org/wiki/Myanmar)*, and the* [*USA*](http://commons.wikimedia.org/wiki/United_States) *(including Alaska (the big red block to the northwest of Canada) and the Hawaiian Islands (that tiny red blur in the Pacific Ocean)*

*(*[*http://commons.wikimedia.org/wiki/File:Metric\_system.png*](http://commons.wikimedia.org/wiki/File:Metric_system.png)*)*

**More on** **Mars Climate Orbiter**

Engineers at Lockheed Martin in Denver, Colorado helped to build and operate the Orbiter spacecraft and provided data and navigation commands for the thrusters aboard the craft. Unfortunately, they used U.S. Customary or “English” units, while NASA had been using metric units for almost a decade.

As mentioned in the article, the English unit for thrust is pound-force-seconds, while the metric or SI unit is Newton-seconds. To convert the two, consider the following:

1 N = 1 kg-m / s2

and

1 lb = 453.59237 g

The pound is already a unit of force, while the kilogram is a unit of mass, so to convert from pound-force in the English system to newtons, the SI unit of force,

F = mass x gravitational attraction

1 lb = 453.59237 g x (1 kg/1000 g) x 9.80665 m/s2

Therefore

1 lb = 4.4482216152605 kg-m/s2 (exactly) or ~ 4.448 N

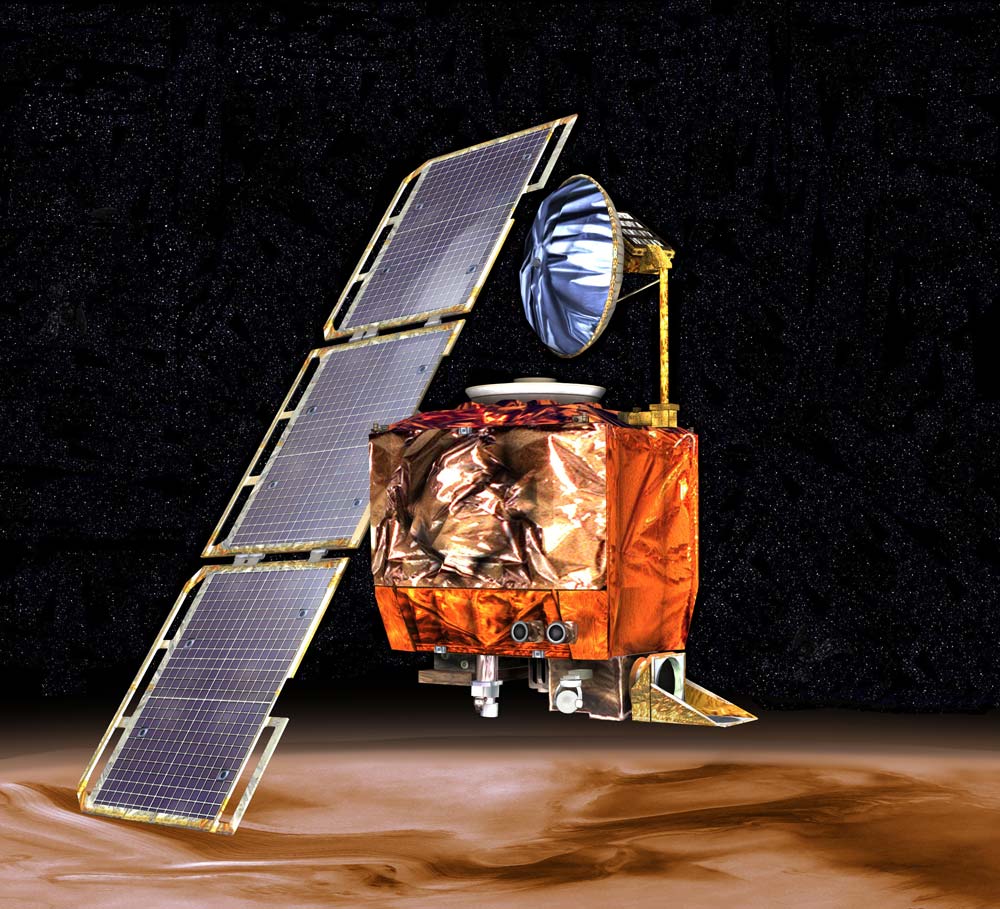
Thus a pound-force-second = 4.448 Newton-seconds

So, any calculations involving the wrong unit here would be off by a factor of almost 4.5!

If Lockheed Martin was supplying information to NASA about amounts of thrust to use to bring the Orbiter into orbit around Mars, their calculated value would be in pound-force-seconds and therefore too large by that factor of 4.5, providing too much thrust and sending the craft much too close to Mars.

*Mars Climate Orbiter, 1998*

*(*[*http://www.jpl.nasa.gov/missions/web/mars\_climate\_orbiter.jpg*](http://www.jpl.nasa.gov/missions/web/mars_climate_orbiter.jpg)*)*



After tracking the flight of the Mars Climate Orbiter for almost 10 months, a planned trajectory correction maneuver (the fourth during the long flight) made on September 8, 1999 was supposed to bring the spacecraft to an insertion point that would bring it around Mars at an altitude of 226 km—the desired altitude for final orbital insertion—on September 23.

But calculations made in the week after that maneuver and before the crash indicated the craft could be lower than that, around 150–170 km from the planet’s surface. And later calculations, made the day before insertion showed the actual altitude to be only 110 km. (Original calculations had established an absolute safe minimum altitude of 80 km.) And calculations made after the crash indicated the orbiter approached at an altitude of only 57 km, which put it well within the Martian atmosphere, where atmospheric stresses likely caused disintegration of the spacecraft.

According to Wikipedia, several software operators had recognized the problem with the calculations involving U.S. Customary units instead of SI units, but their concerns were never recognized (or admitted?) by other scientists and engineers.

The primary cause of this discrepancy [in calculated insertion altitudes] was that one piece of ground software produced results in a [United States customary unit](http://en.wikipedia.org/wiki/United_States_customary_units) ("English"), while a second system that used those results expected them to be in metric units. Software that calculated the total impulse produced by thruster firings calculated results in pound-seconds. The trajectory calculation used these results to correct the predicted position of the spacecraft for the effects of thruster firings. This software expected its inputs to be in newton-seconds.

The discrepancy between calculated and measured position, resulting in the discrepancy between desired and actual orbit insertion altitude, had been noticed earlier by at least two navigators, whose concerns were dismissed. A meeting of trajectory software engineers, trajectory software operators (navigators), propulsion engineers, and managers, was convened to consider the possibility of executing Trajectory Correction Maneuver-5, which was in the schedule. Attendees of the meeting recall an agreement to conduct TCM-5, but it was ultimately not done.

(<http://en.wikipedia.org/wiki/Mars_Climate_Orbiter>)

The initial report of the NASA Jet Propulsion Lab investigation board issued these findings and recommendations in their official report:

A summary of the findings, contributing causes and MPL recommendations are listed below. These are described in more detail in the body of this report along with the MCO [Mars Climate Orbiter] and MPL [Mars Polar Lander] observations and recommendations.

Root Cause: **Failure to use metric units in the coding of a ground software** file,

“Small Forces,” used in trajectory models

[text bolded by Teacher’s Guide editor]

Contributing Causes:

1. Undetected mismodeling of spacecraft velocity changes
2. Navigation Team unfamiliar with spacecraft
3. Trajectory correction maneuver number 5 not performed
4. System engineering process did not adequately address transition from development to operations
5. Inadequate communications between project elements
6. Inadequate operations Navigation Team staffing
7. Inadequate training
8. Verification and validation process did not adequately address ground software

MPL Recommendations:

* **Verify the consistent use of units throughout the MPL spacecraft design and operations**

[text bolded by Teacher’s Guide editor]

* Conduct software audit for specification compliance on all data transferred between JPL and Lockheed Martin Astronautics
* Verify Small Forces models used for MPL
* Compare prime MPL navigation projections with projections by alternate navigation methods
* Train Navigation Team in spacecraft design and operations
* Prepare for possibility of executing trajectory correction maneuver number 5
* Establish MPL systems organization to concentrate on trajectory correction maneuver number 5 and entry, descent and landing operations
* Take steps to improve communications
* Augment Operations Team staff with experienced people to support entry, descent and landing
* Train entire MPL Team and encourage use of Incident, Surprise, Anomaly process
* Develop and execute systems verification matrix for all requirements
* Conduct independent reviews on all mission critical events
* Construct a fault tree analysis for remainder of MPL mission
* Assign overall Mission Manager
* Perform thermal analysis of thrusters feedline heaters and consider use of pre-conditioning pulses
* Reexamine propulsion subsystem operations during entry, descent, and landing

(<ftp://ftp.hq.nasa.gov/pub/pao/reports/1999/MCO_report.pdf>)

**More on** **other mixed-system measurement problems**

In the past there have been other problems with unit conversions between metric (SI) and U.S. Customary systems (English), besides the Mars Orbiter.

**Canada Flight 143**

Here’s the story of Canadian Air Flight 143, as told by Wikipedia:

On July 23, 1983, flight 143 was cruising at 41,000 feet (12,000 m) over Red Lake, Ontario. The aircraft's cockpit warning system sounded, indicating a fuel pressure problem on the aircraft's left side. Assuming a fuel pump had failed the pilots turned it off, since gravity should feed fuel to the aircraft's two engines. The aircraft's fuel gauges were inoperative because of an electronic fault which was indicated on the instrument panel and airplane logs (the pilots believed the flight was legal with this malfunction). The flight management computer indicated that there was still sufficient fuel for the flight; but the initial fuel load had been measured in pounds instead of kilograms. A few moments later, a second fuel pressure alarm sounded for the right engine, prompting the pilots to divert to Winnipeg. Within seconds, the left engine failed and they began preparing for a single-engine landing.

As they communicated their intentions to controllers in Winnipeg and tried to restart the left engine, the cockpit warning system sounded again with the "all engines out" sound, a long "bong" that no one in the cockpit could recall having heard before and that was not covered in flight simulator training. Flying with all engines out was something that was never expected to occur and had therefore never been covered in training. Seconds later, with the right-side engine also stopped, the 767 lost all power, and most of the instrument panels in the cockpit went blank.

(<http://en.wikipedia.org/wiki/Gimli_Glider>)

Without engines, electrical power (produced by the engines) was almost non-existent, save for a few battery-powered emergency flight instruments. Also with no engines, the hydraulic control systems also went out. A backup “ram” system driven by air under the plane only helps when the plane maintains cruising speed, and with both engines out, and speed decreasing as a landing was attempted, that backup system became almost useless.

The pilot, having had much glider experience, was finally able to bring down the plane (itself now essentially a 156-ton glider) safely at close-by Gimli Airport—with no loss of life, and only a few slightly bruised passengers who were injured when they slid down the escape slides. (You can show to your classes one of two videos, either a 7-minute condensed version or a 47-minute full TV version from the “MayDay: Air Crash Investigation” series. See “More sites on other mixed-system measurement problems” near the end of this Teacher’s Guide.)

So, what caused the engines to stop? It turns out it was due to a mix-up of “Canadian” and metric units.

How? How does a modern jetliner—equipped with the latest technology and piloted by skilled people—run out of fuel at 26,000 feet? As with most air disasters, there was no single cause. Flight 143 was brought down by a string of errors in technology, communication, and training, but at the heart of the crisis was a simple mistake in calculating the amount of fuel needed for the flight.

The plane’s instruments should have quickly detected the error. The 767 boasts an advanced fuel quantity processor that accurately gauges fuel on board. But, on this particular plane, the fuel computer had never worked properly, and maintenance workers lacked a spare computer.

Because the 767 was new addition to Air Canada’s fleet, the written maintenance standards were still being revised. When the ground crew was preparing the plane for departure from Montreal, they found that the fuel gauge did not work. A maintenance worker assured Pearson—incorrectly—that the plane was certified to fly without a functioning fuel gauge if the crew manually checked the quantity of fuel in the tanks.

(Marsella, G. The Crash of Flight 143. *ChemMatters* **1996**, *14* (3), pp 12–15)

The ground crew measured how much fuel was left in the two main tanks and planned to subtract that amount from the amount they knew the plane would need to make the trip. That would tell them the amount needed to add to the tanks to complete the trip. Unfortunately, the amounts established for flights were given in kilograms (mass), not liters (volume). And, in keeping with to the Canadian government’s desire to change to the metric (SI) system, the mass was specifically noted in kilograms, whereas the flight crews had for years used pounds as the normal unit for measuring weight.

An incorrect conversion factor was used by the ground crew for the calculation of volume from weight. The number 1.77 was the conversion factor used, but that was for the density of jet fuel in pounds per liter, not kilograms per liter. Their calculations were off! They only filled the tanks with about 5,000 liters, instead of the required 20,000 liters. “At the time of takeoff Flight 143 had about 10,000 kg of fuel—less than half the amount needed to reach Edmonton.” To see the calculations involved, go to the source, above. For more information about this near-catastrophe, see “More sites on other mixed-system measurement problems” near the end of this Teacher’s Guide.)

**Space Mountain, Disneyland, in Tokyo**

At Tokyo Disneyland's Space Mountain, an axle broke on a roller coaster train, causing it to derail.

On December 5, 2003, a roller coaster train derailed as it was returning to the station. No riders were injured, and the ride was closed pending an investigation. A January 2004 investigation completed by Oriental Land Company, the park's owner/operator, determined that an axle on the train had failed because its diameter was smaller than the specifications for the part required. The attraction re-opened in February 2004, after 17 park officials were reprimanded for the accident

(<http://en.wikipedia.org/wiki/Incidents_at_Tokyo_Disney_Resort#cite_note-8>)

The cause was a part (the axle) being the wrong size due to a conversion in 1995 of the master plans for construction from English units to metric units. In 2002, new axles were mistakenly ordered using the pre-1995 English specifications instead of the current Metric specifications.

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Measurement**—This is at the heart of any science, and especially a lab-based science. Our understanding of chemistry (historically) comes from the results of experiments conducted over centuries.
2. **Precision/Accuracy**—Although this is not a focus of the article (since the measurements made for the Orbiter were accurate; they were just made in the wrong measuring system), students must be made to understand the need for their measurements to be accurate.
3. **Uncertainty/Error**—Similarly, each measurement made inherently contains uncertainty, and analysis of possible errors can lead to a better understanding of the results of experiments.
4. **Unit conversions**—Unit conversions between units in the SI system are relatively easy, since they primarily involve powers of ten. Understanding this type of conversion will help students with their “eternal” struggle with unit conversions throughout the chemistry course.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“Maybe the rest of the world will come around to our system of measurement; after all, we ARE the United States!”** *Unfortunately, the rest of the world has recognized that SI is a much more desirable measurement system than the U.S. Customary System and is NOT backtracking to a less desirable system. Our (U.S. Customary) system offers none of the advantages of SI, and since the rest of the world uses SI for their commerce, the U.S. will fall further and further behind and we will have difficulty exporting our goods because they won’t match what the rest of the world is doing/using.*
2. **“If the U.S. system of measurement was good enough for our grandparents, it should be good enough for us now.”** *In our grandparents’ times, commerce was much less globalized than it is now. In the mid-20th century, the U.S. was producing goods primarily for local consumption, and only beginning widespread export to countries worldwide. That is no longer true today, hence the answer to statement #1.*
3. **“I guess we’ve gone as far as we can with establishing standard units for the SI; those standards are ‘set in stone’.”** *As the chart shows in the “More on Le Système International d’Unités” section, the standards used in the seven base units in SI continue to change even today. As science and technology progress allowing scientists to make more accurate measurements, those standards thought to be “exact” are sometimes determined to be rather inexact (e.g., the distance from Earth’s North Pole to the Equator was discovered to vary with longitude), and adjustments need to be made.*
4. **“So, all Congress has to do to get us to adopt SI is to pass a law that says SI is our national system of units. That doesn’t sound so difficult.”** *It’s not quite that easy. Even if Congress DID pass such a law stating that we adopt SI—and we came a bit close to that in 1975 when Congress passed the Metric Conversion Act with the goal of increasing use of metric measurements in our daily lives—that alone wouldn’t prevent us from continuing to use the U.S. Customary units of measure. Change is difficult, and people would probably just continue using units they are familiar with, which would not move the country forward commercially or economically in the global marketplace. The only effective way for us to adopt SI completely would be for Congress to enact a law that forced everyone to use metric—by outlawing the use of conventional units. And many countries that have adopted SI still use non-SI units.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“Why DON’T we (the U.S.) switch to SI?”** *It’s not as easy as it sounds; see “Possible Student Misconception” #4 above for answer.*
2. **“Does America HAVE to go completely SI? Is it all-SI or nothing?”** *Many countries have adopted SI while still maintaining a few of their own standard units of measurement, but those units often cause confusion for international trade or travel; the U.S. could do the same.*
3. **“Why do we use SI (or metric) units in the chemistry lab?”** *Chemistry, often called the “central science”, utilizes the tools of science, and the metric system is the measuring system of the sciences. Since chemistry was a well-established science in Europe, practitioners (scientists) used the measurement units of the land—the metric system—and they’ve stuck with metric ever since.*
4. **“Did Peter Piper really pick a peck of pickled peppers? And how many is that in SI?”** *This is an age-old question with no definitive answer, because the number of peppers depends on their size. And the number of peppers in SI would be the same as in this measurement system. The difference would be that the unit wouldn’t be 1 peck, but it would be 7.6 liters. (According to Wikipedia, a peck is “equivalent to 2 gallons or 8 dry quarts or 16 dry pints [all U.S. Customary units] (7.6 liters [SI units])”. (*[*http://en.wikipedia.org/wiki/Peck*](http://en.wikipedia.org/wiki/Peck)*)*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. To get students used to measuring in metric, have students complete a normal recipe using only SI units. You might start with this one from *Reader’s Digest*, via NIST: <http://www.nist.gov/pml/wmd/metric/upload/Metric_Chocolate_Chip_Cookies_May2011.pdf>.

Or try this experiment, “Partial Thermal Degradation of Mixed Saccharides with Protein Inclusions” (making peanut brittle) from Dave Katz. Although the amounts are given in metric measurements, the U.S. Standard amounts and units are also provided in parentheses. (You might want to delete those from the experiment.) (<http://www.chymist.com/peanut%20brittle.pdf>)

1. This activity has students simulate a space mission, like one involving a space satellite, in which the space flight or satellite team must create their own standard measuring device, measure various objects with their device and communicate their findings back to the “ground crew” or validation team, all within a specified time frame. A class discussion follows to discuss findings and accuracy and precision. (McCue, K. Your Mission: Validate a Stick! *ChemMatters* **2005**, *23* (Special Issue 1), p 10) Also see the reference to Anne Douglass, a NASA scientist in the “References” section below.
2. This two-page table provides conversions involving a series of nonsensical scientific units, utilizing SI prefixes. Students must be familiar with (or have access to a list of) the SI prefixes to understand the conversions. (Golomb, S. MegaMeanings. *ChemMatters* **1984**, *2* (4), pp 14–15)
3. These two questions involve students in calculations that require them to use units and conversion factors to calculate gas pressure of a near-vacuum in space, and mass of Earth’s atmosphere. (Calculating Chemistry: Gases; and The Mass of the Earth’s Atmosphere. *ChemMatters* **1983** *1* (1), p 7)
4. This question provides some basic information (acidic, actually), along with some conversion factors and asks students to calculate the volume of H2SO4 produced by a volcano eruption (Calculating Chemistry: Acid Rain. *ChemMatters* **1983** *1* (2), p 13)
5. This one-page pdf document from NASA’s “spacemath” site provides a one paragraph introduction to each of three famous unit conversion problems: The Mars Climate Orbiter, the Tokyo Disneyland roller coaster accident, and Canadian Flight 143 (the Gimli Glider). It then asks one question for each story that requires students to do conversion calculations from U.S. customary to SI or vice versa.
6. This is a group of (independent) activities centered on the Canadian Flight 143 (the “Gimli Glider”), discussed in the “More on other mixed-system measurement problems” above.
7. Here is a worksheet of questions about the Air Canada Flight 143, the “Gimli Glider”, crash: <http://mrsj.exofire.net/chem/docs/meas_ec.pdf>. This could be used in class as a follow-up to the video clips referenced in “More sites on other mixed- system measurement problems” toward the end of this Teacher’s Guide.
8. Here’s more background on the numbers involved and how the accident involving Flight 143 happened, “Passengers of Flight 143 Learn the Importance of Units”: <http://www.cheresources.com/flightzz.shtml>.
9. Chemistry professor Jerry Bell suggests you have students determine the validity of the data on the “Crash of Flight 143”, the article in the October 1996 issue of ChemMatters. (Bell, J. Letter to the Editor. *ChemMatters* **1996**, *14* (4), p 2)
10. Assign your classes to debate the statement: “Resolved that the U.S. should immediately adopt the International System of Units.” Investigation could include: effects (pro and con) on worldwide trade, scientific research, everyday life, our economy, your chemistry class, etc. Here are two opposing views on this topic, from *Popular Mechanics*, September 1996: “No, Let’s Keep America American” and Yes, America Needs to Be Metrified” offer the pros and cons of the U.S.’s going metric.

(<http://www.gk12.ilstu.edu/chemistry/PowerPoint%202006/Intro%20Word/Yes%20Metric.doc>)

You could stage this debate during National Metric Week (the week in October that contains October 10, 10/10—it was October 5–11 in 2014), but holding it then might tip the scales (pun intended) toward the pro-metric team.

1. The pdf document “Measurement: Uncertainty and Error in Lab Measurements” is a “30-page illustrated guide to fundamentals of measurement. This is intended to be a clear, comprehensive overview of effective measurement technique. Intended for advanced high school or introductory college level students. Includes worked examples and problems.”

(<http://d32ogoqmya1dw8.cloudfront.net/files/sp/library/uncertainty/introduction_measurement_advan.v3.pdf>)

1. For chemistry teachers who also teach physics, Carleton University has a Web site, “Introduction to Measurement (advanced high school/intro college level)” that is a curriculum unit to teach measurement, uncertainty and error to physics students. (<http://serc.carleton.edu/sp/library/uncertainty/examples/example1.html>
2. Commercial vendors have kits to help students learn about measurement, uncertainty and error: (e.g., <http://www.pasco.com/physhigh/measurement/significant-figures.cfm>).
3. Flinn Scientific suggests a measurement competition. See their one-minute video (not much detail provided, but you can get creative): <http://www.flinnsci.com/measurement>.
4. Flinn also has a series of activities and experiments (for sale) involving measurement, including these activities: “Metric Match Game”, “The Metric Measurement Puzzle” and “Metric-ominoes”.
5. Before a discussion of units in class, ask students to bring in:
   1. Packages with units listing the amount of content (mass, volume). Challenge them to find packages that contain only SI units or only U.S. Customary units. (U.S. only units should be hard to find because Congress passed the Metric Conversion Act of 1975 to encourage use of metric units in the U.S.)
   2. Pictures of measuring instruments used in the world around them (e.g., ruler, bathroom scale, etc.)—at home, at the store, on TV, etc. Then discuss what quantities and what units the instrument measures (or have students do this in an activity).
6. This is a series of 11 “blackline masters” (only “experienced” teachers will even know what these are—says a lot about the pdf’s pedigree [age]!). The first four are about the scientific method (but do involve measurement), while the last seven provide many independent, easy activities for students to do to help them learn about measurement. Many are simple paper-and-pencil activities, while a few of them are actual experiments—all are geared primarily to middle school. <http://www.unitedstreaming.com/videos/Scientific%20Method%20and%20Measurement/108_BM.pdf>
7. The U.S. Metric Association Web site contains a page, “Tips to Educators for Teaching the Metric System, and Ideas for Schools Celebrating National Metric Week”. It offers lots of ideas about how to teach students the metric system, first among them is “Stop teaching (and using) the inch-pound system completely. Teach only the metric system.” <http://lamar.colostate.edu/~hillger/ideas.html>
8. This very simple set of paper-and-pencil activities entitled “How Do Scientists Measure Things?” takes students through the basics of measuring. It discusses basics of measuring and the metric system, then has students do activities using that information. This set could be used as a lesson for a substitute teacher on a sick day (early in the year, probably). <http://www.schenectady.k12.ny.us/TechResources/EETT/measurement/Measurement/measurement%20packet.pdf>)
9. The bottom of this sheet provides a short series of questions to ask students to assess their understanding of metric units (e.g., “If Mr. Jones is to travel 4,000 kilometers, should he walk, bike, or take a plane?”). You can construct more of these for your own students. (<http://www.pkwy.k12.mo.us/west/teachers/anderson/pack1/WS12.pdf>)
10. This is a “Measurements in Chemistry” lab activity, but it also contains questions about uncertainty, precision, % error, significant figures and conversions. You might want to use this as a lab assessment or review activity for the topic of measurement. (<http://www.collinsville.k12.ok.us/webpages/documents/HS-FrameR/Chemistry/Lab%201%20Measurment%20in%20chemistry.doc>)
11. This lab activity involves multiple weighings on multiple balances and then filtering and recrystallizing a solid from solution. The goal is to show experimental uncertainty. (<http://chemmovies.unl.edu/chemistry/labs/LABS03.html>)
12. Flinn Scientific has a package of three short videos on measurement: a measurement challenge, graphing mass and volume of salt, and calibrating an unmarked thermometer. (<http://elearning.flinnsci.com/ViewProduct.aspx?product=EL9008>) The videos are free, but you must register to view them.
13. This page from sciencegeek.net provides a series of PowerPoint presentations on a whole curriculum of chemistry. Relevant shows are “Scientific Measurement”, “The SI System”, and “Metric Conversion Practice”. (<http://www.sciencegeek.net/Chemistry/Powerpoints2.shtml>
14. While uncertainty in measurement is not the focus of this article, measurements inherently contain uncertainty. One way to drive this home to students might be to ask the entire class independently to make the same measurement, and then compare class results. A suggested quantity to measure is the time it takes to drop a pen, to the nearest minute. While you would expect that everyone would get the same measurement, it appears that is not the case. If you subscribe to the Journal of Chemical Education, you can access a very simple, brief description of just such an experiment. (Sen, B. Simple Classroom Experiment on Uncertainty of Measurement. J. Chem. Educ. **1977**, 54 (8), p 468; <http://pubs.acs.org/doi/pdf/10.1021/ed054p468>)
15. This experiment combines measurement with a real science scenario—measuring and modeling atoms. The activity has students simulating an atomic force microscope and using their measurements to construct a model of the hidden surface. As written, the activity is geared to middle school, but it could easily be adapted for high school. (Goss, V., Brandt, S., Lieberman, M. The Analog Atomic Force Microscope: Measuring, Modeling and Graphing for Middle School. J. Chem. Educ. **2013**, *90* (3), pp 358–60) (available to JCE subscribers at <http://pubs.acs.org/doi/pdf/10.1021/ed200704j>)
16. A measurement experiment is described (here, for college general chemistry students, but easily adapted to high school students) that asks each student to measure an egg’s mass, dimensions and volume (a different egg for each student). They also have to measure shell, white and yolk, separately—and devise a procedure for the experiment and bring or arrange with the teacher to have their needed equipment to do the separations and measurements. The experiment is from 1990, but it essentially provides teachers with an inquiry-based, “5E” experiment. You can then collect data and do a class analysis, including uncertainty in the discussion. (Newton, T. Measurement of Eggs: A General Chemistry Experiment. J. Chem. Educ. **1990**, *67* (7), pp 604–605; available to JCE subscribers at <http://pubs.acs.org/doi/pdf/10.1021/ed067p604>.
17. This J. Chem. Educ. article is an analysis of an experiment done to evaluate drop-counting as a means of measuring volume. (Ealy, J., Pickering, M. The Microscale Laboratory: An Evaluation of Drop Counting as a Volume Measurement. J. Chem. Educ. **1991**, *68* (5), pp A120–A122; available to JCE subscribers at <http://pubs.acs.org/doi/pdf/10.1021/ed068pA120>)
18. This J. Chem. Educ. publication reports on an alternative method of converting SI units (different from dimensional or unit analysis). It also discusses how to teach the method to your students. (Ford, E., Gilbert, Y. Displacement between Orders of Magnitude Method for SI Unit Conversion. J. Chem. Educ. **2013**, *90* (5), pp 134–136; available to JCE subscribers at <http://pubs.acs.org/doi/ipdf/10.1021/ed300006e>)
19. This might be too “young” for your classes (geared for middle school), but here’s a site from the AIMS Education Foundation showing you how to run a “Mini-Metric Olympics” competition: <http://cmase.uark.edu/teacher/workshops/AIMS-lessons/mini-metrics.pdf>. Maybe you could devise some chemistry-based events for the competition.
20. This Web site from the U.S. Metric Association provides 24 different puzzles and quizzes for students (most for middle school): <http://lamar.colostate.edu/~hillger/puzzles/>. It includes crossword puzzles, word searches, word scrambles, and a few unusual puzzles.

## Out-of-class Activities and Projects (student research, class projects)

1. Students who are interested in promoting the metric system (SI) in the U.S. could put together a promotional flyer (or even a school-sponsored Web site?) to be distributed to students in the school (or more widely distributed throughout the environs of the school). This could be particularly useful if done in time for National Metric Week (held each year in October, the week containing October 10 (10/10—metric, get it?), held in 2014 during the week of 10/5–10/11. The U.S. Metric Association Web site would be a good place to start.
2. If you want students to be active in National Metric Week, you can get ideas from the National Council on Teaching Mathematics (NCTM). NCTM sponsors National Metric Week: <http://www.nctm.org/news/content.aspx?id=10248>. U.S. Metric Association also has information for teachers about metric activities, as well as a brief history of National Metric Week: <http://lamar.colostate.edu/~hillger/ideas.html>.
3. You could assign students to be “Metric Patrol” members, with the task of finding and reporting on consumer products on the market that have incorrectly stated SI units, and writing a letter to the producer of that product (tactfully) explaining the error. Barring that, students could be asked to find and report on a specific number of consumer products with correct SI units. See “Metric Patrol” at <http://lamar.colostate.edu/~hillger/patrol.htm>.

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). 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)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

Powers, A. The Weighty Matter of the Kilogram Standard. *ChemMatters* **1999**, *17* (3), pp 14–15. This article provides a great deal of information about the kilogram standard, and some history of SI.

The *ChemMatters* Teacher’s Guide for the October 1999 article on the kilogram, above, provides a brief timeline of the metric system, extra background information and ideas for class activities and student projects.

Rohrig, B. Thermometers. *ChemMatters* **2006**, *24* (4), pp 45–49. This article provides information about the three most widely used temperature scales and a brief history of their origins.

The December 2006 Teacher’s Guide article dealing with the article above on thermometers provides background information on seven different temperature scales that have existed over the ages and a brief history of SI.

Anne Douglass: Making the World Safe for Blondes. *ChemMatters* **2002**, *20* (Special Issue No. 1), pp 14–15. This article discusses the job of Anne Douglass, the scientist in charge of validating the chemistry instruments for Aura, a NASA space satellite. The Aura satellite’s four instruments measure the chemical composition of the atmosphere, and Douglass has to make sure that those measurements agree with measurements made from ground observations and those made from weather balloons. Validating measurements ensures correct readings. Lack of validation is one reason that old measuring units, like the cubit or the span didn’t work out—there is too much variation in the size of people’s bodies to be able to make any part of the body be a measuring instrument. (In case you’re wondering about the title of the article, about blondes, one of the measurements AURA takes is levels of UV radiation and, while blondes may have more fun, they are also more susceptible to sunburn and skin cancer.)

Banks, P. The Crash of Flight 143. *ChemMatters* **1996**, *14* (3), pp 12–15. The author takes the reader step-by-step through the July 23, 1983 flight of Canada Air Flight 143. The near disaster was caused by a wrong conversion of units from U.S. Customary (also used by Canada for years) to SI. This article was the source for some of the discussion of Flight 143 in the “More on mixed-system measurement problems” section above.

## Web Sites for Additional Information (Web-based information sources)

**More sites on measurement**

World Metrology Day celebrates the role of metrology in our daily lives. Posters from the past 10 or more years are available here at this site. Each one focuses on one area of life that requires measurement (e.g., the home, sports, business/industry, health, environment, and science). (<http://www.worldmetrologyday.org/past_posters.html>)

The National Institute of Standards and Technology (NIST) Web site on units at <http://physics.nist.gov/cuu/Units/> provides a wealth of information on the history of measurement, base SI units, derived SI units, and non-SI units, and unit conversions.

**More sites on history of measurement**

The video clip “The Metre and Time” (7:22) shows a bit of the history of the development of a unified system of measurement, specifically dealing only with length and time; it shows how these two quantities are integrally related in establishing base units: <http://www.youtube.com/watch?v=dvVCNhWJvvo>.

A Web page about the metric system from Science Made Simple focuses primarily on the development of the metric system from the late 18th century to modern-day SI, providing a brief history of metric measurement. It also includes the goals of SI, as well as very brief discussions of other metric measuring systems that are not SI. (<http://www.sciencemadesimple.com/metric_system.html>)

Here is a timeline of the definition of the meter, from the birth of the International System in 1791 to the present, from NIST: <http://www.nist.gov/pml/div683/museum-timeline.cfm>.

NIST provides another very detailed document, “The International System of Units (SI),” that includes a comprehensive discussion of the base and derived units of SI, and how to use these units in writing. Two appendices are included: one provides a history of the decisions made by the General Congress of Weights and Measures (Congress General des Poids et Mesures or CGPM), which oversees the International Bureau of Weights and Measures (Bureau International des Poids et Mesures or BIPM). The first appendix is an historical timeline of the decisions made by the CGPM from 1889 to 2005 in the development of the SI international system of units. The second appendix (available online only at <http://www.bipm.org/en/publications/mises-en-pratique/>) includes very detailed up-to-date information about the SI base units and how they are measured and standardized. The 97-page document from NIST is the U.S. version of the definitive reference booklet known simply as the ”BIPM SI Brochure” published by BIPM. The U.S. document is available at <http://physics.nist.gov/Pubs/SP330/sp330.pdf>.

For an extensive timeline on the history of measurement (from “15000000000 BCE” to the present), visit the “Metrication Matters” Web site: <http://www.metricationmatters.com/docs/MetricationTimeline.pdf>.

**More sites on** **the English (non-metric) system of measurement**

Students (and teachers) may be interested in seeing this Excel spreadsheet list of more than 300 non-SI measurement units from the U.S. Metric Association. You can find it on this page: <http://lamar.colostate.edu/~hillger/traditional.htm>, or you can go directly to the list: <http://lamar.colostate.edu/~hillger/non-SI_units_alphabetically.xls>.

**More sites on** **the metric system**

The Molecular Expressions web site has an interactive page showing orders of magnitude (powers of ten), on which the metric system is based, at <http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/>.

This Vimeo video shows the one of the original “Powers of Ten” videos (1977): <http://vimeo.com/1066547>.

From the U.S. National Institute of Standards and Technology (NIST), the organization charged with maintaining our system of calibrating unit masses and other measuring units, comes this article, “The Kilogram and Measurements of Mass and Force”. It deals with methods used by NIST to maintain our standard kilogram masses, calibrated to the international kilogram standard, made of a platinum-iridium alloy, dubbed BIPM IPK, the International Prototype Kilogram (IPK) from the “Bureau International des Poids et Mesures” (International Bureau of Weights and Measures, BIPM). This is a rather technical document. (<http://www.nist.gov/calibrations/upload/j61jab.pdf>)

NIST also provides this pdf document: “The Dissemination of Mass in the United States …” It deals with the use of the U.S. standard kilogram, dubbed K20 to ensure that all users of kilogram standards in the U.S. are measuring equal kilogram masses. (<http://nvlpubs.nist.gov/nistpubs/jres/119/jres.119.001.pdf>)

Here are more recipes using metric system units and a chart of metric/U.S. Customary unit equivalents from NIST: <http://www.nist.gov/pml/wmd/metric/cooking.cfm>.

**More sites on SI**

In 2008, the National Institute of Standards and Technology, NIST, published a very in-depth resource, “Guide for the Use of the International System of Units (SI)”. The purpose of the guide is “to assist members of the NIST staff, as well as others who may have need of such assistance, in the use of the SI in their work, including the reporting of results of measurements.” The 78-page pdf document primarily deals with the way units should be expressed in publications, but it still contains a lot of information useful to teachers. (<http://physics.nist.gov/cuu/pdf/sp811.pdf>) The NIST Web site also contains this document as a separate set of Web pages: <http://www.nist.gov/pml/pubs/sp811/index.cfm>.

This page from the NIST Web site contains links to detailed discussions of each of the seven base units of the SI system: <http://www.nist.gov/pml/wmd/metric/si-units.cfm>.

Not directly related to this article but still dealing with SI at its very small levels, this is a really nice poster showing photos or drawings of various objects or phenomena at the nano- and micro-levels, with a “yardstick” continuum of the relative sizes of each: <http://www.nist.gov/pml/wmd/metric/upload/doe-scale-of-things-18-jan-05.pdf>.

This site from Purdue University gives a succinct overview of English vs. metric vs. SI, with conversion practice problems for each section. (<http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch1/unitframe.html>)

NIST provides this colorful chart of the 7 base units of the SI, along with coherent derived units (those that use only combinations of the 7 base units), along with their names and symbols. (<http://www.nist.gov/pml/wmd/metric/upload/si-color-diagram-apr-08.pdf>)

The one-page explanation of the arrangement of units on the colorful chart above can be found here: <http://physics.nist.gov/cuu/pdf/sp811.pdf>. Scroll all the way down to the end (page 78) and you’ll see the chart; move up one page and you’ll find the explanation.

This is a pdf of an 8-1/2 x 11 (inch, not centimeter) 2-color poster of “Base Units and Derived Units with Special Names” in the SI system, from Metrication Matters, part of the U.S. Metric Association: <http://lamar.colostate.edu/~hillger/pdf/SI-units-named.pdf>.

And this is a pdf of an 8-1/2 x 11 (inch, not centimeter) 2-color poster of “Base Units and Examples of Derived Units” in the SI system, from the same organization: <http://lamar.colostate.edu/~hillger/pdf/SI-units-derived.pdf>.

The SI Navigator site provides links to many other sites dealing with SI measurement: <http://www.metric1.org/>. It offers SI sites from other countries (using their flag icons), so it helps show that SI is indeed international in scope.

**More sites on the U.S. switch to metric measurement**

This site provides the pdf of the actual Metric Conversion Act of 1975, the law that promotes the use of metric nationwide (but doesn’t outlaw the use of U.S. Customary units): <http://www.gpo.gov/fdsys/pkg/STATUTE-89/pdf/STATUTE-89-Pg1007.pdf>.

This NIST site provides the pdf of the Omibus Trade and Competitiveness Act of 1988 that amended the Metric Conversion Act of 1975: <http://gsi.nist.gov/global/docs/Omnibus.pdf>.

A Washington Post video answers the question, “When will the U.S. switch fully to metric?” It includes a brief discussion on why we need a unified system (3:20). (<http://www.youtube.com/watch?v=xXK-QJ_9SLs>)

This video explains “Why we need the metric system”: YouTube (9:34).

<http://www.youtube.com/watch?v=XI9w8g4UT2I>

The U.S. Metric Association Web site (<http://lamar.colostate.edu/~hillger/#usma>) contains many useful pages for teachers and students, including:

* Consumer products sold in metric sizes: <http://lamar.colostate.edu/~hillger/products/>, including descriptions and photos of products
* Puzzles and quizzes for students (most for middle school): <http://lamar.colostate.edu/~hillger/puzzles/>. It includes crossword puzzles, word searches, word scrambles, and a few unusual puzzles.
* A clickable map of the United States: Clicking on a state will show examples of metric signage (mostly road signs) in that state. (<http://lamar.colostate.edu/~hillger/signs/>)
* Tips for teachers teaching the metric system: <http://lamar.colostate.edu/~hillger/ideas.html>
* A set of flash cards (>60, print back-to-back) for practice on SI units—the “Basic” set: <http://lamar.colostate.edu/~hillger/pdf/flash-cards-basic.pdf>. This set includes conversion problems.
* A second set of flash cards (>120, print back-to-back) for practice on SI units—the “Advanced” set: <http://lamar.colostate.edu/~hillger/pdf/flash-cards-advanced.pdf>. There are no conversions in this set.
* A set of posters, some for sale, some downloadable free: <http://lamar.colostate.edu/~hillger/posters.html>

“Measurement in Sports”, a page from NIST lists SI measurement quantities used in sports settings: <http://www.nist.gov/pml/wmd/metric/sports.cfm>.

And here is a blog from *Scientific American* that explains why the U.S. should “go metric”: <http://blogs.scientificamerican.com/plugged-in/2013/08/20/you-know-what-the-rest-of-the-world-has-figured-out-the-metric-system-its-time-the-us-got-on-board/>.

**More sites on** **the Mars Climate Orbiter**

This video clip (7:20) provides a very detailed analysis, called process mapping, of the entire Mars Climate Orbiter disaster, from launch to accident, from plan to reality: <http://www.youtube.com/watch?feature=player_embedded&v=UV3dNiR13CQ>.

This September 23, 1999 CNN.com news story reports that NASA lost contact with the Mars Orbiter “today”, with lots of speculation about what may have happened to it.

And this CNN.com news story from September 30, 1999 presents a preliminary report on the Orbiter mishap, subject to change when more data was investigated: <http://www.cnn.com/TECH/space/9909/30/mars.metric.02/>.

And here is another news report from the *Washington Post* from October 1, 1999: <http://www.washingtonpost.com/wp-srv/national/longterm/space/stories/orbiter100199.htm>.

These four sites below describe the official NASA position from their own reports:

1. September 23, 1999, the day of the loss (<http://mars.jpl.nasa.gov/msp98/news/mco990923.html>)
2. September 24, 1999, the next day, when they abandon the search (<http://mars.jpl.nasa.gov/msp98/news/mco990924.html>)
3. September 30, 1999, one week later when a preliminary report is issued (<http://mars.jpl.nasa.gov/msp98/news/mco990930.html>)
4. November 10, 1999, when NASA’s Jet Propulsion Laboratory (JPL) issues the investigation board’s report (<http://mars.jpl.nasa.gov/msp98/news/mco991110.html>)

And finally, this site is the pdf of the actual NASA JPL “Mars Climate Orbital Mishap Investigation Board Phase 1 Report” from the group that did the official investigation: <ftp://ftp.hq.nasa.gov/pub/pao/reports/1999/MCO_report.pdf>.

**More sites on** **other mixed- system measurement problems**

**The Gimli Glider**

This site provides a both detailed and personal account of the crash: <http://hawaii.hawaii.edu/math/Courses/Math100/Chapter1/Extra/CanFlt143.htm>.

This site provides audio of the entire *ChemMatters* article, “The Crash of Flight 143”: <http://my.brainshark.com/Guided-Reading-The-Crash-of-Flight-143-536326575>. It is an audio-video series of slides that plays a narrator’s voice reading the actual text that is displayed on the screen, paragraph by paragraph (slide by slide), as well as showing many photos of the crew, the airplane, the crash site, etc., to keep a student’s interest. This would be great for students reading below grade level, or low-vision students.

This site provides the mathematical explanation (with conversion factors) of what happened with Flight 143—why the calculations of the ground crew were wrong, and what they should have done to fix the problem (before it happened): <http://www.cheresources.com/flightzz.shtml>.

A video (47:26) shows a simulated Canada Flight 143, recounting the episode, including the landing, in great detail: <http://www.dailymotion.com/video/x18um8z_mayday-s05e02-gimli-glider-deadly-glide-miracle-flight_shortfilms>.

Here’s a condensed-version video clip (7:25) of the Flight 143 incident. It involves a simulation of the cockpit, rather than actual people in a real cockpit. (<http://wn.com/air_crash_investigation_air_canada_flight_143_gimli_glider_part_3>)

A made-for-TV movie, “Falling from the Sky: Flight 174”, also known as “Freefall: Flight 174” is based loosely on Flight 143. Here’s a trailer (1:30) for the movie, available on DVD on Amazon or elsewhere: <http://www.youtube.com/watch?v=FnSHnqyXqmg>.

**Other incidents**

This ChemWiki page from the University of California–Davis discusses briefly the three major metric/English conversion mishaps discussed above, possibly as a way to motivate students to learn how to do conversions, of which they provide simple example problems: <http://chemwiki.ucdavis.edu/Analytical_Chemistry/Quantifying_Nature/Case_Studies%3a_Metric%2f%2fEnglish_Conversion_Errors>.

The U.S. Metric Association has published a Web page that contains 9 major incidents (some more major than others) that involved incorrect unit conversions. The page includes the Gimli Glider and Mars Orbiter. Other topics range from rice selling at 39 cents a pound (or 39 cents per kilogram[?], depending on whether you’re buying or selling the rice), to amusement park rides measuring the diameter of a roller coaster axle in inches or millimeters, to an escaping 250-kg (or 250 lb?) tortoise. (<http://lamar.colostate.edu/~hillger/unit-mixups.html#spacemountain>)

## General Web References (Web information not solely related to article topic)

PRISM, Partnerships for Research in Science & Math Education hosts a Web site that contains teacher materials for an entire first year and for an AP curriculum. The site includes labs, PowerPoints, worksheets, an outline of each topic, questions, etc. (<http://www.gk12.ilstu.edu/chemistry/index.asp>)

## More Web Sites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

Sciencegeek.net’s Web site contains a series of PowerPoint presentations covering most of the entire first year high school chemistry curriculum. These files are also available in Flash and html5 formats. The html5 allows you to view them on tablets or smartphones. (<http://www.sciencegeek.net/Chemistry/Powerpoints2.shtml>)

The National Institute of Standards and Technology (NIST) provides a free SI Teacher’s Kit. The kit contains a class set of metric rulers and conversion cards, hard copies of activities, an educational CD and other educational resources. “The SI Education CD contains a wide variety of K-12 resources and activities (many for the middle school audience), with several also included as hardcopy prints. These kit resources have been assembled to help students become familiar with the metric system (e.g., developing reference points or that innate understanding of how much a quantity is) and learn more about SI basics.”

Several examples of the content of the SI Educational CD follow:

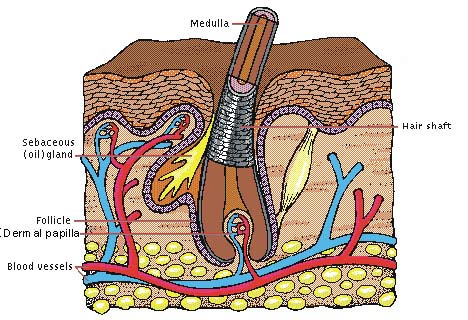
* “Guide for the Use of the International System of Units (SI)”
* “Color Diagram” of Base Units and Derived Units
* “SI Conversion Factors for General Use”
* “Metric Pyramid” study aid
* “Macro, Micro, Nano: The Scale of Things” poster

According to Elizabeth Gentry at NIST, “Each educator may directly request their set of publications [the SI Educators Kit] by providing their basic contact information to [TheSI@nist.gov](mailto:TheSI@nist.gov) (name, school, subject, grade level, phone number, and mailing address; *flier URL*: <http://www.nist.gov/pml/wmd/metric/si-teacher-kit-for-educators.cfm>.... It’s important that each educator contact us directly because we will follow-up with each of them via email for their feedback to learn how the materials were used in their classroom and seek ideas on how we can improve the kit resources.  Parents may also request a set of metric materials for use at home with their children.”

# Red, Brown, Black, Orange Hair Today, Bleached Tomorrow

## Background Information (teacher information)

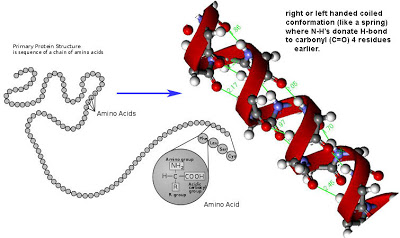
**More on** **the structure of hair**



*(Follicle structure image from*: <http://onlinehairacademy.com/wp-content/uploads/2014/02/follicle.jpg>)

Hair is an important structure. Some functions of hair include: protection, the regulation of body temperature by evaporation of perspiration, transmission of sensory information and gender identification. More complicated than it appears, hair is composed of two major structures; the follicle in the skin and the shaft that extends outside the head.

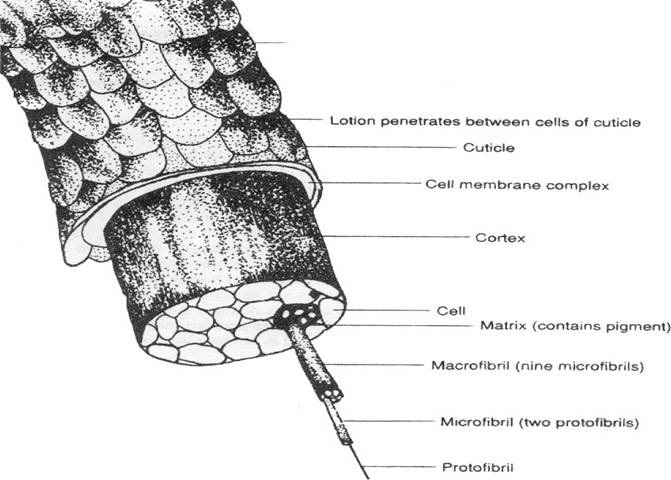
At the base of the follicle is the root which is incased by the papilla. The papilla contains blood vessels that feed the cells that form the new hair. These cells are the fastest growing cells in the body, dividing every 24–72 hours. It is the only living part of the hair.

The shaft is mainly composed of a hard protein called keratin. The structure consists of three layers: the medulla, the cortex and the cuticle.

**Medulla**: This is the core of the shaft which is hollow. It is not present in all human hair. Thick hair generally does have a medulla, while most thin or blond hair does not. The function of the medulla in the hair shaft is not known.

*Structure of keratin*

*(*[*http://bilingualbiology11a.blogspot.com*](http://bilingualbiology11a.blogspot.com)*)*

**Cortex:** The cortex makes up the majority of the hair shaft accounting for 90% of its weight. It determines the strength, elasticity, texture and color of the hair. It is composed of elongated and spindle-shaped protein cells. Within this layer is the melanin, the pigment granules, which determine the color of the hair. Whenever the hair is colored, bleached, permanent waved or relaxed the chemical change takes place in the cortex.

*Structure of a shaft of hair*

*(Baxter, R. Permanent Waves. ChemMatters* ***1993****, 11 (2), p 9)*

**Cuticle:** The outer layer of the hair shaft consists of dead epithelial cells. This layer is transparent. The cells are layered like scales to protect the cortex. The scale always point from the root end of the shaft to the tip of it. Hair conditioners work on the cuticle. Products with a high pH cause the cuticle layer to swell and allow liquids to penetrate into the cortex. Products with a low pH will cause the cuticle to shrink and harden.

*The cuticle of hair consists of scales.*

*(Raber, L. Hair Color: Chemistry to Dye For. ChemMatters* ***2002****, 20 (2), pp 10–11)*

**More on keratin, its bonds, and its relationship to hair structure**

 Keratin, composed of 18 different amino acids, is the major component of hair. Keratin is hard and very resilient. Cysteine, the most abundant amino acid, is responsible for many of the characteristics of the hair shaft. Millions of long polypeptide chains cross-linked with a variety of bond types determine the structure of the cortex. The type of bonds include ionic, hydrogen and disulfide (covalent) bonds.

*The three main type of bonds between proteins in the hair*

*(Fruen, L Natural, Braided, Colored, Straight, and Curly Hair…Thanks to Chemistry. ChemMatters* ***2008****, 26 (3), p 17)*

A description of these three types of bonds follows:

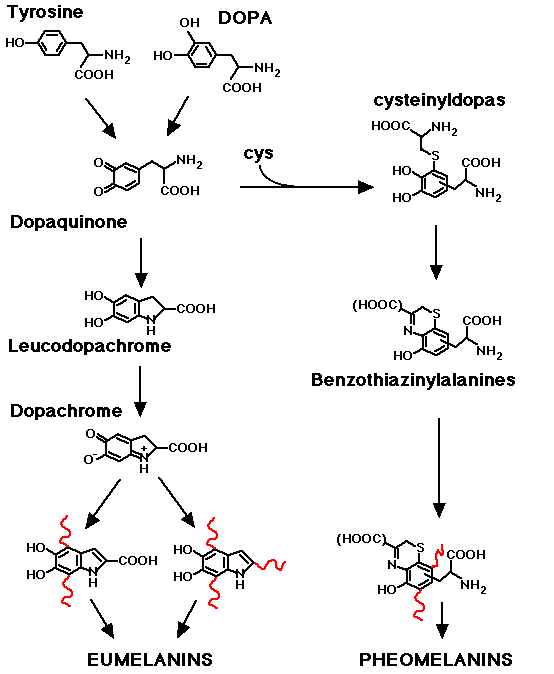
* **Ionic bonds** are easily broken with changes in pH but also readily reform when the pH level is returned to neutral.
* **Hydrogen bonds** make up about 33% of the protein bonds. They are weak and broken by water or heat and again are reformed when the hair is cooled or dried. This is the basis for wet setting hair with curlers and for styling hair with a blow dryer.
* **Disulfide bonds** are fewer in number than either the ionic or hydrogen bonds. They are formed by the sulfur atoms in two separate cysteine molecules. These chemical bonds determine the strength and shape of the hair. In straight hair the cysteine molecules form disulfide bonds that are aligned, which makes the hair shaft straight. Straight hair also has fewer disulfide bonds. The more disulfide bonds the curlier the hair. In curly hair the disulfide bonds bend or arch, causing the hair to curl.

The process of forming permanent waves or the relaxing of curly hair is basically the same. The disulfide bonds are first broken using ammonium thioglycolate, the most common active component in these products.

2 HS-CH2COO– + keratin—S---S—keratin 🡪 –OOCCH2-S-S-CH2COO– + keratin—SH---HS—keratin

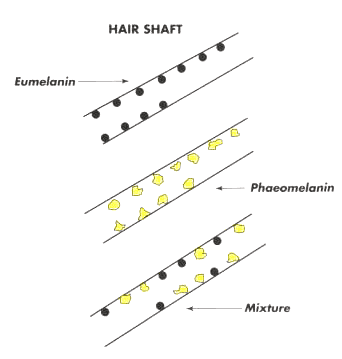
Once the disulfide bonds are broken they can be pulled past each other and the hair can be reshaped—either using a curler or flattening it. The wave/relaxing solutions have a pH around 9 which causes the cortex to swell and allows the solution to penetrate the cortex ensuring that more disulfide bonds are broken. After the hair has been reshaped the ammonium thioglycolate is washed out. A “neutralizer” is then applied. This solution usually contains hydrogen peroxide as the active ingredient. The hydrogen peroxide acts as an oxidizing agent to remove the H from the S-H bonds which allows the sulfur atoms to reform the disulfide bonds.

**More on** **the color of hair**

Hair comes in an amazing spectrum of different colors. Hair color is determined by a class of pigments called melanins. These pigments are also responsible for the color of skin and eyes as well. Melanin is formed from the amino acid tyrosine in cells called melanocytes found in the basal layer of the epidermis. Albinos have do not have tyrosine, so the melanin pigments cannot be formed.

*Synthesis of melanin where the red lines represent where the polymer would be extended: Optical Absorption of Melanin.*

*(*[*http://omlc.org/spectra/melanin/melaninsynth.gif*](http://omlc.org/spectra/melanin/melaninsynth.gif)*)*



Once the melanin is formed it is incorporated as small granules in the cortex of the hair shaft. It is not evenly distributed and varies from one strand of hair to another, which is responsible for the variation of hair color on a person. The melanin makes up less than 1% of the hair shaft.

*Right: Distribution of melanin in hair shaft: A close look at the properties of hair and scalp.*

*(*[*www.texascollaborative.org/hildasustaita/melanina.gif*](http://www.texascollaborative.org/hildasustaita/melanina.gif)*)*

There are actually three types of melanin: eumelanin, pheomelanin and neuromelanin. There are two types of eumelanin, brown and black. Eumelanin is the most abundant of the three melanin types and is responsible for the color of eyes and skin as well as hair. Pheomelanin is responsible for yellow to reddish-brown colors in hair and skin and is more stable than eumelanin. Neuromelanin colors specific regions in the brain but its function is not understood.

The actual color of hair depends on three factors:

1. The ratio of eumelanin to pheomelanin
2. The total number and size of the pigment granules
3. The thickness of the hair.

|  |  |
| --- | --- |
| **Hair Color** | **Facts** |
| Black | Contains a large amount of eumelanin.  It is less dense than other colors. |
| Brown | Higher levels of brown eumelanin.  Medium to thick strands of hair |
| Blond | Small amount of both eumelanin and pheomelanin.  Wide range of ratios that produce colors from white to dark golden  Rare in adults |
| Red | Highest level of pheomelanin (about 67%) and low levels of eumelanin.  Rare for only 1–2% of the population has red hair |
| Gray/White | Lacks any melanin.  Hair is actually clear but looks white or gray because of the way the light is reflected off of the hair |

**More on coloring (dyeing) of hair**

The artificial coloring of hair is a giant industry. It is estimated that 75% of women artificially color their hair. Men are following suit as well. The dyeing of hair is not a new phenomenon. There is archeological evidence that Neanderthal man dyed their hair with clay, roots and berries. Ancient Romans and Greeks colored their hair with plant and animal extracts. During the 1500s BC, the Egyptians used henna plant extracts. The use of natural materials continued until the 1900s. Natural pigments worked by simply coating the hair and would generally wash out after several washings. They were not particularly safe or gentle on the hair and it was difficult to get consistent results from these materials.

|  |
| --- |
| ***p*-Phenylenediamine** |
| [P-phenylenediamine.png](http://en.wikipedia.org/wiki/File:P-phenylenediamine.png) |
| [**IUPAC name**](http://en.wikipedia.org/wiki/International_Union_of_Pure_and_Applied_Chemistry_nomenclature)  1,4-Diaminobenzene |

In 1909 Eugene Scheller, a French chemist, created the first safe commercial hair dye. The dye was based on paraphenylenediamine and he called it Oréal. He founded a company called French Harmless Hair Dye Company, which became L'Oreal a year later. Paraphenylenediamine is still used as a starting material in the production of hair dyes.

*(*[*http://en.wikipedia.org/wiki/P-Phenylenediamine*](http://en.wikipedia.org/wiki/P-Phenylenediamine)*)*

Today there are three basic categories of hair dye: temporary, semi-permanent and permanent hair colors.

**Temporary hair color:** These are solutions of synthetic organic dyes that simply coat and adhere to the hair. The organic dyes may be dissolved in a combination of water, organic solvents, surfactants and conditioning agents. They are easily washed out it one or two washings.

**Semi-permanent hair color:** These hair dyes penetrate the hair shaft. They contain an alkali substance that raises the pH which causes the cuticle to soften and swell so that the dye molecules can get beneath the cells of the cuticle. This adds color without modifying the natural hair color. These dye molecules are small and will gradually leave the hair shaft after 5–10 washings. Since a small amount of dye molecules leave with each washing, the hair color changes slightly after each washing.

**Permanent hair color**: This can be divided into two categories; Oxidation hair dyes and progressive hair dyes. According to the FDA:

Oxidation hair dye products consist of (1) a solution of dye intermediates, e.g.,   
p-phenylenediamine, which form hair dyes on chemical reaction, and preformed dyes, e.g., 2-nitro-p-phenylenediamine, which already are dyes and are added to achieve the intended shades, in an aqueous, ammoniacal vehicle containing soap, detergents and conditioning agents; and, (2) a solution of hydrogen peroxide, usually 6%, in water or a cream lotion.

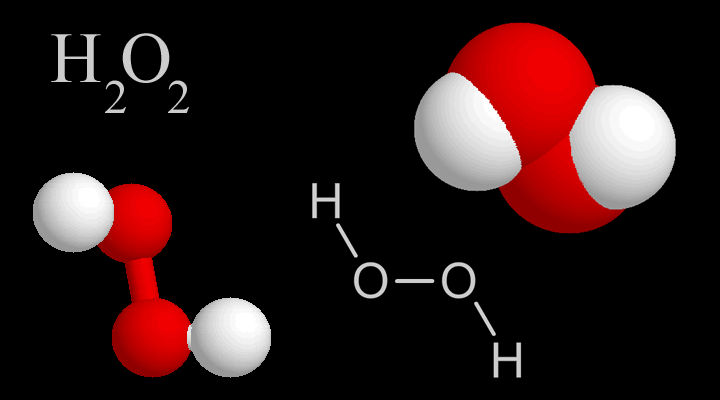
([www.fda.gov/Cosmetics/ProductsIngredients/Products/ucm143066.htm](http://www.fda.gov/Cosmetics/ProductsIngredients/Products/ucm143066.htm))

When these two components are mixed and applied to the hair, the ammonia raises the pH of the cuticle which swells it and causes the cells to separate enough so that the preformed dyes are able to enter the cortex of the hair before they have reacted with each other and with the hydrogen peroxide. The hair dye appears whitish when applied because the pre-formed dyes have yet to react to form the actual dye molecule. Darker colors are created by using higher concentrations of the pre-formed dyes. Tones can be adjusted by adding various chemicals such as 4-amino-2-hdroxytoluene which will give a reddish shade. The hydrogen peroxide is the oxidizing agent. It not only oxidizes the pre-formed dyes, creating the final colored dye molecule, but also it also oxidizes the eumelanin and the pheomelanin, breaking them down to eliminate their color. The newly formed dye molecules form large clusters in the cortex of the hair and are too big to wash out. The hair is permanently dyed.

Progressive dyes, such as Grecian Formula, gradually change the color of the hair over time. They generally contain lead acetate, Pb(CH3COO)2. The solution is applied to the hair daily and the lead ions, Pb2+, react with the sulfur in the keratin molecules creating lead(II) sulfide, PbS, which is a dark color. This eventually causes the hair to change from a light color to almost black over several weeks.

**More on hydrogen peroxide**

Hydrogen peroxide, H2O2, is the simplest peroxide. Below are the various models of hydrogen peroxide.



*(*[*www.windows2universe.org/physical\_science/chemistry/h2o2\_molecule\_big.gif*](http://www.windows2universe.org/physical_science/chemistry/h2o2_molecule_big.gif)*)*

Some of the basic physical properties of hydrogen peroxide follow:

|  |  |
| --- | --- |
| **Properties** | |
| [Molecular formula](http://en.wikipedia.org/wiki/Chemical_formula) | H2O2 |
| [Molar mass](http://en.wikipedia.org/wiki/Molar_mass) | 34.0147 g/mol |
| Appearance | Very light blue color; colorless in solution |
| [Odor](http://en.wikipedia.org/wiki/Odor) | slightly sharp |
| [Density](http://en.wikipedia.org/wiki/Density) | 1.135 g/cm3 (20 °C, 30 percent) 1.450 g/cm3 (20 °C, pure) |
| [Melting point](http://en.wikipedia.org/wiki/Melting_point) | −0.43 °C (31.23 °F; 272.72 K) |
| [Boiling point](http://en.wikipedia.org/wiki/Boiling_point) | 150.2 °C (302.4 °F; 423.3 K) |
| [Solubility](http://en.wikipedia.org/wiki/Solubility) in [water](http://en.wikipedia.org/wiki/Water) | [Miscible](http://en.wikipedia.org/wiki/Miscible) |
| [Solubility](http://en.wikipedia.org/wiki/Solubility) | soluble in [ether](http://en.wikipedia.org/wiki/Ether), [alcohol](http://en.wikipedia.org/wiki/Alcohol) insoluble in petroleum ether |

*(*[*http://en.wikipedia.org/wiki/Hydrogen\_peroxide*](http://en.wikipedia.org/wiki/Hydrogen_peroxide)*)*

Hydrogen peroxide is a nonlinear, nonplanar molecule. When dissolved in water it is slightly acidic. It is thermdynamically unstable and above 80 oC it rapidly decomposes to water and oxygen gas. It is a very strong oxidizing agent. It is stronger that Cl2 and KMnO4. Below is a list of oxidizers and their strengths:

| **Oxidant** | **Oxidation Potential, V** |
| --- | --- |
| Fluorine | 3.0 |
| Hydroxyl radical | 2.8 |
| Ozone | 2.1 |
| Hydrogen peroxide | 1.8 |
| Potassium permanganate | 1.7 |
| Chlorine dioxide | 1.5 |
| Chlorine | 1.4 |

*Hydrogen Peroxide (H2O2) is a Powerful Oxidizer.*

*(*[*www.h2o2.com/products-and-services/us-peroxide-technologies.aspx?pid=112&name=Hydrogen-Peroxide*](http://www.h2o2.com/products-and-services/us-peroxide-technologies.aspx?pid=112&name=Hydrogen-Peroxide)*)*

Louis Jacques Thenard, a french chemist, is credited with the discovery of hydrogen peroxide in 1818. He initially produce H2O2 by reacting barium peroxide with nitric acid. The determination of its molecular formula did not occur until 1892 by Giacomo Carrara using the freezing point depression technique.

Today hydrogen peroxide is mainly produced by the anthraquinone process. This process was patented in 1939. First an anthraquinone is reduced by bubbling in hydrogen to create anthrahydroquinone. A solid metal catalyst, like palladium, is used. The anthrahydroquinone is then filtered to remove all traces of the metal catalyst which might decompose the hydrogen peroxide as it is formed. The anthrahydroquinone is oxidized back to anthraquinone by bubbling in air. The hydrogen peroxide is a by-product of this reaction (see the structures below). The hydrogen peroxide is then purified from the anthraquinone by extracting the H2O2 with demineralized water in a large liquid-liquid extraction vessel. The anthraquinone solution is reused in the process.



anthraquinone anthrahydroquinone



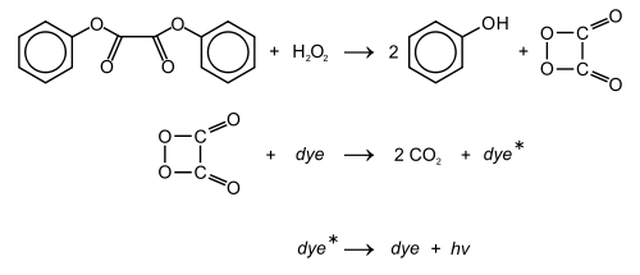
*The Manufacture of Hydrogen Peroxide*

*(*[*http://nzic.org.nz/ChemProcesses/production/1E.pdf*](http://nzic.org.nz/ChemProcesses/production/1E.pdf)*)*

This colorless, strong oxidizing agent we call hydrogen peroxide has a long list of uses, from bleaching, water treatment, disinfectant, acne treatment, rocket fuel, glow sticks and explosives. Two million tons of hydrogen peroxide are produced annually and about half of that is used to to bleach paper. Besides bleaching hair it is used to bleach teeth as well.

Hydrogen peroxide serves as a disinfectant; when it is poured on a cut the blood catalyzes its decompostion, 2H2O2 🡪 2H2O + O2, and the oxygen helps kill bacteria. Hydrogen peroxide is used as a reactant to produce organic peroxide explosives. These explosives are too unstable to use commercially.

Glow sticks would not glow without H2O2. The glass vial inside the glow stick contains hydrogen peroxide. The tube is filled with an ester, diphenyl oxylate, and a dye. When the glass is broken the hydrogen peroxide reacts with the ester to form phenol and a molecule of peroxyacid ester which decomposes immediately to carbon dioxide and energy, which the dye absorbs and then releases as a photon of light.

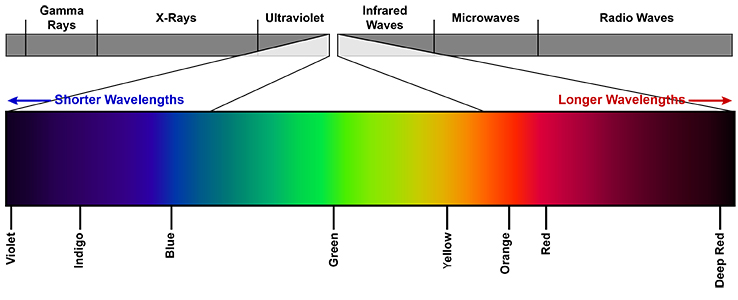


*Chemical reaction in a light stick*

*(*[*http://0.tqn.com/y/chemistry/1/S/a/b/glowstickrxn.jpg*](http://0.tqn.com/y/chemistry/1/S/a/b/glowstickrxn.jpg)*)*

**More on** **color, light, chromophores and the electromagnetic spectrum**

One of the distinguishing features of a substance is its color. This is a result of the substance’s interaction with electromagnetic radiation. The electromagnetic (EM) spectrum is the vast range of energies of electromagnetic radiation, which is commonly treated as a wave phenomenon. EM radiation is characterized by its wavelength and its frequency. The higher the energy the shorter the wavelength and the higher the frequency. The only part of the EM spectrum that the human eye can detect is the narrow visible light region, which covers a range from approximately 400 to 800 nm. Each wavelength produces a different color; the longest wavelength is red and the shortest is violet.



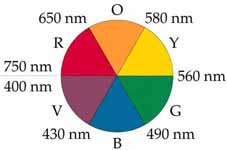
*The visible spectrum*

*(*[*www.srh.noaa.gov/jetstream/clouds/images/visible\_spectrum.jpg*](http://www.srh.noaa.gov/jetstream/clouds/images/visible_spectrum.jpg)*)*

The explanation for the colors we see is explained by the following:

When a sample absorbs visible light, the color we perceive is the sum of the remaining colors that are reflected or transmitted by an object and strike our eyes. An opaque object reflects light, whereas a clear one transmits it. If an object absorbs all wavelengths of visible light, none reaches our eyes from that object. Consequently, it appears black. If it absorbs no visible light, it is white or colorless. If it absorbs all but orange, the material appears orange. We also perceive an orange color, however, when visible light of all colors except blue strikes our eyes. Orange and blue are **complementary colors.** Thus, an object has a particular color for one of two reasons: (1) It reflects or transmits light of that color; (2) it absorbs light of the complementary color. Complementary colors can be determined using an artist's color wheel, shown. The wheel shows the colors of the visible spectrum, from red to violet. Complementary colors, such as orange and blue, appear as wedges opposite each other on the wheel.

(Brown, Theodore. *Chemistry the Central Science*, Upper Saddle River, Prentice Hall, 2006. <http://wps.prenhall.com/wps/media/objects/3313/3393071/blb2404.html>)



*(*[*http://wps.prenhall.com/wps/media/objects/3313/3393071/imag2404/AAAYPEX0.JPG*](http://wps.prenhall.com/wps/media/objects/3313/3393071/imag2404/AAAYPEX0.JPG)*)*

When light hits a substance, some of its energy can be absorbed by molecules. An electron in the molecule may absorb a certain amount of energy moving it from one energy level to a higher one. If the wavelength of light absorbed is in the visible region then the substance is colored. Organic molecules that have conjugated double bonds, a series of alternating single and double bonds with pi electrons, absorb light in the visible region more readily than ones with single bonds or ones with isolated double or triple bonds. The pi electrons are more likely to absorb energy in the visible region and move to a higher energy level.

(For more information on pi bonds and the extended conjugate system go to: <http://instruct.uwo.ca/chemistry/2223/downloads/chromphores.pdf>)

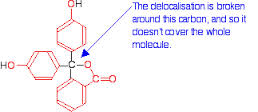
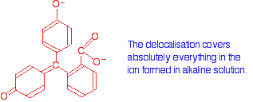
The longer the conjugate system, the longer the wavelength of light absorbed. The molecules that absorb energy in the visible region are referred to as chromophores. For organic molecules to absorb light in the visible region an extended, continuous conjugation is needed. For instance, beta-carotene has eleven conjugated bonds and absorbs light at 425 nm, which is in the blue region of the visible spectrum. Since blue light is absorbed beta-carotene appears orange. See the table below for other examples:

|  |  |  |  |
| --- | --- | --- | --- |
| **Compound Name** | **Structural Formula** | **Number of conjugated bonds** | **Wavelength absorbed, EM region** |
| Ethene (ethylene) | H2C=CH2 | 1 | 171 nm, UV |
| 1,3-butadiene | H2C=CH-CH=CH2 | 2 | 217 nm, UV |
| Trans 1,3,5-hexatriene | H2C=CH-CH=CH-CH=CH2 | 3 | 274 nm, UV |
| 1,3,5,7-octatetraene | H2C=CH-CH=CH-CH=CH-CH=CH2 | 4 | 310 nm, UV |
| beta-carotene | http://upload.wikimedia.org/wikipedia/commons/thumb/2/27/Beta-Carotin.svg/792px-Beta-Carotin.svg.png | 11 | 425 nm, visible |

*(Information for table came from various sources including these:* [*http://instruct.uwo.ca/chemistry/2223/downloads/chromphores.pdf*](http://instruct.uwo.ca/chemistry/2223/downloads/chromphores.pdf) *and* [*www.800mainstreet.com/elsp/Elsp.html*](http://www.800mainstreet.com/elsp/Elsp.html)*)*

Another common example of extended conjugation and color is the common acid/base indicator phenolphthalein. We know that phenolphthalein is colorless in acid and magenta in base. Both forms (see structures below) absorb ultraviolet radiation but our eyes cannot detect that. Thus, the acid form appears colorless. The basic form also absorbs light at 553 nm, which is in the green region, which makes it appear red/violet (magenta) (see the color wheel above).

In the acidic form the conjugation is broken around the central sp3 hybridized carbon atom so it only absorbs high energy, short wavelength photons in the ultraviolet region. In the base form the central carbon atom becomes part of a double bond extending the conjugation over the entire molecule. This shifts the absorption of light to longer wavelengths and into the visible region which is associated with an increase in the conjugation of the molecule.

*What Causes Phenolphthalein Molecules to Absorb UV and Visible Light*

*(*[*http://chemwiki.ucdavis.edu/Physical\_Chemistry/Spectroscopy/Electronic\_Spectroscopy/Electronic\_Spectroscopy\_Basics/What\_Causes\_Molecules\_to\_Absorb\_UV\_and\_Visible\_Light*](http://chemwiki.ucdavis.edu/Physical_Chemistry/Spectroscopy/Electronic_Spectroscopy/Electronic_Spectroscopy_Basics/What_Causes_Molecules_to_Absorb_UV_and_Visible_Light)*)*

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic chemistry**—The structure of hair and the pigment molecules are organic structures.
2. **Polymers**—The protein in hair, keratin, is a natural polymer.
3. **Bonding**—Hair pigment contains conjugated double bonds. The keratin is cross-linked with disulfide bonds, hydrogen bonds and ionic bonds.
4. **Oxidation-Reduction**—Hydrogen peroxide is an oxidizing agent that takes the electrons from the double bonds in the pigment molecules causing a change in their structure which makes them colorless.
5. **Visible light and color and the electromagnetic spectrum**—This article explains how molecules absorb energy from the electromagnetic spectrum. The electrons absorb EM radiation and move from a ground state to an excited state. It explains the energies associated with the visible region of the electromagnetic spectrum. It further explains the color we observe when certain wavelengths of light are absorbed.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“Sunlight is a healthier way to lighten hair.”** *Sun does lighten hair but may not be any healthier. The scalp is sensitive and can be sunburned easily. This can also damage the hair follicle. The sun may leave the hair feeling dry and rough.*
2. **“Bleached hair grows slower than unbleached hair.”** *Bleach will not cause hair to grow slower. If the bleach damaged the hair it may be brittle, making the tips break off. As a result of the breakage, the hair may make it seem like it is not growing.*
3. **“Red hair is determined by a single gene, with the allele for red being recessive to alleles for other colors.”** *Hair color is determined by the amount of eumelanin (brown/black pigment) and pheomelanin (red) in the hair which will vary even within an individual. Red hair has a large amount of pheomelanin.*

*“Red hair color is not an example of a simple genetic trait. While the amount of red pigment may be mainly determined by one gene (MC1R), there is a large number of different MC1R alleles, and other genes affect the amount of brown pigment, which plays a major role in determining hair color. The complicated genetics means that it is possible for two red-haired parents to have non-red-haired children.” (*[*http://udel.edu/~mcdonald/mythredhair.html*](http://udel.edu/~mcdonald/mythredhair.html)*)*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“Why does hair appear gray?”** *Gray hair does not have a gray pigment. It does not have any pigment and is actually colorless. It appears white or gray because of the way the light is reflected from it. The hair appears gray when the white hair is mixed with dark hair. Some people refer to it as “salt and pepper” hair. Scientists recently discovered that the lack of pigment is due to a build-up of hydrogen peroxide in the hair follicle which oxidizes the melanin (pigment) as it is formed. The hydrogen peroxide is produce in the hair follicle throughout one’s life. As we age there is a reduction of the enzyme catalase in the follicle. Catalase breaks down the hydrogen peroxide into water and oxygen. With a reduction of catalase the hydrogen peroxide builds up and a colorless hair shafts result.*
2. **“Why does even brown hair coloring appear whitish when first applied?”** *The hair dyes contain two basic components packaged separately and are mixed together before applying to the hair. One component is hydrogen peroxide and the other contains an ammonia solution of dye intermediates. These are essentially colorless and develop color when they are oxidized by the hydrogen peroxide. As this combination of solutions start to penetrate the hair they also begin to react to form the desired color.*
3. **“Why does swimming in a pool turn blond hair green?”** *The green color is caused by copper ions in the water binding to the hair. Copper ions are in algaecides. They are also naturally present in some waters. The copper(II) ions are blue and the yellow of the hair makes it look green.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. An investigation looking at hydrogen peroxide as an oxidizing and reducing agent can be found at <http://chemmovies.unl.edu/chemistry/smallscale/SS021.html>. This includes the materials needed, procedure, time required and expected results. There are also movie clips to aid in the set up.
2. This is a well written investigation for high school students published in the *Journal of Chemical Education*. In the investigation students prepare natural dyes. Included are all the teacher directions and a student-ready lab sheet. (“Colors to Dye for: Preparation of Natural Dyes”, <http://pubs.acs.org/doi/pdfplus/10.1021/ed076p1688>)
3. A good way to demonstrate how hair curls is to use two strips of sticky stuff such as two pieces of Velcro™ a few inches long, or two pieces of Scotch™ tape (the removable type). Stick the two pieces to each other and wrap them around a cylindrical object such as a marker pen. Next, while holding the inner piece in place, unstick the outer piece, then stick it back down again. When the double strip is removed from the object it will retain the curled shape. This idea is from the Teacher’s Guide for the *ChemMatters* April 1993 issue.
4. “Better Hair through Chemistry” from the online version of the Exploratorium provides several easy activities related to hair and its structure. Instructions are given for building a hair hygrometer and using it to measure changes in humidity. There are also instructions for a healthy hair test and for creating curls. ([www.exploratorium.edu/exploring/hair/hair\_activity.html](http://www.exploratorium.edu/exploring/hair/hair_activity.html))
5. A fun demonstration showing the oxidation of hydrogen peroxide is Elephant Toothpaste. The reaction produces lots of steaming foam that resemble toothpaste that an elephant would use. It requires minimum materials, although you must be extremely cautious when using 30% H2O2. There are many references and videos available online. Here two references that are easy to follow: <http://chemistry.about.com/od/chemistrydemonstrations/a/elephanttooth.htm> <http://ncsu.edu/project/chemistrydemos/Kinetics/Elephants%20Toothpaste.pdf>.

## Out-of-class Activities and Projects (student research, class projects)

1. Students could tie dye with bleach to see the effect of an oxidizing agent on chromophores. This is sometimes called reverse tie-dyeing. The process is very similar to tie-dyeing, but instead of adding color to a white tee-shirt you are removing color from a colored garment. This could also could be performed as an in-class lab. There are many references and videos giving directions for the process on line. One of these is: <http://www.lilblueboo.com/2012/08/tie-dyeing-with-bleach.html>. A good video for this method of tie-dyeing is at: <https://www.youtube.com/watch?v=9AIQODnSkm4>.
2. Students could do research on the effects of bleaching and dyeing hair on their health. They could research the safety of the products that are used in these processes.

## References (non-Web-based information sources)



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). 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)**. Scroll about half way down the page and click on the *ChemMatters* DVD image at the right of the screen to order or to get more information.**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

Baxter, R. Permanent Waves. *ChemMatters* **1993**, *11* (2), pp 8–11. This article deals with what happens at the cellular and molecular level when various chemicals are applied to hair to create waves. The illustrations concerning bonding (making and breaking) and the structure of hair follicles are useful references.

Raber, L. Hair Color: Chemistry to Dye For. *ChemMatters* **2002**, *20* (2), pp 10–11. For those interested in the chemistry of dyeing hair, this article details the materials used for coloring the hair.

Fruen, L. Natural, Braided, Bleached, Colored, Straight, and Curly Hair…Thanks to Chemistry. *ChemMatters* **2008**, *26* (3), pp 15–17. Doing things to hair other than washing requires the right chemicals—think of conditioners, styling gels, and hair dyes. The ways in which hair responds to these chemicals is well documented in this 2008 article.

*ChemMatters* Teacher’s Guide. October **2008**, p 74. This section of the Teacher’s Guide that accompanies the Fruen hair article above provides extensive information on hair dyes, shampoo and hair structure. It also includes some fun facts about hair.

Wood, C. The Art and Chemistry of Dyes. ChemMatters **2009**, *27* (1), pp 13–15. This article deals predominantly with the dyeing of cotton and wool. It does describe the dyes and chromophores.

## Web Sites for Additional Information (Web-based information sources)

These sites covers many of the topics listed below.

Good Hair Days: A Case of Good Chemistry: <http://health.howstuffworks.com/skin-care/hair-care/straightening-treatments/a-case-of-good-chemistry-info.htm>.

Hair Color: Research Update: <http://www.pgbeautyscience.com/assets/files/research_updates/P&G_ResearchUpdate_Hair_Color.pdf>.

This is a nice Prezi presentation that describes many of the topics listed below: <http://prezi.com/jjv9ufvuuthl/nus-chem-comm/>.

**More sites on** **the structure of hair**

This is an extensive, well written article that covers many aspect of hair, including the structure of hair, bonding and curling of hair, hair products and the bleaching and the dyeing of hair. (<http://www.dartmouth.edu/~humananatomy/part_1/chapter_4.html#chpt_4_hairs>)

“Better Hair through Chemistry” is a basic, well written article about hair. It discusses the chemistry involved in the structure of hair, the characteristics of hair, and bleaching and dyeing of hair. (<http://www.exploratorium.edu/exploring/hair/index.html>)

More information on the structure of hair and melanin is given in this article. It includes many good drawings and photomicrographs of hair. (<http://www.chem.sc.edu/analytical/chem107/lab4_032205.pdf>)

This site provides some information on the anatomy of hair, hair growth and its shape: <http://dermatology.about.com/cs/hairanatomy/a/hairbiology.htm>.

“A Close Look at the Properties of Hair and Scalp” is just that. It covers 3 topics: structure of hair, layers of the hair, and the chemical composition of hair. In addition, each section includes activities that, can easily be adapted for the classroom. (<http://www.texascollaborative.org/hildasustaita/module%20files/activity3.htm>)

This is a good slide program on the structure of hair: <http://www.slideshare.net/dralisyed/1-structureof-hair-euro-july-08>.

This site has a very nice graphic of the hair shaft as well as some interesting facts about hair: [http://www.hair-science.com/\_int/\_en/topic/topic\_sousrub.aspx?tc=ROOT-HAIR-SCIENCE^PORTRAIT-OF-AN-UNKNOWN-ELEMENT^WHAT-WE-DO-SEE&cur=WHAT-WE-DO-SEE](http://www.hair-science.com/_int/_en/topic/topic_sousrub.aspx?tc=ROOT-HAIR-SCIENCE%5ePORTRAIT-OF-AN-UNKNOWN-ELEMENT%5eWHAT-WE-DO-SEE&cur=WHAT-WE-DO-SEE).

**More sites on** **color of hair**

These are clearly-written articles about hair and hair color in general:

<http://chemistry.about.com/cs/howthingswork/a/aa101203a.htm> and

<http://www.webexhibits.org/causesofcolor/7F.html>

This is an in depth article on the production of melanin in both plants and animals: <http://pwp.surfglobal.net/rmangile/Pigeons/Biosynthesis%20of%20Eumelanin%20and%20Pheomelanin.html>.

This is a short article explaining the genetics of hair color, focusing on red hair: <http://udel.edu/~mcdonald/mythredhair.html>.

Information about the melanins that create the color in our hair, eyes and skin is given at this Web site: <http://www.webexhibits.org/causesofcolor/7F.html>.

This is an extensive, detailed article about melanins and their analysis:

[file:///C:/Users/goode/Downloads/Quantitative%20analysis,%20PCR523-531,2003.pdf](file:///\\acs.org\..\..\goode\Downloads\Quantitative%20analysis,%20PCR523-531,2003.pdf).

The production of melanin is described in this article: “How Albinism Works”, <http://health.howstuffworks.com/skin-care/problems/medical/albinism1.htm>.

The latest explanation about why hair turns gray is given in this article, <http://www.newsweek.com/science-looks-alternative-hair-dye-75873>.

**More sites on dyeing of hair**

This article describes the types of hair dyes and their potential hazards: <http://www.cancer.org/cancer/cancercauses/othercarcinogens/intheworkplace/hair-dyes>.

The FDA presents a short discussion of hair dyes and hair relaxers here: <http://www.fda.gov/forconsumers/byaudience/forwomen/ucm118527.htm>.

This article from *Chemical and Engineering News* describes the process of dyeing hair, including some of the history as well as some advances that have been made in the chemistry of home dyeing processes. (<http://pubs.acs.org/doi/abs/10.1021/cen-v086n006.p032>)

**More sites on hydrogen peroxide and hair bleaching**

**“**Why is Hydrogen Peroxide used to Bleach Hair?” The title says it all. Hair dyeing is also touched on here. (<http://www.thechemicalblog.co.uk/why-is-hydrogen-peroxide-used-to-bleach-hair/>)

This is a journal article about the bleaching of hair. It is a very detailed, technical article about bleaching. (<http://www.nononsensecosmethic.org/wp-content/uploads/2014/05/Hair-Bleaching.pdf>)

This article describes several oxidizing agents, including hydrogen peroxide: <http://pages.towson.edu/ladon/orgrxs/reagent/oxidizer.htm>.

The characteristics of hydrogen peroxide are described in this article: <http://www.h2o2.com/products-and-services/us-peroxide-technologies.aspx?pid=112&name=Hydrogen-Peroxide>.

An excellent graphic about the uses of hydrogen peroxide can be found at: <http://www.compoundchem.com/2014/09/30/hydrogenperoxide/>.

This is a Prezi presentation about the bleaching of hair. It does include the chemistry of the process. (<http://prezi.com/rx5ivx011x7a/bleaching-hair/>)

The characteristic and the production of hydrogen peroxide are described in this technical article: <http://nzic.org.nz/ChemProcesses/production/1E.pdf>.

This site contains an explanation of the contents of a glow stick and how it works: <http://chemistry.about.com/od/howthingsworkfaqs/a/howlightsticks.htm>.

This is an old article from the *Journal of Chemical Education*, but the information is still valuable. It contains a wealth of information about hydrogen peroxide. (<http://pubs.acs.org/doi/pdfpls/10.1021/ed028p260>)

**More sites on** **color, light and the electromagnetic spectrum**

This provides agood explanation of energy shifts in molecular orbitals when EM radiation is absorbed. It includes a discussion of the colors seen in beta-carotene, phenolphthalein and methyl orange. (<http://chemwiki.ucdavis.edu/Physical_Chemistry/Spectroscopy/Electronic_Spectroscopy/Electronic_Spectroscopy_Basics/What_Causes_Molecules_to_Absorb_UV_and_Visible_Light>)

This contains an excellent description of the absorption of light by chromophores, the effect of conjugation and pi electrons and the colors observed. Great graphics are incorporated in the explanations. It includes experiments with phenolphthalein and the extraction and separation of chlorophyll. (<http://www.800mainstreet.com/elsp/Elsp.html>)

This site has more detailed information about EM spectrum, light, absorption, and the effect of conjugation: [http://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/spectrpy/uv-vis/spectrum.htm](%20http://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/spectrpy/uv-vis/spectrum.htm).

These resources give a clear, concise explanation of light absorption and color of various compounds:

<http://instruct.uwo.ca/chemistry/2223/downloads/chromphores.pdf> and

<http://archives.library.illinois.edu/erec/University%20Archives/1505050/Organic/Arenes/Chapter%205/sec5-14/5-14.htm>.

This site is an excellent tutorial on the EM spectrum, light, color and visible spectroscopy. It also explains why the sky is blue! (<http://www.physicsclassroom.com/class/light>)

This is a good YouTube explanation of how conjugated bonds absorb light and when they absorb light from the visible region. It includes an explanation of phenolphthalein. (<https://www.youtube.com/watch?v=EJz-4ZzUA_s>)

# Pheromones: The Language of Animals

## Background Information (teacher information)

**More on** **the discovery of pheromones**

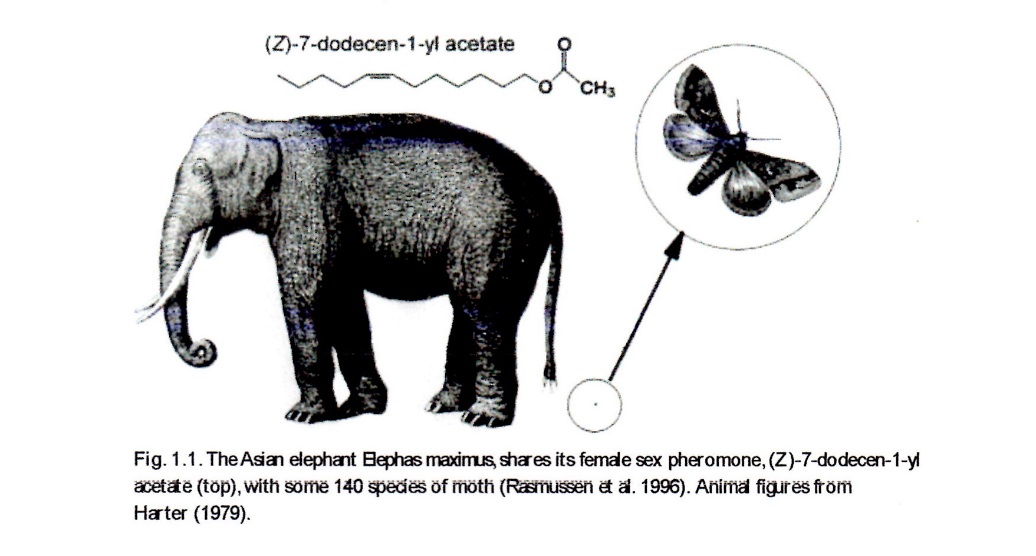
The initial awareness of pheromones in the insect world came from the observations and early experimentation by the French naturalist Jean-Henri Fabre. Fabre is considered one of the great entomologists—a keen observer and writer, the author of *“Souvenirs Entomologiques”,* which documented all his experiments and discoveries in the world of insects. Fabre discovered the power of the insect sex pheromones quite by accident in the 1870s. Male peacock moths came flitting in the open windows of his laboratory, landing on the mesh cage of a female. He tried to fool the males by moving her cage to different locations, but the males always found their way back to her. Actual identification of pheromones did not occur until the 1950s with the purification of only 5.3 mg of the male silk moth attractant *bombykol*, from the scent glands of 313,000 male silk moths! (Some short biographical references about Fabre can be found at <http://www.efabre.net/>, <http://www.efabre.net/biography/fe/biography.htm> and <http://www.e-fabre.com/en/biography/bio.htm>.)

**More on** **the basics of pheromones**

Pheromones are chemicals produced as messengers that affect the behavior of other individuals of insects or other animals. They are usually wind borne but may be placed on soil, vegetation or various items. One authority on the topic of the science of chemical use by insects claims that each species of insect relies on some one hundred chemicals in its life, to engage in such routine activities as finding food and mates, aggregating to take advantage of food resources, protecting sites of oviposition, and escaping predation. It has been found that pheromones may convey different signals when presented in different combinations or concentrations. Pheromones differ from sight or sound signals in a number of ways. They travel slowly, do not fade quickly, and are effective over long distances. Sound and sight receptors are not needed for pheromone detection, and pheromone direction is not limited to straight lines. (reference: <http://www.si.edu/Encyclopedia_SI/nmnh/buginfo/pheromones.htm>)

In mammals, there are two general categories of pheromones—releaser pheromones and primer pheromones. Releaser pheromones act quickly. One such releaser pheromone is used by animals such as dogs, wolves and cats to mark their territory. As these compounds vaporize, they signal to other members of the same species that the marker animal is the occupant of the territory. Domestic lactating rabbits release a mammary pheromone that triggers immediate nursing behavior by the baby rabbits (pups). Some mammals also possess an alarm pheromone which, when released, causes other members of their species to either take flight or stand and fight. The chemical nature of the alarm pheromone has not been deciphered nor where within the animal it is produced. But there is a special cluster of ciliated cells located at the very tip of an animal’s nose that detects airborne molecules even before the vomeronasal region of the nose or nasal epithelium are able to do so.

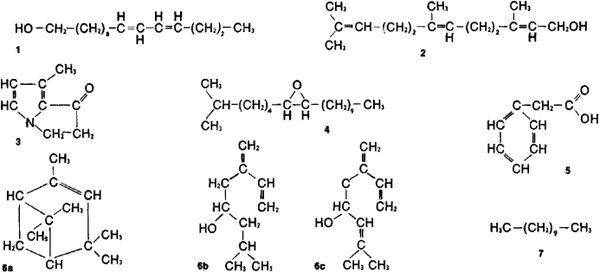
Primer pheromones, on the other hand, induce delayed behavioral or psychological responses. They basically activate other systems (priming), such as the endocrine system when it is involved in reproductive physiology.

There are many documented examples of how pheromones play into the lives of various animals, in particular, insects. And because of the fact that insects can be destructive to plants useful to humankind, such as food crops, both natural and synthetic pheromones have been developed to attract and capture these undesirable insects. An interesting bit of trivia is that the molecular structure of an elephant pheromone is the same as that of some 140 species of moth!

*(*[*http://catdir.loc.gov/catdir/samples/cam033/2002024628.pdf*](http://catdir.loc.gov/catdir/samples/cam033/2002024628.pdf) *)*

Pheromones have long been known to be instrumental in the mating behavior of insects. Examples include male silkworm moths traveling up to 30 miles to a source of attractant from the female of the species. The male Cecropia moth is thought to be able to detect a few hundred molecules of the attractant in a cubic centimeter of air. In the honeybee, the particular pheromone secreted by the queen and picked up by the workers in the hive actually suppresses the development of the ovaries of the female worker bees so that they do not develop into a competing queen bee. Another twist in the effect of a pheromone in the behavior of insects is found with the male mealworm beetle. After a male mates with a female, the male spreads a pheromone over the female that acts as an anti-aphrodisiac, discouraging other males from trying to mate with the same female. This may conserve some of the energy of the female. Parasitic wasps use other scale insects to harbor the eggs they lay. The wasp is able to find this specific scale insect host because the wasp can detect an identifying sex attractant pheromone given off by the potential host! The wasp lays its eggs in the body of the scale host in which the wasp larvae feed and develop into new wasps. Some male cockroaches and crickets produce a pheromone called seducin from their bodies, on which the females nibble during copulation. This pheromone is an aphrodisiac. Another clever development in the insect world has to do with certain spiders producing a pheromone that is identical to the sex attractant of a female moth. This attracts night flying male moths which, when they navigate to the source of the pheromone, are captured by the spider.

Some molecular formulas for insect pheromones include:



*Chemical composition of certain pheromones: (1) sex attractant of female of Asiatic silkworm, (2) marking substance of certain bumblebees, (3) aphrodisiac of male of Danaidae butterfly, (4) attractant of female of gypsy moth, (5) component of marking secretion of a rodent (clawed jird), (6a, 6b, 6c) three components of clustering pheromone of Scolytus bark beetle, (7) anxiety pheromone of Lasius ant*

*(*[*http://encyclopedia2.thefreedictionary.com/Pheromone*](http://encyclopedia2.thefreedictionary.com/Pheromone)*)*

**More on** **the use of pheromones for insect control**

The fact that pheromones are involved so much in the reproductive cycle of insects, including the undesirable ones, has been a motivating force for chemists to decipher the molecular structure of some of these pheromones. Over the last 50 years, chemists have identified pheromones from well over 1500 different insect species. Insects detect these pheromones with their antennae, their “nose”, so to speak. Long lasting pheromones allow insects to mark territorial boundaries or sources of food. Other signals are short lived and provide some kind of warning or an indicator of readiness for mating. The chemical makeup of these compounds can range from some kind of small hydrophobic molecules to water soluble peptides.

There are three main uses of pheromones in the integrated pest management of insects. The most important application is to determine the presence or absence of a particular insect in an area and also to determine their concentration for making a decision as to whether or not a control program needs to be implemented. Examples of monitoring include urban pest control of cockroaches, the management of stored grain pests, and tracking the spread of major pets such as the gypsy moth, the Japanese beetle, and the Medfly.

Pheromone traps have many applications. At the port of entry for shipping containers from other countries, traps are used to monitor the movement of exotic insect pests into most major North American ports. Another major use of pheromones is to “mass trap” insects in order to remove them from a feeding and breeding population. Mass trapping has been used to control the destructive bark beetle, the coddling moth (a serious pest of apples and pears), and certain moth pests that are destructive to some crops. In this case, a synthetic pheromone is dispersed onto crops. The false odor attracts males away from females waiting to mate, reducing the rate of mating. This false odor masks the insect’s own attractant and thus may prevent the sexes from getting together, which results in the reduction of the population density. In some cases, the effect has been so great that the pests have been eliminated in a particular locale.

An example is the use of a synthetic pheromone to control the beet army-worm. A field is flooded with the pheromone (which vaporizes), luring males to the area, away from females. The chemical is effective for a hundred days, way past the window of opportunity for mating. The beet army-worm has a wide host range, occurring as a serious pest of vegetable, field, and flower crops. Among susceptible vegetable crops are asparagus, bean, beet, broccoli, cabbage, cauliflower, celery, chickpea, corn, cowpea, eggplant, lettuce, onion, pea, pepper, potato, radish, spinach, sweet potato, tomato, and turnip. Field crops damaged include alfalfa, corn, cotton, peanut, safflower, sorghum, soybean, sugar beet, and tobacco.

A somewhat different approach to using pheromones is to attract insects in large numbers by utilizing synthetic trail pheromones. As an example, ant trail pheromones direct the insects to insecticidal bait, eliminating the pests directly rather than trying to interrupt the reproductive process. Of course, if the ant is eliminated, so is its reproductive mode!

A long list of insects for which there are pheromones is available at <https://en.wikipedia.org/wiki/Pheromone_trap>.

**More on controlling animal behavior through hormones**

There is interest in the use of pheromones to control the behavior of domestic animals (pets). In particular, dogs and cats can get stressed. Changes like a new home, a new family member or an annoying dog or cat next door can precipitate unwanted behaviors like marking or urinating in the house, excessive barking or meowing, or simply going on a rampage of destruction around the house. Evidently there are some pheromones that are calming or appeasing. They may relieve stressed animals. These pheromones are said to mimic natural cat or dog pheromones. They come in various forms including sprays, plug-in diffusers, wipes and collars. While these pheromones can be used with cats and dogs, they are not effective for treating aggression in dogs.

What does the research say about the effectiveness of these products? Research, funded by the products’ makers, claim that they help soothe stressed pets in some circumstances. One cat pheromone called Fellway mimics a cat’s facial pheromones which it deposits when rubbing its cheeks against a surface, marking the area as being safe, supposedly. This chemical may reduce scratching and some types of cat spraying. But it does not address the underlying problems that cause spraying on horizontal surfaces, such as beds or couches.

Another pheromone product called Comfort Zone mimics the pheromone released by nursing dogs to comfort their puppies. The product may help with general anxiety as well as stress caused by loud noises such as thunder or fireworks. It may also help to mollify separation anxiety or to calm dogs in shelters. But owners should also do behavior modification with the animal.

Further research suggests that the dog appeasing pheromone (D.A.P., above) might reduce anxiety in puppies during training. Other than that, scientific studies did not find convincing evidence of benefit for anxiety associated with veterinary care, anxiety in shelter dogs, or barking and elimination (urination or defecation) indoors by recently adopted dogs.

In a limited number of cat studies, none provided convincing evidence of a benefit. Some decrease in urine spraying happened with some cats. Pheromone therapy was also not clearly beneficial for calming cats in hospitals or facilitating the stressful process of placing IV catheters in hospitalized cats. It seems as if these products are providing some sense of calm to the owners rather than their pets. Certainly, veterinarians have little basis for recommending these pheromone-based products to the owners of their pet patients.



[*http://www.petcomfortzone.com/dogs/behavior-advice/puppy-whining-and-howling*](http://www.petcomfortzone.com/dogs/behavior-advice/puppy-whining-and-howling)

In contrast to the inconclusive studies on the effectiveness of commercial products such as D.A.P. (dog appeasing pheromone), recent work at Texas Tech University points to a better product with scientific validation of its effectiveness. The product is the result of research by Dr. John McGlone into the use of a pig pheromone for calming dogs, more specifically for silencing dogs that bark too much. Dr. McGlone actually came across the effectiveness of the pig pheromone, known as an androstenone, by accident. The androstenone is normally produced by male pigs (boars) and sets female pigs into a breeding mode. Dr. McGlone had some of this pheromone in a bottle which he sprayed on his barking dog one day out of frustration. The dog immediately went quiet! Further testing of the pheromone on a whole variety of dogs stopped their barking also. A new product was born, called Boar Mate. And the pheromone is a synthetic rather than the natural derivative. Dr. McGlone evaluated the product in a series of experiments which included a placebo, of course. Refer to <http://www.sciencedaily.com/releases/2014/08/140824213155.htm> for a complete description of the testing program by Dr. McGlone. And as a result of this work, Dr. McGlone introduced a new term to the pheromone literature. Because the pheromone from one animal affected the behavior of another animal, the chemical was classified as an interomone.

**More on the murky state of research into human odors associated with priming the endocrine system**

This is a field of research where the opinions of experts range from animated support and even promotion to healthy scientific skepticism. Within the research ranks are accusations of all kinds about the veracity of data and how the experiments have been conducted, particularly when it involves all the variables of human behavior.

On one side of the debate are the pheromone boosters, some of whom have founded companies that sell pheromone-based perfumes and pharmaceuticals. On the other side are skeptics who argue that the phrase "human pheromone" is a contradiction in terms. Between the two extremes lies a middle ground of researchers who are doubtful of the strongest claims but unwilling to ignore the possibility that humans, like many other animals, use chemicals to communicate.

Among them is Martha McClintock, PhD, who can be credited with starting the human pheromone phenomenon. In 1971, the University of Chicago psychologist, then an undergraduate at Wellesley College, published a study showing that the menstrual periods of women who lived together tended to converge on the same time every month, an effect thought to be mediated by pheromones.

Now, more than 30 years later, McClintock and others in the middle ground are finally making progress in understanding the effects of human pheromones. Many aspects of the field remain unclear--including the definition of the term "pheromone" itself --but at least one conclusion can be drawn from the research conducted so far: Their effects are far more dependent on social and psychological context than originally suspected.

(<http://www.apa.org/monitor/oct02/pheromones.aspx>)

Scientists now suggest there are four kinds of human pheromones—primers, releasers, modulators and “signalers”—that provide information to the recipient without directly altering behavior. There is the opinion among some researchers that the term pheromone should be used only in the narrowest sense—in part because those who use looser definitions can label and sell almost anything as a pheromone. Two of the human secretions that have attracted attention and debate about their effects and about their classification as pheromones are the hormone-like chemicals, androstadienone and estratetraenol, which are found in human sweat. Some researchers claim there is evidence to support the idea that these two sweat products are pheromones and induce sexual responsiveness in males and females. But Charles Wysocki, PhD, of the Monell Chemical Senses Center in Philadelphia, PA, disagrees.

“There's no good evidence in the biomedical literature that these are human pheromones," he says. According to his analysis of McCoy's data (another researcher), the additive appeared to work only because women who received the placebo and the "pheromone" started out with different levels of sexual activity, then regressed toward the mean--a statistical flaw disguised by the study's data analysis methods.

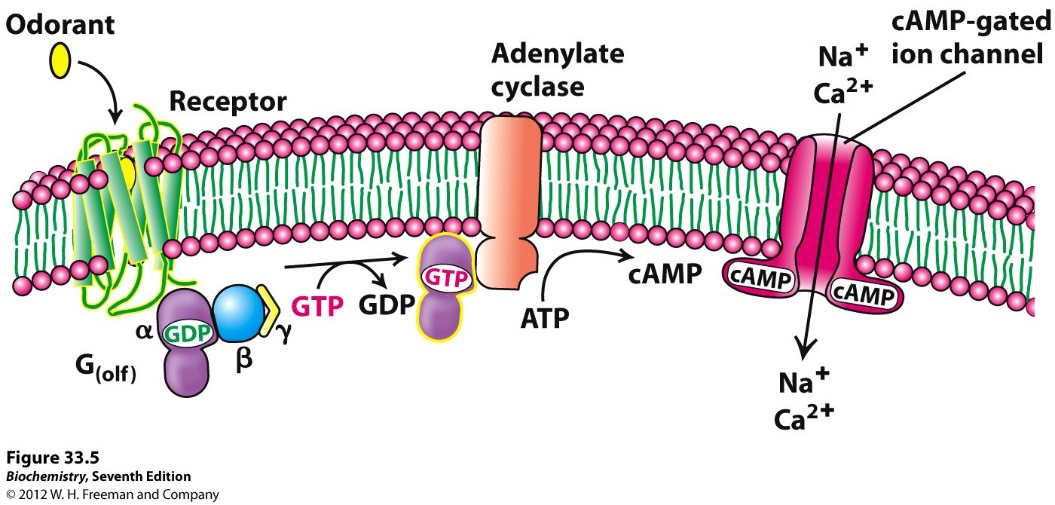
Martha McClintock PhD, too remains skeptical. **Social and psychological conditions** are important mediators of pheromonal effects, she says, and any claims that a particular product will increase the user's opportunities for sexual intercourse regardless of context are, in her opinion, misleading.

“It's like saying that if you see a red light, you cannot control yourself from stopping no matter the circumstance," says McClintock. "Human behavior just isn't like that in any domain.”

(<http://www.apa.org/monitor/oct02/pheromones.aspx> )

McClintock was one of the earliest researchers investigating potential human pheromones. In the 1970s she collected women’s underarm fluids and showed that when applied to the upper lip of a female recipient, the fluid could either hasten or delay a recipient’s menstrual period. But they were not able to identify the exact chemicals responsible for the effect. These substances were considered primers, substances that can influence long-term changes in hormone levels. What they were really hoping to find were so-called “releasers”, fast acting pheromones that are found in other non-human animals that trigger stereotypical behavioral responses related to sexual reproduction activity. Later research activities claimed to have found and isolated such releaser hormones that were then manufactured and sold by companies started by some of the researchers! But the scientific community has been reluctant to support claims of specific releaser pheromones that have been identified, as mentioned above. (For more details about the work of McClintock, refer to the reference immediately above.)

**More on how odors are detected by insects**

The chemistry behind detecting odors in insect antennae involves specialized proteins that change physical shape which, in turn, change neural cell membrane structure, allowing for certain ions (Ca2+, K+, Na+, and Cl–) to flow in or out of the cell, which sets off a nerve impulse.

*(*[*http://oregonstate.edu/instruct/bb451/summer14/stryer7/CH33/figure\_33\_05.jpg*](http://oregonstate.edu/instruct/bb451/summer14/stryer7/CH33/figure_33_05.jpg)*)*

The description that follows relates to the illustration above.

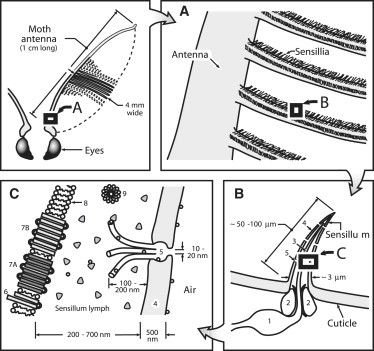
Rather than binding specific ligands, olfactory receptors display affinity for a range of odor molecules, and conversely a single odorant molecule may bind to a number of olfactory receptors with varying affinities. Once the odorant has bound to the odor receptor, the receptor undergoes structural changes and it binds and activates the olfactory-type G protein on the inside of the olfactory receptor neuron. The G protein (Golf and/or Gs) in turn activates the lyase - adenylate cyclase - which converts ATP into cyclic AMP (cAMP). The cAMP opens cyclic nucleotide-gated ion channels which allow calcium and sodium ions to enter into the cell, depolarizing the olfactory receptor neuron and beginning an action potential which carries the information to the brain.

(<http://en.wikipedia.org/wiki/Olfactory_receptor>)

The following series of drawings provides the structural details of a moth antenna, which includes the physical interactions of the sensory neuron membrane proteins, pheromone-binding proteins, and the phospholipid bilayer portion of the neuronal membrane. Essentially, what you have are the important structural components that provide the chemical interaction between pheromone molecules and the insect’s neural network for “sensing” the presence of specific chemicals. This “sensing” in the insect’s brain then leads to specific behavior that the pheromone is meant to provoke.

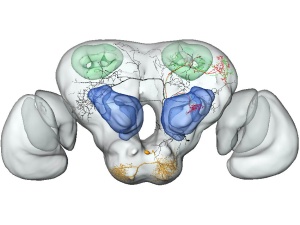
*(A) A close-up view of the hairy branches of moth antenna.*

*(B) Diagram of the olfactory sensillum ([1] olfactory receptor neuron; [2] auxillary supporting cells; [3] dendrite of an olfactory receptor neuron projecting into the hollow space of the sensillum; [4] cuticle wall of the hair; [5] cuticular pores).*



*(*[*http://ac.els-cdn.com/S1074552109000295/1-s2.0-S1074552109000295-main.pdf?\_tid=37aa1d7a-62b6-11e4-be1e-00000aab0f26&acdnat=1414949728\_24bffeccad4594299e411807624b6d87*](http://ac.els-cdn.com/S1074552109000295/1-s2.0-S1074552109000295-main.pdf?_tid=37aa1d7a-62b6-11e4-be1e-00000aab0f26&acdnat=1414949728_24bffeccad4594299e411807624b6d87)*)*

*(C) The peripheral components of the sensillum trichodeum ([6] sensory neuron membrane protein [SNMP]; [7] olfactory receptor and coreceptor; [8] phospholipid bilayer of the neuronal membrane; [9] micelles formed by fatty acids; shaded triangles, pheromone-binding proteins (PBPs); open circles, pheromone molecules). The pheromone molecules adsorbed on the cuticle wall of the sensillum migrate along the surface into the pore canal penetrating the cuticle and diffuse through the pore tubules into the sensillum lymph. PBPs come to interact with the ligands. The pheromone molecule may diffuse by itself through the barrier to associate with the membrane protein and then activate the receptor (Benton et al., 2007). Alternatively, ligand can either activate the PBP (Laughlin et al., 2008) or be delivered by the micelles (Honson, 2006).*

The brain of a moth, which is smaller than a pinhead, is shown at right. The blue areas are the primary smell center. Learning and memory take place in areas that are colored green. The protrusions on the sides are the visual areas, otherwise known as eyes.

*(Norwegian University of Science & Technology (NTNU) Dept. of Biology: (*[*http://earthsky.org/earth/inside-a-moths-brain*](http://earthsky.org/earth/inside-a-moths-brain)*)*

The basic operational mechanism for detection of odors (and, of course, pheromones) is that there are olfactory receptor cells that contain specific proteins that interact with an odorant’s molecular structure when they meet within some kind of olfactory structure (an antennae in insects, ciliated epithelium within a mammal’s nose). An insect’s olfactory receptor cell is called an olfactory sensilia and is found in the antennae. Each cell has only one kind of protein for each type of odorant molecule. In a mouse there are more than 1000 different kinds of receptor proteins. In a human, we are talking about some 350 different kinds of receptor proteins. Each of these different receptor proteins is genetically coded for its synthesis. The receptor proteins are linked to receptor neurons. A nerve impulse is generated when an odorant molecule links to the receptor protein within the receptor neuron’s cell membrane, causing a deformation of the membrane protein which in turn sets off a cascade of chemical changes within the neuron cell that generates an impulse (see the illustration of moth antennae, above).

## Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic compounds**—In the biological/chemical world, organic compounds are fundamental to structure and function of living organisms. Because of a carbon backbone in the molecule’s structure, bonding that results can produce an almost infinite number of configurations with important functional groups attached. This allows for a variety of different pheromones for example helping one colony of ants to distinguish its members from those of another colony.
2. **Hydrogen bonding**—As mentioned in the article, the type, hence strength, of bonding between pheromone molecules determines the ease with which the molecules can dissociate from each other in the phase change from a liquid to a gas.
3. **Polar molecules (dipoles)**—Dipole moments found in a pheromone’s molecular structure are responsible for the molecule’s intermolecular bonding and the molecules’ phase—liquid versus gas, depending on temperature.
4. **(London) dispersion forces (temporary dipoles)**—The weakest of the types of intermolecular bonding between pheromone molecules, these forces are produced from temporary dipoles within the molecule shifting from moment to moment because of the molecule’s temperature-dependent vibrations.
5. **Phase changes**—When a pheromone is produced within an organism (most likely as a liquid), it usually depends upon a phase change to a gas in order to be transmitted over a distance to another recipient organism.
6. **Kinetic molecular theory of gases**—Because gas molecules are constantly in motion, volatile substances such as pheromones can reach an animal’s detection apparatus at some distance from the source.
7. **Pheromone**—For pheromones to function as a gaseous substance, these organic compounds must contain between 5 and 20 carbon atoms, with a molecular weight between 80 and 300. The size and weight limits are related to molecular diversity and olfactory efficiency.

## Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“Human pheromones have been identified, since they are sold for enhancing sexual attraction.”** *Although “pheromones” are purportedly available as human pheromones and sold for enhancing sexual attraction in various perfumes, there is no evidence that human pheromones exist or that they enhance sexual attraction as in other animals. Some studies have tried to link odor of men’s sweaty underwear to women’s sexual responses, but most scientific studies do not find a link. Underarm sweat from male or female when placed on the upper lip of females is found to affect the timing of the menstrual cycle. There are plenty of odors that females respond to, but they are not specific responses as in the case of other animals and insects related to pheromone emissions. A specific human pheromone has yet to be isolated chemically.*
2. **“If we synthesize a molecule that occurs in nature (as in the gypsy moth lure), then it is natural.”** *For a chemical to be natural, it has to be produced in nature by a living plant or animal or from a non-living source such as that which is extracted from the earth. But to put together (synthesize) a molecule that has the exact same structure as that extracted from natural sources is still synthetic.*
3. **“Liquids evaporate or vaporize only at high temperatures, as in the boiling of water.”** *First, remember that water* ***does*** *evaporate at almost all temperatures; it doesn’t need to boil to form vapor. The temperature at which a liquid evaporates, whether at the boiling point or not, is dependent on the molecular structure of the molecule, which in turn determines the type of intermolecular force. If you compare the rate at which water evaporates at room temperature with that of an organic compound such as carbon tetrachloride (CCl4), you find that carbon tetrachloride will evaporate much more quickly than water because the intermolecular bonds between the carbon tetrachloride molecules are much weaker than those between water molecules.*

*The type of intermolecular bond results from the bonding within the molecules. The water molecule ends up being a polar molecule which means it possesses slight positive and negative electrical charges on opposite ends of the structure (dipoles). This allows for attractive forces between water molecules (dipole-dipole interactions—hydrogen bonding). The carbon tetrachloride molecules are the exact opposite, or non-polar. Their intermolecular forces are much weaker than those of water. So it takes less kinetic energy for separation of carbon tetrachloride molecules in the evaporative process.*

*Liquid molecules do not have to reach the boiling point in order to evaporate because some of the molecules have enough kinetic energy to break intermolecular bonds and become gaseous. Non-polar molecules create a higher vapor pressure (from more gaseous molecules) at a given temperature than polar molecules because of their weaker intermolecular forces.* ***NOTE****: Vapor pressure relies on the existence of three distinct types of intermolecular forces—London forces (temporary dipoles), present in all molecules; dipole-dipole interactions, which are the result of a molecule’s polarized structure; and hydrogen bonds, which are the result of a hydrogen atom covalently bonded to a highly electronegative atom (such as oxygen) in a polarized structure being attracted to another highly electronegative atom in another neighboring molecule.*

## Anticipating Student Questions (answers to questions students might ask in class)

1. **“Why are dogs more sensitive to smell than humans?”** *It all has to do with the brain. If you look at a dog’s brain, you will find 20 to 40 times as many nerve receptors for interpreting odors than in our brains. Testing a dog’s sensitivity of smell for a particular chemical, hydrogen sulfide, we find that the lowest concentration of hydrogen sulfide in air that a dog can detect is 10-13 %. (1 part per quadrillion). The lowest concentration of hydrogen sulfide detected by humans is 10-6 % (10 ppb). (from ChemMatters* Teacher’s Guide for December 2012, to accompany *ChemMatters* article “What’s That Smell?”) *Note that the MSDS for hydrogen sulfide lists the short term exposure limit (10 minutes) at 15 ppm, a level so low we cannot even detect it at its toxic level—but dogs can.*
2. **“Can we smell human pheromones and what are the particular functions of those we can smell?”** *There have not been any human pheromones isolated and analyzed to date. There is some anecdotal evidence to suggest that certain responses can be elicited in females when underarm sweat from either males or females is placed on the upper lip of a female, can affect the timing of the menstrual cycle. But sweat is not a pheromone. (Refer to the details of misconception #1 in the previous section (“Possible Student Misconceptions”).*
3. **“At what concentration and at what distance can a male moth detect a female moth’s sexual pheromone attractant?”** *As an example, the male silkworm moth can detect a female as far away as one mile. The pheromone secreted by a female gypsy moth can be detected by the male species at concentrations as low as ONE molecule in 1 x 1017 molecules of air!*
4. **“Are pheromones required for sexual reproduction to occur in insects?”** What we are really talking about is the techniques used by insects to attract a mate for reproduction. Naturally, the release of a pheromone is one such device. But insects also use a number of other “attractants” including visual clues, auditory clues, and flashes of light as in the case of the firefly. Visual clues simply mean that a male will detect a female by sight, will inspect, and, if truly a female of his species, will engage in reproduction. In the case of butterflies, color and the pattern of flight by the female provide the identification cues for the male. Female fireflies use a specific light-signaling code to attract a male. Crickets and cicadas use sound to attract mates. The “singing” is usually produced by the male species.
5. **“If a pheromone-based trap for Japanese beetles attracts the insect to a garden area, wouldn’t that simply lure the beetles to the plants rather than to the trap?”** *In reality, there is the possibility that some of the beetles lured in the direction of the garden might find plants to eat. But the pheromone lure is strong enough (think sex!) to attract the majority of beetles away from the plants.*

## In-class Activities (lesson ideas, including labs & demonstrations)

1. Olfactory fatigue is the temporary, normal inability to distinguish a particular odor after a prolonged exposure to particular airborne compound. Some animals such as dogs do not suffer from this fatigue because of their special nasal architecture. Humans do experience olfactory fatigue. Several experiments on this topic can be found at the following Web sites—<http://www.sciencebuddies.org/science-fair-projects/project_ideas/HumBio_p031.shtml#materials>: and <http://academic.evergreen.edu/curricular/perception/Lab1006.htm>. This latter Web site has very good questions for the students to think about with regard to the topic of olfactory fatigue.
2. Another Web site on olfactory fatigue activity is found at <http://faculty.washington.edu/chudler/chems.html>. ). The teacher guide for this activity is found at <http://faculty.washington.edu/chudler/pdf/chemstg.pdf> .
3. Students could synthesize esters which are normally used as flavoring in foods, but for this exercise would simply be the production of pleasantly smelling compounds that they can recognize. Ester synthesis involves the use of concentrated sulfuric acid. But if done in small quantities it presents less of a lab safety issue. Or the teacher can add the acid for the students at the correct step in the procedure. Refer to the following Web site for a complete lab exercise in ester synthesis: <http://www.nuffieldfoundation.org/practical-chemistry/making-esters-alcohols-and-acids>
4. Although this ChemMatters article deals with smell in the insect world, students could map their tongue for the locations of the principle tastes of salt, bitter, sweet and sour (acidic). Smell is often involved with a particular taste. And for insects, while using smell for locating both mates as well for locating food sources, also use taste for evaluating the type and quality of a food source. This exercise would also point out to students the specificity of neural receptors. Most biology lab manuals contain the exercise procedure. A printable outline of the tongue with the locations on the tongue for the different categories of taste is found at <http://www.teachervision.fen.com/tv/printables/orange/SL-27.pdf> . A Web site for the lab procedure can be found at <http://faculty.washington.edu/chudler/chtaste.html>. You can also actually see the taste buds on the tongue and compare the number for different people. See the following Web site for the simple instructions: <http://www.bbc.co.uk/science/humanbody/body/articles/senses/tongue_experiment.shtml> Additional background information and discussion about the integral role of smell with taste and touch for the sensations of what some people call the flavor of foods is found at <http://www.tastescience.com/default.html> . Smell is often involved with a particular taste.

## Out-of-class Activities and Projects (student research, class projects)

1. Student activities involving insects provide learning on how to design an experiment. A list of research ideas with ants but no particular set of procedures (i.e., students design the experiment) can be found at <http://www.science-projects.com/behavior.htm>.  
   Here is another list of experiments with ants: <http://www.all-science-fair-projects.com/science_fair_projects/78/3/47e9f497402253a67d9ef19e5e99d17d.html>
2. Two specific experiments with ants dealing with concentrations of sugar (solutions) and type of sugars are found at <http://www.crystal-clear-science-fair-projects.com/ant-behavioral-science-projects.html> and <http://www.crystal-clear-science-fair-projects.com/ant-behavioral-science-project.html>. This reference includes where to obtain the ants.
3. Another experiment with ants tests both ant attractants as well as ant repellents. To do this particular study, ants can be obtained from biological supply companies that the biology teachers are familiar with. For all aspects of this activity, consult <http://www.sciencebuddies.org/science-fair-projects/project_ideas/Zoo_p025.shtml#materials>.
4. An experiment dealing with ant trails and their chemical signals (pheromones) is found at <http://www.sciencebuddies.org/science-fair-projects/project_ideas/Zoo_p016.shtml> .
5. Students could investigate the use of pheromone-based insect traps for such destructive insect pests as the Gypsy moth and Japanese beetle. What other devices are used either separately or in conjunction with the traps?
6. An experiment to determine the chemical basis for ant behavior involves extracting and testing chemicals from ants to test their effect on a group of nest mates’ behavior. The second part to the experiment is to modify the extracted ant scent using several organic solvents to see what effect this has on the ants’ behavior. The procedure for extracting the scent chemicals is documented. Refer to <http://www.sciencefairexperiments.org/Zoology/Chemical-Basis-for-Ant-Behavior.php>.
7. A large collection of experiments done by students (as science projects) is found at <http://www.juliantrubin.com/fairprojects/zoology/ant.html>. Each experiment is described completely by a student who actually did the experiment. This particular Web site has a collection of experiments on both ants and termites.
8. Another Web site with a collection of investigations into ant behavior suggests topics to investigate but does not give specific procedural details; however, is does point out what variables need to be tested and makes suggestions about experimental setups. This site would be useful for providing students with an investigation of a topic without resorting to the cookbook style of class experiment. These topics for investigation are closer to open-ended research. Refer to <http://www.all-science-fair-projects.com/science_fair_projects/78/3/47e9f497402253a67d9ef19e5e99d17d.html%2056>.

## References (non-Web-based information sources)



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**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online on the same Web site, above. Simply access the link and click on the “Past Issues” button directly below the “M” in the *ChemMatters* logo at the top of the Web page.**

Kimball, A. Human Pheromones: The Nose Knows. *ChemMatters* **1997**, *15* (2), pp. 6–8. This *ChemMatters* article deals specifically with the search for human pheromones and the difficulties that entails. Several molecular formulas of several human odorants (as opposed to pheromones) are described. These male odorants may induce or prime the female endocrine system to begin the menstrual cycle.

Eboch, C. What’s That Smell? *ChemMatters* **2012**, *30* (4), pp 12–14. This *ChemMatters* article deals extensively with the sense of smell, including that of humans, fish, and also dogs whose keen sense of smell is used for detecting bombs, cancer, and of course the pheromones of a canine reproductive partner. There is also a very useful Teacher’s Guide.

## Web Sites for Additional Information (Web-based information sources)

**More sites on** **the work of two great entomologists—Jean-Henri Fabre (19th C) and EO Wilson (20th C)**

An extensive biography about the work in entomology of Jean-Henri Fabre is found at <http://www.e-fabre.com/en/biography/bio.htm>.

A very good PBS video program about the work of EO Wilson is found at <http://www.pbs.org/wgbh/nova/nature/lord-ants.html>.

**More sites on** **the basics of pheromones**

A twenty-eight page treatise on all aspects of pheromones that is clearly written and useful as a primary reference on pheromones is found at <http://catdir.loc.gov/catdir/samples/cam033/2002024628.pdf>.

A second Web site from the animal science research labs at the Texas Tech University provides a good amount of information on pheromones related to dogs, cats, pigs, horses, rats, and mice. It also provides the details of their research into the use of pig pheromones to control dog behavior. This is in contrast to some of the poorly done research into the use of the commercial products sold for controlling undesirable behavior in dogs and cats. A video shows the use of one commercial pheromone product to control the behavior of a dog. There is also a PowerPoint program at this same Web site that presents the science of pheromones. It could be useful for class. Refer to the following Web site: <http://www.depts.ttu.edu/animalwelfare/Research/Pheromones/index.php>.

**More sites on** **commercial insect lures and traps**

A short and readable essay on the current state of pheromone use in controlling insects is found at <http://mypestprevention.com/2013/09/pheromones-insect-control/>. A complementary article from a state agriculture service is found at <http://www.unce.unr.edu/publications/files/ag/other/fs9841.pdf>.

A commercial Web site, <http://www.pestcontrolindia.com/pheromone-lures-and-traps.aspx>, shows examples of various types of pheromone-based insect traps.

The Web site <http://www.insectslimited.com/pheromones-home> provides detailed information about the various pheromone traps that can be used to control insect pests that eat food as well as clothing!

An extensive reference on the use insect traps of all kinds for a large variety of applications is found at <http://www.insectslimited.com/history-of-pheromones.php>. It also includes a history of pheromones.

**More sites on the life of ants**

In case students have not seen the life activities of colonies of different ants, their exceptional physical strength and energy reserves, refer to the hour-long program from National Geographic, <http://www.youtube.com/watch?v=55tXhnlZoOg>.

A second, short (3 minute), but very informative video shows the behavior of ants concerning laying and following scent trails under lab conditions where the evidence is clearly documented. Refer to the Web site <http://blog.wildaboutants.com/2010/06/27/questions-about-ant-pheromones/>. There is also printed information about various aspects of an ant’s anatomy and the function of its various appendages.

A third article about determining the specificity of odor detection in desert ants is found at <http://blogs.scientificamerican.com/thoughtful-animal/2011/06/23/nosejobs_for_ants/>. This might be a useful article for students to read because of how the experiment was set up, what data was collected and, most importantly, what questions were answered from the data.

**More sites on biological control of insects using pheromones and bacteria**

This site provides the story behind the gypsy moth invasion and control methods, including the *Bacillus thuringiensis* as well as pheromone-based traps. This is a commercial site but provides useful information about various methods to control a variety of insects, as well as the gypsy moth. (<http://bugspray.com/article/gypsymoths.html#gypsy-moth-control-traps>)

**More sites on** **the chemical basis for detecting odors**

For basic information on how an odor detected by an insect becomes neural information, refer to this Web site: <http://insects.about.com/od/behaviorcommunication/f/how_insects_smell.htm>.

A related Web site concerning the different ways by which insects either attract or find a mate is found at <http://insects.about.com/od/matingreproduction/p/findamate.htmb>.

Finally, for a discussion about how insects taste their food or their prey, (which, neurologically, is related to smell), consult the final Web site in this series, from About.com, at <http://insects.about.com/od/behaviorcommunication/f/how-insects-taste.htm>.

**More sites on** **current thinking about the existence of human pheromones**

This site from the highly respected and world famous Monell Chemical Senses Center (Philadelphia, PA) for basic research into taste and smell details the proceedings of a 2003 seminar on the state of human pheromone research. View this comprehensive study at <http://www.monell.org/images/uploads/Monell_Spring03.pdf>.

A balanced review of both the history of the search for human pheromones and the present debate about the very existence of human pheromones from several scientific quarters is found at <http://www.apa.org/monitor/oct02/pheromones.aspx>. A related reference from the same professional organization, the American Psychological Association, lays out a newer definition of a human pheromone that delineates four subcategories under the term pheromone. (<http://www.apa.org/monitor/oct02/othername.aspx>)

A second article on the current state of affairs about human pheromones from *Scientific American* is found at <http://www.scientificamerican.com/article/are-human-pheromones-real/>. The article tries to present a balanced and non-anecdotal basis for accepting or rejecting claims about the existence of human pheromones and their actions.

A Web site from Macalester University looks at pheromones in a comprehensive way, including the issue of the existence of human pheromones. It can be found at <http://www.macalester.edu/psychology/whathap/UBNRP/pheromone10/pheromones%20intro.html>. An interesting section of this reference includes the evolutionary reasons for pheromones—what are the benefits for possessing pheromones, biologically speaking.

**More sites on** **moth behavior related to finding food, mates and avoiding predators—it’s not just pheromones**

**T**he American Museum of Natural History provides a blog that describes a number of interesting tools, including sight, used by moths to find food and mates, as well as to avoid becoming food for other predators, such as bats! The design and coloration of moth wings are integral to communication as well as protection. Refer to <http://www.amnh.org/explore/news-blogs/news-posts/happy-national-moth-week>.