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**February 2015 Teacher's Guide for**

***Fermentable Foods: Trouble in Your Diet***

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# About the Guide

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Articles from past issues of *ChemMatters* can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013.

The *ChemMatters* DVD also includes Article, Title and Keyword Indexes that covers all issues from February 1983 to April 2013.

The *ChemMatters* DVD 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

* 1. What is meant by the term “macronutrients”?
  2. How are gluten and celiac disease related?
  3. What is the connection between irritable bowel syndrome and FODMAP?
  4. What is the difference between irritable bowel syndrome and celiac disease?
  5. Oligosaccharides are classified as a type of carbohydrate. What are their chemical characteristics?
  6. What happens to oligosaccharides made from glucose subunits when they reach the small intestine?
  7. What happens when oligosaccharides made from the sugars galactose or fructose reach the small intestine, compared with those oligosaccharides made from glucose subunits?
  8. What sugar is produced when amylase breaks down the disaccharide maltose?
  9. What are the sugar components of the disaccharide lactose, compared with those found in maltose?
  10. How do undigested sugars produce a bloated feeling as well as diarrhea in the intestine?
  11. Why do people with irritable bowel syndrome differ in terms of what sugars produce their condition?
  12. Explain the difference between celiac disease and FODMAP intolerance.
  13. What does the “F” in FODMAPs stand for?

# Answers to Student Questions

* + 1. **What is meant by the term “macronutrients”?**

*Macronutrients refer to organic compounds that you need in large quantities to store energy.*

* + 1. **How are gluten and celiac disease related?**

*Gluten, which is a group of proteins found in many grains, can cause celiac disease in some people.*

* + 1. **What is the connection between irritable bowel syndrome and FODMAP?**

*Irritable bowel syndrome can be caused by foods that contain a range of carbohydrates (sugars) that are represented by the letters in the FODMAP acronym. Sugars included are* ***F****ermentable* ***O****ligosaccharides,* ***D****isaccharides,* ***M****onosaccharides,* ***a****nd* ***P****olyols*

* + 1. **What is the difference between irritable bowel syndrome and celiac disease?**

*Irritable bowel syndrome is due to a person’s intolerance for certain FODMAPs that are consumed. Celiac disease is classified as an immunological disease, which means that a person’s immune system reacts to a foreign substance such as gluten. It is the same type of reaction associated with allergies.*

* + 1. **Oligosaccharides are classified as a type of carbohydrate. What are their chemical characteristics?**

*They are organic compounds which contain carbon as well as hydrogen and oxygen in a 2:1 ratio, as in water. They are made up of simple sugars (monosaccharides) which are joined together to form chains. Oligosaccharides are small molecules containing between 3 and 10 monosaccharides.*

* + 1. **What happens to oligosaccharides made from glucose subunits when they reach the small intestine?**

*In the small intestine, an enzyme called pancreatic amylase chemically breaks apart the bonds connecting any glucose subunits in the oligosaccharides, resulting in individual glucose molecules.*

* + 1. **What happens when oligosaccharides made from the sugars galactose or fructose reach the small intestine compared with those oligosaccharides made from glucose subunits?**

*Compared with glucose-based oligosaccharides, those made with galactose or fructose cannot be broken apart into smaller units by amylase. Rather there are other enzymes that can break up these types of oligosaccharides. However, people differ in terms of how much of these oligosaccharides they can handle—from large, to modest, to almost nothing at all. Any unreacted or undigested oligosaccharides move into the large intestine where they can cause bloating and diarrhea.*

* + 1. **What sugar is produced when amylase breaks down the disaccharide maltose?**

*The maltose is broken down into two glucose units.*

* + 1. **What are the sugar components of the disaccharide lactose, compared with those found in maltose?**

*The two sugar units of lactose are glucose and galactose, whereas maltose is made up of two glucose units.*

* + 1. **How do undigested sugars produce a bloated feeling as well as diarrhea in the intestine?**

*These undigested sugars contribute to a fermentation process through bacterial action. Various gases are produced which makes for a bloated feeling (an expanding “balloon”!).   
In addition, the sugars draw in water from the cells that line the intestinal wall, making the contents of the intestine (the stool) watery. And you have diarrhea!*

* + 1. **Why do people with irritable bowel syndrome differ in terms of what sugars produce their condition?**
    2. **Explain the difference between celiac disease and FODMAP intolerance.**

*Celiac disease is an immunological disease which means that a person’s immune system mistakenly identifies gluten in food as dangerous. This immune response damages the lining of the small intestine, producing severe digestive complications. FODMAP intolerance is not an autoimmune disease but rather a digestive disorder that produces an irritable bowel from the ingestion of certain sugars which are not fully digested which results in these sugars fermenting in the large intestine and producing abdominal pain, bloating and diarrhea.*

* + 1. **What does the F in FODMAPs stand for?**

*The F in FODMAPs stands for the process of fermentation, which is the culprit responsible for producing the irritability associated with bloating and diarrhea in irritable bowel syndrome.*

# Anticipation Guide

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:**  *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. Carbohydrates store energy. |
|  |  | 1. Gluten intolerance and FODMAPs sensitivity are related. |
|  |  | 1. Carbohydrates include sugars, starch, and cellulose. |
|  |  | 1. The main function of the small intestine is to absorb nutrients and minerals from food. |
|  |  | 1. The enzyme amylase works to break down all small sugars. |
|  |  | 1. Some common monosaccharides are glucose, galactose, and fructose. |
|  |  | 1. Only about 10% of adults are lactose-intolerant. |
|  |  | 1. Polyols are added to foods because they taste sweet. |
|  |  | 1. Fermentation in our small intestines produces hydrogen, carbon dioxide, and methane. |
|  |  | 1. Rice contains the compounds that people with FODMAP intolerance should avoid. |

# 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 and writing 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 Reading**:\
   1. ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
   2. ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
2. Links to **Common Core Standards for Writing**:
   1. 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).
   2. ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.
3. **Vocabulary** and **concepts** that are reinforced in this issue:
   1. Skepticism
   2. Amino acid
   3. Protein
   4. Enzyme
   5. Organic molecular structures
   6. Polymer
4. To help students engage with the text, ask students which article engaged them most and why, or what **questions** they still have about the articles. The Background Information in the *ChemMatters* Teacher’s Guide has suggestions for further research.

**Directions:** As you read the article, complete the graphic organizer below to explain how each of the substances represented in the acronym FODMAP contributes to digestive problems for people with FODMAP sensitivity.

|  |  |  |  |
| --- | --- | --- | --- |
| **Substance** | **Foods containing the problematic substance** | **Examples of the chemical** | **Chemical explanation of the problem** |
| **Oligosaccharides** |  |  |  |
| **Disaccharides** |  |  |  |
| **Monosaccharides** |  |  |  |
| **Polyols** |  |  |  |
| **How fermentation contributes to the problem** |  |  |  |

***Connect***: On the back of this paper, write a statement about whether you think you have some FODMAP sensitivity, providing evidence for your ideas.

# Background Information

**(teacher information)**

**More on** **the basics of FODMAPs**

The issue of people having digestive tract disorders that need be analyzed in terms of cause often fall into two main categories—celiac disease (the autoimmune condition with sensitivity to gluten) and the complex issue of irritable bowel syndrome (IBS) that could have multiple causes under that umbrella of FODMAPs. The *ChemMatters* article makes clear the fact that there is somewhat reliable testing that can be done to determine if a person is suffering from celiac disease. But when it comes to determining what specific irritants in FODMAPs might be causing an irritable bowel, the sorting out of possible culprits becomes more difficult.

In our society these days, there are many people who are into gluten-free diets even though they do not have celiac disease. It is all the rage. The number of people who have celiac disease is less than 1% of the population. But recent research has shown that some people with irritable bowel syndrome are sensitive to gluten even though this is not celiac disease sensitivity. Some people would like to label this condition wheat intolerance rather than non-celiac gluten sensitivity. At the same time, it may not really be the gluten in the wheat, but rather one specific sugar category—the fructans.

The other issue about people feeling better when they cut out gluten may be the victims of the *nocebo* effect, which means that when they believe something is making them sick, it causes the sickness to happen! There are also recent studies that suggest again that the mental influences the physical. In a recent study published in the journal *Gastroenterology*, people with self-diagnosed gluten sensitivity actually didn’t feel any better when they were put unknowingly on diets without gluten. But scanning many documents related to non-celiac gluten sensitivity reveals many people giving testimony to their eliminating a variety of non- digestive tract symptoms when they have avoided wheat in their diet. Some of the symptoms were associated with various neurological problems. There is one scientific paper (government) that seems to support this particular type of reaction. But there are also many anecdotal responses by people to what they think is a reaction to eating wheat, hence gluten. But again, there is more to wheat than gluten. Things seem to revert back to the complicated situation with FODMAPs, where any one food product can contain a plethora of chemicals that an individual might be allergic to in a non-celiac way.

One interesting concern that has been expressed about non-celiac individuals going on a “gluten-free” diet is that they are missing some necessary dietary requirements including folic acid, some B vitamins, as well as adequate amounts of fiber, calcium, iron and vitamin D. However, if a person is aware of these deficiencies, he or she can provide another source of these particular nutrients. Folic acid is found in leafy green vegetables. Broccoli and dried fruit are good sources of iron. B-12 is found in meat and dairy products. Nutritional yeast is also a good source of vitamin B-12 as well as some other B vitamins. But there is much evidence to suggest that a person who wants to be gluten free by eliminating wheat products would be better served by taking on the task of evaluating foods and their possible source of the FODMAPs which many authorities believe to be the source of irritable bowel syndrome (IBS). However, trying to determine which if any of the FODMAPs is causing IBS is best done through a dietician’s help—not necessarily a convenient thing to be doing. There are sources of information about diets that eliminate FODMAPs.

**More on** **FODMAPs diets**

Various academic groups are involved in experimenting with a variety of diets that control or eliminate various FODMAP’s. One dietary program that was developed in 2005 by researchers at Monash University in Australia is an intensive treatment and should be supervised by a registered dietician. The program takes a person between two and six weeks to eliminate and reintroduce foods, in order to identify what foods contain digestive triggers for setting off a person’s reaction to a particular sugar. The first step is to eliminate foods that are high in FODMAPs such as wheat, rye, onions and legumes. Then there is lactose which is found in soft cheese, yogurt and milk. Fructose is found in high-fructose corn syrup, honey and certain fruits like apples and pears. Sorbitol, found in artificial sweeteners is another FODMAP sugar to be evaluated. Fiber is also limited as it can create digestive troubles. The next step is to re-introduce these foods one at a time to see what sets off gastrointestinal turmoil.

While going through this process, it is important that a person meet other dietary nutrients that are listed as “nutrients of concern” mentioned in the previous paragraph above. They include fiber, as mentioned previously, potassium (4700 mg from food), calcium (1000 to 1300 mg), iron, vitamin B-12, and vitamin D. A person working through the FODMAPs evaluation needs to provide these supplements through other non-FODMAP sources. An all-inclusive vitamin supplement would do the trick, except for fiber.

Here’s a sample daily menu, provided by FODMAP expert Kate Scarlata:

**Breakfast**

High-Fiber Breakfast Porridge

1/9 cup old-fashioned oatmeal

4 teaspoons red quinoa

4 teaspoons oat bran

½ cup lactose-free milk

½ cup water

1/3 tablespoon chia seeds

1/3 tablespoon chopped walnuts

Dash of cinnamon

Dash of maple syrup

1/6 cup chopped strawberries

**Lunch**

Bibb Lettuce, Feta and Pecans with Dijon Dressing

¼ head Bibb lettuce

1/8 cup Feta cheese, crumbled

¼ tablespoon red wine vinegar

¼ teaspoons Dijon mustard

¼ chopped tomato

¾ tablespoon olive oil

Dash of sea salt

Dash of pepper

½ teaspoon fresh chives, chopped

1/8 cup pecans, toasted

Blueberry Kiwifruit Smoothie

¼ cup frozen blueberries

1 small kiwifruit, peeled

1/3 cup lactose-free vanilla yogurt

Ice as desired

**Dinner**

Maple Dijon Pork and Pineapple Kabobs

3 teaspoons maple syrup

3 teaspoons Dijon mustard

1/4 pound pork tenderloin

1/2 red pepper

1/8 fresh pineapple

1/4 zucchini

Baby Kale Salad with Simple Mustardy Dressing Dash sea salt

½ tablespoon red wine vinegar

1 teaspoon fresh chives, chopped

1 teaspoon Dijon mustard - best quality like Maille

1 ½ tablespoons olive oil

1 medium-size potato

Dessert

Frozen Banana Pop

1 peeled banana

1/8 cup nonfat vanilla Greek yogurt

1/8 cup finely chopped unsalted peanuts

1/2 tablespoon mini semi-sweet chocolate chips

(<http://health.usnews.com/best-diet/low-fodmap-diet/menu>)

**Nutrition**

Here’s a breakdown of the nutritional content of a typical day on a low FODMAP diet, alongside recommendations from the U.S. Government’s “2010 Dietary Guidelines for Americans”. Diet figures were calculated by *U.S. News and World Report*, using ESHA Food Processor software.

| **Low FODMAP Diet** | | **Recommended** | |
| --- | --- | --- | --- |
| Calories | 1,417 | Women | Men |
| 21-25: 2,000 26-50: 1,800 51+: 1,600 | 21-40: 2,400 41-60: 2,200 61+: 2,000 |
| Total Fat | 44% | 20%-35% | |
| Saturated | 8% | Less than 10% | |
| Trans | 0% | N/A | |
| Total Carbohydrates | 46% | 45%-65% | |
| Sugars (total except as noted) | 18% | N/A | |
| Fiber | 24 g. | Women | Men |
| 19-30: 28 g. 31-50: 25 g. 51+: 22 g. | 19-30: 34 g. 31-50: 31 g. 51+: 28 g. |
| Protein | 15% | 10%-35% | |
| Sodium | 1,693 mg. | Under 2,300 mg., under 1,500 mg. for 51+ | |
| Potassium | 3,456 mg. | At least 4,700 mg. | |
| Calcium | 607.5 mg. | 19-50: 1,000 mg. 51+: 1,200 mg. | |
| Vitamin B-12 | 1.5 mcg. | 2.4 mcg. | |
| Vitamin D | 1.5 mcg. | 15 mcg. | |

Recommendations apply to adults 19 and older except as noted. Recommended calories assume a sedentary lifestyle. g.: grams. mg.: milligrams. mcg.: micrograms. Because of rounding, protein, fat and carbohydrate content may not add up to 100 percent.

(<http://health.usnews.com/best-diet/low-fodmap-diet/menu>)

Monash University maintains a Web site ([www.med.monash.edu/cxes/gastro/fodmap/](http://www.med.monash.edu/cxes/gastro/fodmap/)) dealing with the Low FODMAP diet for Irritable Bowel Syndrome. Available from this Web site are a number of resources and products, including smart phone apps, a blog, and frequently asked questions (FAQ).

Refer to the following Web sites for more recipes from Kate Scarlata, author of *The Complete Idiot’s Guide to Eating Well with IBS*. (<http://blog.katescarlata.com/fodmaps/> and <http://blog.katescarlata.com/low-fodmap-recipes/>)

**More on** **digestion in the gut—enzymes and bacteria**

The basic problem created by FODMAPs in the digestive system is incomplete break-down of the various sugars of FODMAPs, in order to be absorbed into the blood stream from the small and large intestine. This is due primarily because of inadequate enzyme production and utilization. Some of this is genetic, as in the case of lactose intolerance. So with inadequate absorption comes the bacterial fermentation of the sugar residues in the gut. The bacterial flora is an important and necessary component of the gut. For some people with certain infections that do not respond to antibiotics, the use of fecal bacteria has proved very effective. One particular infection from *Clostridium difficile* has a 90% cure rate when treated with fecal bacteria! The thought is not pleasant but the results are welcomed! The treatment is known as “fecal microbiota transplantation” (FMT).

Bacterial fermentation in the gut is a basic and necessary process of digestion—it is a positive rather than a negative. By means of fermentation, gastrointestinal microbes break down nutrients that cannot be hydrolyzed by mammalian enzymes. Certain bacteria break down complex carbohydrates to meet as much as 5-10% of our daily energy requirements. Without that particular fermentation, a substantial amount of energy would be lost in feces. There is also fermentation that yields short-chain fatty acids (acetic, propionic, and butyric acids) from protein; these are important because they facilitate the uptake of water and electrolytes, reducing the osmotic effect of unabsorbed carbohydrate molecules, which otherwise would produce the diarrhea associated with FODMAPs.

Some studies have shown that the ingestion of fructo-oligosaccharides increase the fecal counts of endogenous bifidobacteria by a factor of 10. You may be familiar with the term “probiotics”, particularly associated with yogurt. Yogurt contains some of these bifidobacteria, including *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. This large class of bacteria (the “bifido” refers to their Y-shape) is considered very beneficial to the health of the gut, though the specifics of their multiple functions are lacking in many instances—it is more deduction by what happens if the flora are absent!

Some Bifidobacterium strains are considered as important probiotics and used in the food industry. Different species and/or strains of bifidobacteria may exert a range of beneficial health effects, including the regulation of intestinal microbial homeostasis, the inhibition of pathogens and harmful bacteria that colonize and/or infect the gut mucosa, the modulation of local and systemic immune responses, the repression of procarcinogenic enzymatic activities within the microbiota, the production of vitamins, and the bioconversion of a number of dietary compounds into bioactive molecules.

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

**More on the sugars of FODMAP**

The different categories of sugars found in FODMAP that may create problems for people whose digestive systems cannot adequately process them have some interesting properties.

**Oligosaccharides: (includes disaccharides and polysaccharides)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Oligo-saccharide** | **Description** | **Component mono-saccharides** | **Glycosidic linkage** |
| Sucrose | Common table sugar | Glucose and fructose | Glucose-1α-2-fructose |
| Maltose | Product of starch hydrolysis | Two glucose units | glucose-1α-4-glucose |
| Trehalose | Found in fungi | Two glucose units | glucose-1α-1-glucose |
| Lactose | Main sugar in milk | Galactose and glucose | galactose-1β-4-glucose |
| Meibiose | Found in legumes | Galactose and glucose | galactose-1α-6-glucose |
| Cellibiose | Building block of cellulose | Two glucose units | glucose-1β-4-glucose |
| Laltotriose | Produced by alpha amylase (common enzyme in human saliva) on amylose in starch | Three glucose units | α-1,4-glycosidic bonds |
| Raffinose | Found in beans and vegetables like cabbage, Brussels sprouts, broccoli, asparagus | Glucose, galactose and fructose | 1α-6-glycosidic linkage |
| Melibiose | Produced by hydrolysis of raffinose | Galactose and glucose residue | β(1,6) glycosidic bond |
| Maltotriose | Can be fermented by both algae and lager yeast | Three glucose units | α(1,4) glycosidic linkage |
| Maltotetralose | Cannot be fermented by algae or lager yeast | Four glucose units | α(1,4) glycosidic linkage |
| Malto-pentalose | Cannot be fermented by algae or larger yeast | Five glucose units | α(1,4) glycosidic linkage |

(<http://chemistry.tutorvista.com/organic-chemistry/oligosaccharides.html>)

Oligosaccharides are commonly found on the plasma membrane of animal cells and play a role in cell-cell recognition. Among other processes where recognition is important is in mammalian fertilization where the egg membrane verifies the “legitimacy” of a sperm cell (i.e., that it is of the same species).

Stachyose, a galactose-oligosaccharide, contains three different sugars (2 galactose molecules, one glucose and one fructose molecule). It is an active supporter of bacterial growth in the gut. Because this sugar is not readily absorbed in the large intestine and remains in the lumen, certain bacteria in the gut digest this sugar for its nutrients. In turn, the bacteria are able to multiply, keeping a good colony of these microbes active in the digestion process. These particular bacteria that flourish with stachyose have also been found to destroy two types of harmful bacteria—those that cause bacterial pneumonia, and a species that produces vaginal infections. The mechanism of their action on these harmful bacteria is not known.

Fructans, although listed as a potential FODMAP sugar that can cause problems in the gut of some people, is actually a dietary constituent in food that has been shown to have a number of protective properties in the body. A series of studies demonstrate that inulin-type fructans (plant dietary fiber that stores carbohydrates) modulate the secretion of gastrointestinal peptides involved in appetite regulation as well as lipid metabolism. Moreover, a large number of animal studies and preliminary human data show that inulin-type fructans reduce the risk of colon carcinogenesis and improve the management of inflammatory bowel diseases.

Another fructan, oligofructose, works in conjunction with the inulin-type fructan as a dietary fiber, affecting gut microflora by increasing health-promoting bacteria and reducing potentially harmful species. This is called a pre-biotic function (This term, along with probiotic, is bandied about when people are promoting healthy diets.) This oligofructose and inulin combination also induces changes in the colon’s epithelium that are constructive, rather than destructive as occurred in celiac disease and prolonged conditions of IBS from fermentation of FODMAPs.

**Polyols:**

The sugar alcohols include sorbitol, mannitol, and xylitol. Mannitol is a sugar which, when ingested, does not raise blood glucose levels as much as sucrose. Therefore it is a preferred sugar for diabetics to use. Mannitol is one of the most abundant energy- and carbon-storage molecules in nature, produced by a plethora of organisms, including bacteria, yeasts, fungi, algae, lichens, and many plants. Another unique application of mannitol is to reduce acutely-raised intracranial pressure (e.g., brain trauma), until other procedures can be applied.

Xylitol is made either from corn cobs or tree bark! The preferred source is corn cobs since they are a discard from corn harvest. If taken from trees, it means the end of the tree—

not an environmentally friendly process! The corn cob source uses a natural ion-exchange interaction of hydrogen, hydrochloric acid, and steam. The waste water from this process is used for mushroom farming adjacent to the factory itself, and the pulp is used for fuel. Xylitol has a third of the calories of sucrose which makes it a good sugar for diabetics. Interestingly enough, xylitol is toxic to dogs, should they come across some candy containing xylitol.

Sorbitol intolerance is very much genetically-based. Some statistics that relate to this principle are the following:

**Frequency in population:**

* More than 50% of adults experience significant symptoms following ingestion of more than 10 g.
* Intolerance appears more common in Asians and American blacks than in whites.
* Overall, 30 to 75% of adults malabsorbed 10g of sorbitol.
* Present in up to 70% of patients with Irritable Bowel Syndrome

(<http://www.foodintolerances.org/food-intolerances-sorbitol.aspx>)

**More on lactose intolerance**

Lactose intolerance comes in varying degrees of severity—it isn’t all or nothing. The lactase enzyme is produced in the cells of the epithelium that line the small intestine and is secreted into the lumen of the intestine. Here it catalyzes the breakdown of the lactose disaccharide into its two component sugars, glucose and galactose. Reduced enzyme production means the undigested lactose sugars are not absorbed and become fodder for bacterial fermentation with all the problems associated with irritable bowel syndrome (IBS).

Three reasons people may develop lactose intolerance are:

* The normal result of aging, which seems to occur universally! There is the thought that if you reduce or cease your intake of milk-derived products, which may be part of getting older, that your lactase production decreases. It lacks stimulus. This also suggests that you can stimulate the production of lactase by regularly using milk and milk products, gradually increasing the amount consumed so as not to set off IBS too soon.
* Result of disease or injury (secondary lactose intolerance). Such disease conditions include celiac disease, gastroenteritis, and inflammatory bowel disease such as Crohn’s disease. Surgery to the bowel can temporary interfere with lactase production.
* Congenital lactose intolerance—you are born with the condition.

Here are the factors that can make you or your child more prone to lactose intolerance, according to the Mayo Clinic**:**

* **Increasing age**. Lactose intolerance becomes more common as you age — the condition is uncommon in babies and young children.
* **Ethnicity**. Lactose intolerance is most common in black, Asian, Hispanic and American Indian people.
* **Premature birth**. Infants born prematurely may have reduced levels of lactase because this enzyme increases in the fetus late in the third trimester.
* **Diseases affecting the small intestine.** Small intestine problems that can cause lactose intolerance include bacterial overgrowth, celiac disease and Crohn's disease.
* **Certain cancer treatments.** If you have received radiation therapy for cancer in your abdomen or have intestinal complications from chemotherapy, you have an increased risk of lactose intolerance.

(<http://www.mayoclinic.org/diseases-conditions/lactose-intolerance/basics/risk-factors/con-20027906> )

The condition of lactose intolerance can be determined by several different test procedures:

* Lactose tolerance test involves drinking a liquid with high levels of lactose. Two hours after drinking the liquid, a blood sample is analyzed for the amount of glucose. Low amounts of glucose means the body is not properly digesting and absorbing the lactose-laden drink.
* Hydrogen breath test measures how much hydrogen is given off in your breath from the digestion process. Normally very little hydrogen is detectable. If lactose is not being digested, then it is fermented in the colon which produces both hydrogen and methane gases, both of which can be detected in the exhaled breath.
* Stool acidity test is done with infants and children if the other tests above cannot be done. Having been given a lactose drink, a child has a stool sample tested for lactic acid from the undigested lactose.

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Organic**—Almost all food is organic in the true sense of the word (not the popular term for food grown without pesticides) (i.e., it contains molecules with carbon in them). The sugars in FODMAPs are allorganic molecules.
2. **Carbohydrates**—It is the sugars in FODMAPS that are potential sources of energy for bacteria that create fermentation in the large intestine, producing the symptoms of irritable bowel syndrome (IBS).
3. **Enzymes**—These organic molecules are crucial to the chemical digestion of many FODMAP sugars, acting as catalysts.
4. **Alcohols**—Some of the FODMAPs are sugars with the molecular structure of an alcohol which means the presence of the –OH group(s).
5. **Proteins**—A category of large organic molecules, constructed from amino acids which produce a large variety of molecules.
6. **Osmosis**—This is a physical process in which water concentration is lower on one side of a cell membrane than the other side, producing a net movement of water toward the side of lower water concentration. Diarrhea in IBS is because the high concentration of undigested sugars in the gut means less water than in the cells that line the gut, resulting in a net movement of water into the gut, producing diarrhea.
7. **Rates of Reactions**—Rates of reactions in metabolism, in particular those associated with the breakdown of sugars, are dependent on enzymes.
8. **Fermentation**—This anaerobic process used by bacteria in the large intestine for producing biological energy is responsible for the bloating condition associated with IBS.
9. **Digestion**—Chemical digestion of food is the breakdown of carbohydrates, proteins, and lipids into smaller molecules that can pass through cell membranes and is often under enzymatic control.

# Possible Student Misconceptions

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

1. **“If you are lactose intolerant, you cannot drink milk or eat ice cream.”** *First, the condition of lactose intolerance varies in severity for different people. Some people do not suffer from the symptoms if they consume small amounts of a product containing lactose. Second, people can take pills with the lactase enzyme before eating ice cream or drinking whole milk. Otherwise, a person can purchase lactose-free milk and ice cream.*
2. **“If you develop diarrhea from eating food, simply take anti-diarrhea medicine.”** *You can take the medicine but it will not really treat the cause of the diarrhea. In fact, if the diarrhea is caused by bacteria or protozoans, it is better NOT to take the medicine but rather to allow the diarrheal condition to essentially flush the organism from the intestinal tract. This is also true for diarrhea caused by certain foods which need to be flushed by the diarrhea. Medical advice is to let the diarrhea run its course over a period of two or three days without taking any “medicine”. Eating certain foods (BRAT diet—bananas, rice, apples and toast) and keeping adequate hydration are important while suffering from diarrhea. If a person experiences a painful condition, or there is evidence of blood in the stool, or there is a fever, then medical evaluation is needed.*

For the teacher: *Some antidiarrheal medicine works on the nervous system in the intestinal area to slow down over-active neuronal responses that evacuate the gut lumen before enough water is absorbed and the residue is expelled. In the case where the diarrhea is associated with FODMAP problems, it is not so much a nerve issue but simply one of an excess amount of water in the gut (due to fermented sugars that draw in water by osmosis). The gut responds by evacuating the content volume, a watery product.*

# Anticipating Student Questions

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

1. **“If you start a low *FODMAP diet, do you have to be on that diet forever?*”** *Once you have identified the offending FODMAP sugars in specific food sources, you can then eat whatever is desired, avoiding those foods that you have determined to be a source of irritable bowel syndrome.*
2. **“Is a low FODMAP diet safe for vegetarians and vegans?”** *It is necessary that people who try a low FODMAP diet make sure they are getting enough protein in their diet, which can come from selected vegetables. Lacto-ovo vegetarians can meet their protein needs through eggs, hard cheeses, and lactose-free milk products. For those who do not eat eggs and dairy products, low-FODMAP nuts, seeds, milk substitutes and grains can provide some protein. Tofu, tempeh and seitan (non-celiacs only) are also allowed in all phases of the diet. Last, small amounts of well-rinsed canned lentils and chick peas have been shown to be low-FODMAP.*
3. **“How do you handle foods that do not show up on a low FODMAP diet list?”** *Keep in mind that FODMAPs are carbohydrates. Therefore, there are no FODMAPs in foods comprised of protein or fat. A person on the low-FODMAP diet can eat these foods freely. When in doubt about a food that does not show up on FODMAP food lists, one can make a guess based on the FODMAP content of similar foods.*
4. **“Is the low FODMAP diet too complicated for the average person?”** *It is recommended that people who want to succeed with a low FODMAP diet (determining what foods create a problem because of a particular FODMAP sugar), should really engage a trained nutritionist familiar with FODMAP diets and protocol.*
5. **“Are there non-food items that we consume that may contain FODMAPs?”** *In fact there are things such as medications, supplements and probiotics that may contain some of the FODMAPs. As they say, read the labels carefully or consult the medical literature or a pharmacist. Probiotics should be avoided until your elimination procedures indicate that a particular probiotic is not creating problems associated with FODMAPs!*
6. **“What fruit can I eat on a FODMAP elimination diet?”** *Fruit is the most limited group to deal with in an elimination diet.* *Fruits with more fructose than glucose are not allowed on the basic diet. Fruits with a large quantity of polyols are not allowed on the basic diet. Fruits containing fructans are not allowed on the basic diet. Fruits are allowed if the fructose and glucose in the fruit are balanced (less than .5 grams excess/100 grams of food), the total fructose per serving is not too high, and they are low in polyols and fructans.*

## In-Class Activities

**(lesson ideas, including labs & demonstrations)**

1. A lab activity that works with the amylase enzyme is found at <http://www.nuffieldfoundation.org/practical-biology/investigating-effect-ph-amylase-activity>. Though this activity deals only with the variable of pH, it does provide the prep instructions for making amylase solution (rather than having students use their saliva) and testing solutions.  
   For testing other variables including temperature effects and concentration of substrate, refer to this reference. (<http://www.odinity.com/effects-temperature-ph-enzyme-concentration-amylase/>) which includes graphed results, though students could do their own graphing. Refer to the previous Nuffield lab activity (#1) for preparing the amylase solution. A reference for an amylase experiment with good background information that could be used with either of the previous labs referred to above can be found at <http://intro.bio.umb.edu/OLLM/111F98/pdfs/Amylase.pdf>.
2. A basic lactase experiment using milk is found at <http://www.learnnc.org/lp/pages/3398>. A second lab activity that is very comprehensive is found at <http://www.towson.edu/cse/beop/mdll/Lab_Activities/looking_into_lactase_mdll_teacher_manual.pdf>. Although this lab refers to kits that are available to teachers in Maryland, the complete description of materials, their use, a schedule for conducting the activity and background material are easily obtained from the printout. There is a teacher’s guide as well.
3. This is a simulation of lactase activity with the ability to manipulate the variables (temperature, pH, substrate concentration) to show the effects on the rate of digestion through graphical analysis: <http://forio.com/simulate/jdarkow/lactase-enzyme-actions-with-data-analysis/run/>.
4. A comprehensive lab on fermentation with several fermentation activities resulting in different products is found at <http://www.accessexcellence.org/AE/AEC/AEF/1995/kolb_biotech.php>.
5. Another lab activity dealing with the fermentation of apple cider is found at <http://www.somersetmade.co.uk/oldscrump/makingcider.php>.  
   This is a fun page describing the principle stages of cider fermentation. Details are given on the following subjects: an overview of the cider making process, a discussion of the characteristics of the apple juice, the microbiology of the process, the changes in the composition of the cider during fermentation, and finally a description of how to make your own cider. A great classroom activity!
6. If your school has Vernier hardware and software, it can be used for a yeast fermentation lab exercise that investigates the rate of fermentation by yeast using different sugar substrates. This lab will determine the specificity of the enzymes in yeast for metabolizing different sugars. Refer to <http://www.vernier.com/files/sample_labs/BWV-12B-COMP-sugar_fermentation.pdf>.
7. An open lab version of this investigation into yeast fermentation is found at <http://www.vernier.com/files/sample_labs/BIO-I-10-sugar_metabolism_with_yeast.pdf>, which requires the students to do some of their own research into fermentation and devise lab procedures for investigating the process.
8. Another Vernier lab exercise deals with the action of lactase, determining the sugar product with glucose testing strips. A second part of the lab is to use yeast activity to produce CO2 from the enzyme action on several different sugars, including lactose, glucose, and galactose. Refer to two Web sites, one for the introduction to the lab activity and a second containing the lab activity details. It is recommended that you have the Vernier lab manual for experiments in both biology and chemistry, as well as the software to operate their LabPro and LabQuest data collector hardware. See <http://www.vernier.com/experiments/bwv/24a/lactase_action/> and <http://www.vernier.com/files/sample_labs/BWV-24A-COMP-lactase_action_CO2.pdf>.
9. Using a product called “Beano”, students can test the effectiveness of this gas eliminator which contains the enzyme alpha-galactosidase which breaks down the complex sugars found in gas-producing foods. For a description of the lab procedure, refer to the Web site <http://www.accessexcellence.org/AE/ATG/data/released/0167-JudyBrown/>. This lab is well written and contains background information. An information reference (Q & A’s) by the manufacturer of Beano is found at <http://www.beanogas.com/faqs/>.

# Out-of-class Activities and Projects

**(student research, class projects)**

1. Students could research the chemistry (and microbiology) behind the process of converting milk into yogurt, then experiment with making yogurt. The process involves pH changes, physical changes that are related to chemical changes brought on by bacterial action on lactose and other sugars which students should observe and note, connecting to background information they obtained by “literature” searches (internet searches). The *ChemMatters* article cited below (“Say Cheese”) provides a good description of the changes in milk at the molecular level. A comprehensive lab activity on the subject can be found at <http://www.westminster.edu/acad/sim/documents/SMakingYogurt.pdf>.

# 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.**

This *ChemMatters* article explains the role of lactose in cheese making. Interesting details about the world of cheese can be found here, including the composition of a number of the more common cheeses and how they are produced. Lactose is a crucial component of the mix that is converted into cheese by bacterial action on the lactose. The article also includes a recipe for making soft cheese from whole milk, should students want to try this under adult supervision. (Baxter R, Say Cheese. *ChemMatters* **1995**, *13* (1), pp 4–7.)

For some background on how the digestive system produces a variety of gases, most of which are odorless, consult the *ChemMatters* article on flatus, listed below. In the article there is a discussion about one particular gas, methane, which is produced by certain ruminant animals (sheep, goats, cows) and emitted into the atmosphere where it acts as a potent greenhouse gas. There is also the production of gas in people who are lactose intolerance, lactose being one of the FODMAP sugars. The Teacher’s Guide that accompanies the magazine provides additional background material and suggestions for activities related to the topic of gases in general. (Vanderborght, C. Flatus: Chemistry in the Wind. *ChemMatters* **2003,** *21* (1) pp 11–13)

For a complete description of the digestive process, including mechanical as well as chemical digestion (the role of specific enzymes and their pH requirements), see the *ChemMatters* article, Rohrig, B. 24 Hours: Your Food on the Move. *ChemMatters* **2012**, *30* (1), pp 6–8. The Teacher’s Guide for this article includes ideas for a number of in-class activities with appropriate Web sites for the details, plus additional background information.

A *ChemMatters* article that provides the details behind celiac disease, including information about the causative agent, gluten, is found here: Hill, M. Attack of the Gluten. *ChemMatters* **2013,** *30* (1), pp 9–11. Also found in this article is a simple activity of making bread in order to “feel” the role of gluten in providing “bulk” to the bread mixture.

The October 2013 Teacher’s Guide accompanying the gluten article above provides additional background information on celiac disease and some of the chemistry behind the change in the physical state of gluten as it is manipulated when kneading the bread mix of flour, water, and yeast. There is also a number of activities tied in with bread making, including the effect of yeast under different conditions of temperature.

An article from *ChemMatters* concerning lactose tolerance is found in the April 2013 issue. This two page article presents the specifics of the chemistry associated with lactose and the issues for people who cannot digest this milk sugar. Refer to: Rohrig, B. Not Milk? Living with Lactose Intolerance. *ChemMatters* **2013**, *31* (2), pp 18–19. There is also a Teacher’s Guide to complement the article with useful references and background information.

The December 2013 Teacher’s Guide that accompanies the lactose intolerance article above provides extensive background information along with suggested in-class activities related to lactose and the enzyme lactase.

# Web Sites for Additional Information

**(Web-based information sources)**

**More sites on FODMAP diets**

The following Web site from Stanford University provides a lot of useful information on determining if a food is on the low or high end of FODMAP. There is a handy reference chart for the two categories of low and high FODMAP sources. Refer to <https://stanfordhealthcare.org/content/dam/SHC/for-patients-component/programs-services/clinical-nutrition-services/docs/pdf-lowfodmapdiet.pdf>.

A second Web site that is also rich in details about the types of food to avoid and those that are safe in terms of FODMAPs is found at <http://www.ibsdiets.org/fodmap-diet/fodmap-food-list/>. This is a very complete reference for those who need to plan meals that contain minimal FODMAPs.

**More sites on** **determining if an elimination diet for IBS is working**

For those who need to go through the process of determining what foods contain FODMAPs by the elimination process, the following Web site provides guidance: <http://www.sharecare.com/health/irritable-bowel-syndrome-ibs-treatment/how-know-fodmap-working-ibs>. People are advised that the process is best done with the help of a registered dietician.

**More sites on** **the genetics of lactose tolerance/intolerance**

A series of paper activities dealing with the genetics of lactose tolerance/intolerance is found at <http://www.hhmi.org/biointeractive/pedigrees-and-inheritance-lactose-intolerance>. This site from the Howard Hughes Medical Institute Includes teacher materials and student handouts for a number of activities including:

* “Pedigrees and the Inheritance of Lactose Intolerance”: Students explore the effects of different diets on the evolution of an enzyme that breaks down starch.
* “Diet and the Evolution of Salivary Amylase”: Students explore the genetic changes associated with lactose tolerance/intolerance and how the trait is inherited in families.
* “Milk—How Sweet Is It?” Students simulate a lactose tolerance test.
* “Got Lactase? Blood Glucose Data Analysis”: Students interpret the results of two different tests for lactase persistence.
* “Lactose Intolerance: Fact or Fiction”: Students evaluate and discuss several statements about lactose intolerance and evolution before and after watching a film.
* “The Making of the Fittest: Got Lactase? The Co-evolution of Genes and Culture” (Short Film)
* “Film Guides: Got Lactase? The Co-evolution of Genes and Culture”

A related article on “How did milk help found Western civilization?” is available at <http://www.slate.com/articles/health_and_science/human_evolution/2012/10/evolution_of_lactose_tolerance_why_do_humans_keep_drinking_milk.html>. This is a short essay that may appeal to some students. It makes for interesting reading.

**More sites on the history and uses of fermentation**

A readable document for students about the history of fermentation and its uses, old and new, can be found at <http://www.accessexcellence.org/LC/SS/ferm_background.php>. A second reference on the history of the development of wheat cultivation—the increase in gluten from plant breeding and how it became the source of gluten intolerance—might also prove enlightening to students who, for the most part, are far removed from agricultural practices. Refer to <http://www.scientificamerican.com/article/gluten-sensitivity-may-be-a-misnomer-for-distinct-illnesses-to-various-wheat-proteins/>.

**More sites on controlling or minimizing irritable bowel syndrome**

Research into explaining the benefits of eating yogurt to reduce or eliminate various digestive tract irritations and disturbances from things like FODMAPS is described in an abstract from the *American Journal of Clinical Nutrition* which again suggests that the cultivation of the right bacterial flora and fauna in the gut is central to alleviating or even preventing various intestinal “disturbances”. Refer to <http://ajcn.nutrition.org/content/80/2/245.full> for the abstract as well as the complete scientific report which describes the attempt to scientifically discern what is behind apparent anecdotal evidence for the amelioration of different irritable bowel conditions through eating yogurt.

**More sites on** **the clinical procedures for the hydrogen test**

This site, <http://www.gastrolab.com.au/hydrogen-methane-breath-testing-at-gastrolab.html>, explains the basis for the exhaled breath tests and what is involved in the examination procedure itself when testing for fermentation of undigested sugars in the FODMAP group.

A related Web site that shows quantitative data (graphical) and its interpretation concerning the hydrogen/methane breath test is found at <http://www.food-intolerance-network.com/miscellaneous-further-info-for-patients/h2-test.html>. This could be used in class when appropriate for teaching graphing and interpretation skills in the curriculum.

**More sites on** **fructose metabolism and connections to IBS**

The sugar fructose remains a controversial sugar, particularly as found in high fructose corn syrup, with its metabolism usually taking place in the liver—which means it is processed as a fat rather than a sugar. This in turn may create problems with fat deposition. However, there is the issue of malabsorption of fructose which, in turn, can create the problems associated with FODMAPs and irritable bowel syndrome (IBS). Some ideas suggest that fructose with equal amounts of glucose can be absorbed through the intestine rather than remaining in the gut to create the IBS problem. A good discussion of this issue as well as the role of fructans is found at the Web site <http://www.foodsmatter.com/allergy_intolerance/fructose_intolerance/articles/fructose_good_bad_malabsorbed.html>.