

2015

Brewing Makes You Smarter

Joe Potter
Grand Valley State University

Follow this and additional works at: <https://scholarworks.gvsu.edu/honorsprojects>



Part of the [Food Science Commons](#)

ScholarWorks Citation

Potter, Joe, "Brewing Makes You Smarter" (2015). *Honors Projects*. 398.
<https://scholarworks.gvsu.edu/honorsprojects/398>

This Open Access is brought to you for free and open access by the Undergraduate Research and Creative Practice at ScholarWorks@GVSU. It has been accepted for inclusion in Honors Projects by an authorized administrator of ScholarWorks@GVSU. For more information, please contact scholarworks@gvsu.edu.



Joe Potter

Frederik Meijer Honors College Senior Project
Grand Valley State University
Winter 2015

Foreword

“I mean really, what’s the point? I’m not European, I don’t plan on being European, so who gives a crap if they’re socialists?” - Ferris Bueller, *Ferris Bueller’s Day Off* (1986)

“The best learning happens in real life, with real problems and real people, and not in classrooms.” - Charles Handy

How many times have you sat in a classroom, stared blankly ahead, considered what the instructor was saying, and asked yourself, “When am I ever going to use this?” As I think back on all the years I’ve spent in some sort of educational setting, I recall hearing this question muttered countless times from under the breath of classmates and friends (and honestly, from my own mouth on occasion). Granted, I heard it most in my middle and high school days: back then, the toxic combination of hormones, teenage angst, and the feeling that you’re still a long ways away from the real world makes it easy to question why the educational system is requiring that you learn the details of covalent bonding, the themes of *Hamlet*, or the rise and fall of an ancient Chinese dynasty.

But even after entering college, which we attend by choice in exchange for a good chunk of tuition, I continued to hear the question, and at times asked it myself. Don’t get me wrong, as the student of a liberal arts college (and a total trivia buff), I really do believe in the value of being a diversely educated, well-rounded human being. I typically enjoy learning about new things, even when it’s unlikely that the knowledge will ever be useful in my career or personal life. And I hardly think that anyone else would enroll in college if they didn’t (at least on some level) share these sentiments. Still, in the heat of a finals-week study session, as the panic sets in and the six-or-so coffees wear off, it can be easy to blurt out in frustration, “Why do I need to know this? When am I *ever* going to use this?”

Here’s my point: no matter how much you love learning merely for the sake of learning, at a certain point it becomes more rewarding to actually *use* what you’ve learned in the classroom for an application out in the real world. Whenever I have the opportunity to do so, I get a satisfied feeling that reaffirms the value of my education, thinking to myself, “I just applied my knowledge to solve a problem.” And I believe that the more moments you have like that, the more you internalize and fully understand the material which you’ve studied in school.

Unfortunately, it might be difficult to find such opportunities as an undergrad. Of course there are some ways, such as participating in research, or if you’re lucky, landing a lower-level job in your major field. However, those positions are likely to be limited, and still may only draw on a portion of your schooling. In my case, I found the opportunity to most fully utilize my education in a somewhat surprising place: beer.

Although many might not initially recognize it, beer is actually a tremendously important and sophisticated beverage, and there are some fantastic stories to be told behind

every glass of cold brew. Beer's frequently cited as the third most consumed drink in the world (behind water and tea) and it holds a significant place in the history and civilization of the human race. The production of alcoholic beverages (wine and spirits included) is scientifically rich, and the industry itself has been a driving force behind much of the research and discovery which laid the foundations for multiple areas of modern science.

My story as it pertains to beer began during my freshman year of college. I was enrolled in an Honors class that examined many aspects of the food we eat (e.g. where it comes from, how it's marketed and regulated, differences in food systems around the world, etc.). On one special occasion, a guest lecturer from the chemistry department gave a talk on homebrewing, followed by actually making a batch of beer with us. I harbor a strong "do-it-yourself" attitude instilled in me at a young age by my older brother; couple this with the intense appreciation for good beer shared by my father and sisters, and it's not surprising that homebrewing struck a chord with me. I was only eighteen at the time, and thus never actually got to taste the beer we made that day, but the event still had a profound and lasting impact.

Unlike some hobbies, homebrewing provides a tangible end product to be proud of, and it's a product that many people value. (Craft beer continues to gain popularity in the United States, holding an increasing percentage of national beer sales and with more breweries popping up all the time.) Being able to offer good, homemade beer to friends and family is, therefore, a very special and satisfying feeling. What's more, the high quality brew you can produce yourself can often be made for a fraction of the price you'd pay at a store or bar for a similar product (following a moderate initial investment for the necessary equipment). And even further, making good beer at home is relatively *easy*.

Tangible benefits aside, the other aspect of brewing that struck me almost immediately is the vast amount of science behind it. Disciplines such as general chemistry, organic chemistry, biology and biochemistry all play a role in crafting the perfect brew. In fact, many concepts directly involved in brewing are the very same concepts that are specifically emphasized in undergraduate courses of these disciplines. The extensive overlap of brewing science with my course studies, and the effect this has had on my academics, has been the biggest impact of beer on my life.

After being introduced to brewing, and beginning to notice the numerous beer-related concepts hidden within my curricula, my educational experience began to benefit greatly. Viewing my subsequent courses in the context of brewing kept me all the more curious and truly interested in the material. Because I could *use* what I was learning in the classroom for a relevant, real world application, I had more motivation to gain a complete understanding of that material. Additionally, employing the concepts in a hands-on experience helped me retain them better than any exam ever could. For those reasons, I simply learned the material better, and my performance on said exams reflected this. (These benefits of experiential learning are undoubtedly the rationale behind the lab portion of science courses, although in the case of brewing you're synthesizing beer opposed to something like 2-methyl-4-heptanone.) Likewise, seeing (and tasting) a tangible end product made through the application of classroom knowledge made me appreciate and truly value having learned it. In short, studying those concepts in school helped me better understand the brewing process, and utilizing those

concepts in the brewing process helped me better master them for school. It was a two-way street: my classes helped with my brewing, and brewing helped with my classes.

Further, at its basics, the brewing process is simple enough that it can be understood knowing only fundamental science, and this provides an opportunity to *immediately* apply your undergraduate education: It's refreshing to see your knowledge able to be employed "as is," rather than merely as a prerequisite for the graduate- or doctorate-level education required by scientific endeavors outside of brewing. This isn't to say that the expert can't delve deeper when desired (the gritty details of brewing really are the studies of PhDs, and a lot still remains a mystery to scientists), but the overall process is simple enough to clearly illustrate those key concepts gleaned in undergrad science courses.

In the end, I imagine my academic experience would have been wildly different if I hadn't been introduced to brewing that fateful day as freshman. I learned the material more completely, retained it more effectively, and found it more enjoyable when I could relate my classes to beer. Finally, brewing enabled me to make connections between diverse areas of my education, from carbohydrates to cholera, and became the single endeavor that most fully drew on all of my studies. Like human beings and the living yeasts that make our beer, my education and brewing have shared a symbiotic relationship, continually bettering one another. This is why I believe that brewing makes you smarter.

* * *

My belief is that other students could also benefit by being exposed to brewing early on in their collegiate careers. Because the process tells a logical, straightforward story that highlights the main concepts studied in science class, I believe beer can be an interesting, concrete, relatable, and even enjoyable way to illustrate the fundamental ideas. Further, due to its popularity at the moment, I think beer could be an effective means of sparking an interest for science in someone where one did not previously exist. The result is a better-rounded person, which should be one of the main goals of a collegiate education. Brewing lends itself particularly well as a way to turn newcomers on to science because the overall process is simple, but the details wildly complex. Therefore, brewing is approachable to people of varied academic backgrounds, but can always challenge them to dig deeper and continue learning.

One History

Tonight, millions of people in this country are going to sit down after a long day of hard work and enjoy a beer. If you could pick one of those people at random, and magically take a look at their drink, the statistics tell us that it would most likely be pale yellow and produced by one of three companies. But maybe not. Maybe, by chance, it's a deep red, and came from the growing microbrewery upstate. Or maybe it's black and opaque with a creamy brown head, and flowed from a tap under the same roof as where it was brewed.

Distant and diverse as they may be, these three beers are relatives and all share a common ancestor (though it takes an 8,000 year journey to the dawn of civilization to find it). Like most things, beer has not remained untouched by evolution: The story of beer's humble beginnings and its ascent to the third most popular drink in the world (behind water and tea) is an amazing tale. Along the way, it's had a hand in many invaluable advancements of the human race, yet many people still haven't heard beer's story. Although there is a great deal of rich history and science packed into a single glass of a seemingly commonplace beer, it frequently gets overlooked.

But not by you. By continuing to read, you'll see the proof (no pun intended) of just how important beer really is, and hopefully recognize that life as we know it would be radically different if ancient man hadn't blessedly stumbled upon the miracle of beer.

Before we start looking at the story of beer and its impacts, it's helpful to understand a bit about what beer actually is, as well as a *basic* intro to the process of brewing it. (We'll get into more detail later.) Generally speaking, beer is an alcoholic beverage made from water and cereal grain, most often barley or wheat. To put it very simply, the grain gets placed in water, and sugars within the grain dissolve into it, almost like making tea. The next part gets a little funky. It relies on single-celled microorganisms called yeast swimming around in the stuff.

Without these microbes, we would not have beer. They perform the crucial step in the process, making the alcohol. Yeast eat those dissolved sugars from the grain and release alcohol as their waste (along with a gas called carbon dioxide which will be more important later). They are like little factories: put in sugar, get out booze. As the yeast eat, they reproduce, and therefore it only takes a few yeast cells to get everything started. The process of converting sugar to alcohol is referred to as "alcoholic fermentation," and once the yeast have had their feast, the liquid has been "fermented." Only now do we truly have beer.

Now normally we'd think of microscopic critters living in our food as a very bad thing. When food gets contaminated with nastier organisms such as *E. Coli* or *Salmonella*, it can lead to some extreme discomfort (think food poisoning) or even death. But the case is a lot different for yeast; they're perfectly safe to have in our beer. (In fact, they're pretty nutritious, and brewer's yeast is a common dietary supplement. In most modern brewing though, yeast rarely makes it into the final product; it gets filtered out for flavor and clarity reasons or

settles to the bottom of the bottle, allowing the drinker to pour off the liquid and leave the yeast behind.)

It's the story of the yeast that makes beer's discovery somewhat of a miracle. Today, virtually all brewers add yeast themselves to make sure the job gets done, but experts suspect this was not the case for the first beers enjoyed on Earth.[1] The key thing to realize is that there are wild strains of yeast floating in the air around us all the time. When you consider this, it begins to tell us how beer probably originated.

The story likely went something along these lines:

Prehistoric man had some grain stored in a pot for later consumption. It started raining and filled with water. The pot sat around for a while, forgotten, and the sugars in the grain ended up dissolving. Next comes one of the most serendipitous moments in the history of mankind. Some airborne yeast came floating along and just happened to settle down in the neglected pot. Being surrounded by sugar, the yeast started doing what they do best. Sometime later, humans rediscovered the jug, and as one author put it, "Some brave soul must have partaken of the result and experienced some sort of euphoria. The rest is history." [1] The discovery of beer was probably an *accident*.

This process where yeast from the environment settles onto something by chance and starts producing alcohol is referred to as "spontaneous fermentation," [1] and it's likely it happened to other things before it happened to beer. This is because yeast are not picky. They can take a variety of sugary substances and ferment them into something alcoholic. For making beer, the sugar source is grain. Use grapes instead and you get wine. Allow yeast to eat sugars from rice and you have saké, ferment honey and it's called mead. Feed yeast molasses, concentrate it up to about 40% alcohol through a process called distillation, and you've got rum. Do the same with nectar from Mexican blue agave, and you'll (unfortunately) make tequila.

When you realize the array of things they will eat, you also see that it would have been easy for early hunter-gatherer food sources like fruits or honey to become fermented by wild yeast. (Evidence even exists of a drink made from fermented animal's milk which may have been a precursor to beer [1]). Grain wasn't a major food source until later in human history, and thus it probably didn't get fermented until later as well. But while beer may not be the oldest alcoholic drink enjoyed by humans, it did become the most popular (and likely tasted a hell of a lot better than fermented milk).

Some researchers have suggested that when nomadic peoples of the Stone Age realized they could make beer from grain, it convinced them to settle down and grow their food instead of chase it. That shift is probably the biggest turning point in the history of the human race. While crediting beer for it is a nice thought, and would certainly help in the argument of beer's importance, the idea is probably a little romantic. Most historians now believe that purposeful brewing closely followed the switch from hunting-gathering to agriculture, rather than stimulated it. [1] However, beer eventually did play a role in *what* they decided to grow, and the implications of that are still felt today. Experts feel that beer had a direct part in a phenomenon that really has defined life as we know it: the domestication of cereal grains.

Try to imagine a life without grain. Now stop. It's impossible. It means no bread or bread products, no pasta. No more pizza, ramen, or Lucky Charms (the cornerstones of the collegiate diet). A big chunk of the food pyramid vanishes. These plants are vital pieces in our food system, and we owe it to beer for getting the grain train rolling. Ian Hornsey, author of *The History of Beer and Brewing*, tells us that the desire for beer likely was the drive behind the domestication of cereals. Domestication or artificial selection is the process of choosing the individuals with the most favorable traits to humans (for instance, the stalks of grain with the largest kernels), and only allowing those individuals to reproduce. Over many generations, the whole population comes to possess those characteristics. Thus, the grains we enjoy today are well suited to our dietary desires, and the selection process was sparked by beer-making.

Aside from helping to define an important part of the human diet, one archaeologist, Brian Hayden, feels that beer's "social lubrication" qualities may also have played a significant role in the emergence of human civilization. Walk into any brewery today and you'll notice that beer brings people together and helps connect them in a very special way. Hayden believes the same was true for early man. He states that feasts were an essential part of the development of complex societies and civilization.[2] Feasts would have been large, ceremonial gatherings where bonds between groups were formed, reciprocal relationships were established, and social networks were solidified. And a central piece to every feast? Alcohol. Hayden believes that copious quantities of beer were required for gatherings like these, and the need for the grain to make it was a major motivator for domestication.[3]

This brings us to Mesopotamia, the home of the world's first civilization, and the birthplace of such invaluable inventions as writing and the wheel. Most brewing historians agree that true beer production (rather than the chance spoilage of stored grain) began in the city of Babylon around 6000 BC.[1] There has been some recent debate on this topic: in a 2012 paper, an archeologist claimed to have evidence of beer brewing in Turkey dating a full 2,000 years before that, but some people aren't convinced due to a lack of definitive chemical evidence.[4] Like in most science, people disagree.

Beer was a central part of life to Mesopotamians. It was a staple, enjoyed at every meal.[1] Rich in carbohydrates, vitamins and proteins,[5] and not terribly alcoholic,[1] beer was as nutritious as it was refreshing, with better taste and digestibility than raw grain.[6] Workers were paid in beer, or ingredients from which to make beer. (Again, there is some doubt here due to a lack of written evidence documenting beer as compensation for labor, but many scholars simply believe that the practice was so commonplace that it never occurred to anyone to actually write it down.[1])

In fact, Mesopotamians held beer in such high regard, they specifically credited a goddess for its invention, and put the production of it under the watchful eye of another deity, the famous Ninkasi.[1] One of the earliest pieces of writing, the *Hymn to Ninkasi*, inscribed on a Sumerian tablet dating to 1800 BC, is sometimes referred to as man's first recipe (often by beer enthusiasts).[5] While the poem does give a detailed, linear description of the brewing process, it is not comprehensive.[1] Further, it makes no mention of ingredients. Records a full thousand years older do state which grains which were issued to breweries, but these were little more than receipts.[1] Despite the fact that a modern brewer probably cannot replicate

Sumerian beer based on the *Hymn* alone, the real value of it lies in the fact that it proves just how important beer was to Mesopotamian society. The poem even compares beer to the waters of the Tigris and Euphrates, the two rivers that form the Fertile Crescent, the “cradle of civilization.” These rivers were the lifeline of Mesopotamia, and a likening to them should not be taken lightly.[1]

It’s also worth mentioning that brewing was the only profession in Mesopotamia to be placed under the protection of a female deity. In fact, most brewing in the ancient world was performed by women. In addition to production for the public, beer was also made for personal consumption (the ancient equivalent of homebrewing), and this was also the task of the woman.[1] These professions were eventually taken over by men when it was recognized that they could be lucrative,[7] but knowing that women were the primary brewers for much of human history definitely challenges the modern stereotype that all brewers are burly, bearded men.

We’ll now turn our focus to Egypt, the other beer hotbed of the ancient world. The story here was much the same as in Mesopotamia. Beer was ubiquitous, everyone from the Pharo on down drank it.[1] Even though Mesopotamians were brewing before the Egyptians, the latter brought something else to the table, a product that is still a dietary staple today: modern bread.[1] Egyptians discovered that if dough was allowed to sit for a while prior to baking, it would begin to rise, and the end result was a lighter, spongier loaf than when baked directly. It turns out this rising action is due to our old friends, the booze-producing yeasts.

Bread and beer are closely related. They’re both made from grain, and thus contain lots of sugars capable of being fermented. If yeast get into bread dough, they’ll do the same thing that they do in our beer: eat sugar and produce alcohol and carbon dioxide gas (CO_2). In baking, however, it’s the second product of fermentation that concerns us. The release of the CO_2 within the loaf creates little bubbles of gas, forcing the bread to rise and become spongy. Bread prepared this way was much more gastronomically pleasing than unrisen bread. So what happens to the alcohol? It gets cooked off by the heat during baking (and thus we don’t get drunk off of turkey sandwiches).

Egyptians made the connection between bread and beer even though they really didn’t understand yeast’s role (and it wouldn’t be until the 19th century that anyone fully did). By this time, brewers were no longer content to rely on spontaneous fermentation for their beer production and needed a way to initiate fermentation themselves. Though they didn’t know it, what they really needed was some way to get a few yeast cells into each new batch. Once that was accomplished, the yeast would multiply and to get fermentation going. The simplest way was by adding a bit of old beer (which would contain some cells) to the new batch. It was also realized that rising bread could be added to beer, or beer to bread,[1] providing the necessary yeast for the production of both goods. Once some cells were introduced, they would rapidly multiply and off they’d go fermenting.

In the practice of seeding new batches of beer with yeast from old ones, brewers were unknowingly performing artificial selection on the organism. Only good batches that turned out well were used to initiate fermentation in the next ones. By doing this time and again, they eventually weeded out microorganisms that didn’t do a good job of fermenting and fulfilling

their needs. Grüss remarkably reported in 1929 that yeast samples from pots of Egyptian beer got progressively purer as he moved from oldest to youngest, observing less contaminating bacteria.[1] Egyptians were selecting for cleaner microbial cultures and domesticating an organism they didn't even know existed.

Another famous story concerning the long standing mystery of yeast is the tale of the *Reinheitsgebot*, the German Beer Purity Law of 1516. The law stated that the only three ingredients allowable for making beer were water, barley, and hops for flavoring (we haven't addressed hops yet but will in a later chapter). Considered by some to be the world's first food safety law ensuring the production of good beer,[4] some historians feel the law may have been more about making sure that wheat was reserved for breadmakers instead of brewers.[8] Regardless of its motivation, you've probably noticed that the law lacks the crucial "ingredient" which makes the magic happen. Because microorganisms hadn't been discovered yet, and no one knew that they were the agents of fermentation, yeast couldn't be included in the law. After yeast were identified and their role in the fermentation process was proven, a Danish microbiologist named Emile Christian Hansen developed a method for producing cultures of pure yeast in 1888.[9] Now that it could be added directly to the beer, the *Reinheitsgebot* had to be amended and yeast included as one of the allowable ingredients.[10]

Until pure cultures were available, the organisms would have to enter the beer by adding portions of previous batches, as mentioned before, or through the use of equipment which yeast had stuck to and colonized. A famous example brewers love to give is the "family brewing stick," heirlooms that were passed down through generations which ensured the production of good beer. If that particular spoon wasn't used when making the beer, fermentation wouldn't happen (or would be initiated by undomesticated, wild yeasts, which could have unpredictable results). Clearly, these utensils were harboring the family yeast strain, and those cells wouldn't get into the beer unless they were used.

When people talk about beer in earlier times, a mention of its role as a "safe beverage" usually comes up at one point or another. For much of human history, obtaining clean water could be a real challenge. Many microorganisms naturally found in water are capable of making us sick; even the remotest, clearest mountain stream can harbor vicious pathogens. In addition, water supplies may become extremely dangerous after contamination with human feces. A plethora of dangerous infections are classified as "fecal-oral," meaning they occur when microorganisms originating from feces somehow become ingested by humans. Commonly, the microbes are taken in by consuming contaminated drinking water. Making the problem worse, these organisms often increase their own transmission by ramping up the rate of defecation in the victim (in other words, causing diarrhea). More feces in the environment means it's more likely someone else will become infected, and the cycle repeats. Sewerage systems and water treatment technology have made such diseases rare in advanced nations, but they are still a major problem in developing countries where lack of infrastructure and education fail to prevent people from separating where they eat and where they...well, you know.

Beer fits in here because it is a beverage with many antimicrobial aspects. First, the brewing process involves heating the liquid to a temperature sufficient to kill most microbes. Yeast get added after this step, and therefore, survive just fine to complete fermentation. In fact, establishing a healthy yeast population can help inhibit the growth of other contaminating organisms by outcompeting them for resources. (If you're the latecomer to the party, there's not likely to be any pizza left for you.) The addition of hops contributes compounds called alpha- and beta-acids, as well as flavonoids, which all have antimicrobial properties.[11] The alcohol itself is also inhibitive. (These characteristics lower the likelihood that beer will get infected with other organisms, but they do not guarantee against it, as we will see shortly.)

Hornsey tell us that some scholars have suggested, maybe facetiously, that the lack of safe drinking water which accompanies urbanization lead to the need for alternative, safer beverages like beer. Whenever a big group of people settles in one place, the large amounts of bodily waste produced increases the risk of contaminating the water supply. This is especially true in the absence of plumbing. In terms of timing, the theory seems plausible: brewing really took off after people started settling down in the large cities of Mesopotamia and Egypt. In terms of actual evidence, however, records from as late as the Middle Ages do not suggest that water was avoided for safety reasons.[12] But even if people weren't taking advantage of it, the science is unquestionable: beer *is* safer than water. And one interesting story from 19th century England proves it.

London in 1854 was not a pretty sight. We're talking about Charles Dickens-esque, overcrowded, poverty ridden slums. In the poor areas where the sewer system didn't reach, human waste was disposed of in cellars or just thrown out into the streets. In such unsanitary conditions, disease was common. Not all that surprisingly, in August of that year, a deadly cholera epidemic broke out. This disease is characterized by severe, watery diarrhea of such volume that victims can die of dehydration. It's caused by a fecal-orally transmitted bacteria called *Vibrio cholerae*, and it's main mode of transmission is contaminated drinking water.

With eighty-three people killed by cholera in just three days,[13] something needed to be done. Enter John Snow, a physician who believed the problem could be approached systematically. Snow conducted surveys on who was contracting the disease, specifically inquiring about where the victims lived. Famously, he took a map of the city and made tick marks at the addresses of each of the victims. In this process, he noticed a high concentration of cases on Broad Street. But right in the thick of Broad Street, surrounded by tick mark-ridden buildings, sat the brewery. The number of cholera cases there? Zero.

Snow went on to figure out that all the victims got their water from the same pump on Broad Street. He eventually convinced city officials to remove the pump's handle, and sure enough, the epidemic subsided. For his brilliant work, John Snow is now considered the father of epidemiology, the study of the causation and spread of disease.[14] But what was different about the brewery? It turns out that the seventy employees there just drank the beer they made, which they preferred over water anyway.[13] Beer really did save their lives.

Now that we've seen some of the societal and cultural impacts of beer, we'll take a look at the role it played in the history and advancement of science. As time moved on, the popularity of beer and other alcoholic beverages turned them into very valuable industries. In the 1820s, the French wine industry alone was worth the equivalent of \$2.5 billion in today's currency.[4] With that kind of money at stake, a bad batch of brew could prove disastrous for a company, and a way to keep these drinks from spoiling was highly sought after. Also, a big part of the process, fermentation, still wasn't well understood. It's not a great business strategy to have a major part of your production rooted in a mystery, and thus producers really stood to benefit from figuring out just what in the hell was going on with fermentation.

Alcoholic fermentation was one of the biggest, most debated topics in science during the 1800s. Many of the world's most famous researchers spent at least part of their careers studying it in one way or another.[4] Anton van Leeuwenhoek, the father of the microscope and first person to observe single-celled organisms, examined fermenting wine and saw yeast cells (although neither he nor anyone else at the time knew what they were or what they were doing).[15] Antoine Lavoisier, pioneer of the Law of Conservation of Mass which states that mass cannot be created or destroyed in chemical reactions, used his expertise to figure out that it was sugar that was being converted into alcohol and carbon dioxide. Theodor Schwann, discoverer of the Schwann cells of the human nervous system, proposed that the things seen by van Leeuwenhoek were alive, and that they were the agents of fermentation.[4] Though Schwann was on the right track, his view was met with opposition from the leading chemists of the day. Leading the fight was Justus von Liebig, founder of organic chemistry and a pioneer of agricultural fertilizers (not exactly a lightweight).[16] Von Liebig believed fermentation was a chemical process that didn't require living yeast. It would take one man, a French scientist and one of the most brilliant minds in history, to bring all the pieces together. His name was Louis Pasteur.

In the 1850s, Pasteur was called in to assess why some batches of beer and wine turned out fine, while other spoiled. Comparing a good batch and a bad one under a microscope, he noticed the round yeast cells described by van Leeuwenhoek and Schwann were present in both. But the bad batch also contained black rods (which turned out to be contaminating bacteria). He then set up a series of simple, yet elegant experiments to prove what Schwann had suggested:

1. He heated a sealed container of grape juice enough to kill any organisms inside. After a few days, he found no alcohol, proving that something living was causing fermentation.
2. He heated a second flask, killing everything, but afterward added some yeast cells from the good wine. In a few days, he found the juice had become alcoholic. This proved that yeast made the alcohol, and that they needed to be living to do so.
3. Lastly, he heated one more flask, but this time added the black rods from the bad batch. Sure enough, the sample turned sour, showing that living bacteria could ruin the beverage.

Pasteur's realization that the presence of bacteria could ruin a good batch of wine got him thinking that their presence in *us* could cause problems as well. This led to his hypothesis

of germ theory, the idea that microorganisms cause disease, which has become the foundation of modern medicine.[14, 17]

Pasteur thus proposed a method to prevent spoilage in beer and wine, a process now called “pasteurization” in his honor. The liquid was heated to a certain temperature and held there for a given amount of time to sufficiently to kill most microbes, then cooled back down. Pasteurization is now common for many beverages and foods, from cheese, to eggs, to peanut butter, and has saved countless lives throughout history. But many may be surprised to learn that it was first developed for beer, not milk.

Louis Pasteur would go on to have other successes in the field of microbiology and medicine, including the development of vaccines against dangerous infectious diseases such as anthrax, fowl cholera, and rabies.[14] And we owe it to fermented beverages for bringing him into that realm of science.

Other valuable scientific advancements were products of the beer brewing industry. In 1909, Søren Sørensen was head of the chemical department at Carlsberg Laboratory in Denmark. This research institute was founded and backed by the brewing company of the same name.[18] The purpose of the lab, according to their original 1875 charter, is “to develop as complete a scientific basis as possible for malting, brewing and fermenting operations.”[19] Sørensen was focusing on the acidity of solutions.

Acids and bases are important in many areas of chemistry. Most people are aware that strong acids have the capability to dissolve things, but strong bases can be just as corrosive. There are many ways to define acids and bases, but for our purposes we will use the simplest Arrhenius definition here: acids are chemicals that increase the amount of “hydrogen ions” in a liquid. Hydrogen ions are very reactive, and the more of them that are around, the more acidic the liquid (and the less basic). Bases, on the other hand, increase the amount of “hydroxide ions.” These too are very reactive, and a solution that has a lot of them is said to be very basic (and less acidic). Acidity and basicity move in opposite directions: increase one, decrease the other.

When Sørensen was working in the Carlsberg Laboratory, he came up with a convenient way to quantify the acidity of a solution: the pH scale. Without getting too deep into the math of how it’s calculated, the scale runs from zero to fourteen, with seven being in the middle at a “neutral” pH. (Neutral means there are equal concentrations of acid and base, neither one is dominant, and the amounts of both are minute.) Things below seven on the scale are acidic, things above seven are basic. This system is so widely used, it’s difficult to imagine any chemistry without it.

Another scientific tool born of brewing is the statistical Student’s T-test. While employed by Guinness Brewery in Dublin, Ireland, an Englishman named William S. Gossett was involved in quality control. He wanted a way to get accurate numbers that represented *all* of the beer in the brewery, without having to take many, many samples. This led him to develop the T-test, which is still pervasive in research. A version of the test is often used to decide when two outcomes are “significantly different,” meaning that the difference is due to some variable in the experiment rather than inherent random chance. (For example, a T-test

may be used to prove that the length of a disease is significant shorter when taking a drug, instead of the difference just being due to chance.)

Once we actually figured out what yeast were, they became valuable research tools. Yeast are eukaryotic organisms, meaning their DNA is enclosed within a membrane. Bacteria, on the other hand, are prokaryotic, lacking a membrane. Eukaryotes, which include plants and animals (like us), tend to be more complex organisms than prokaryotes. Because yeast can grow easily and reproduce quickly in the lab, *Saccharomyces cerevisiae* (the scientific name for brewer's yeast) became a great model organism for running scientific tests in eukaryotic systems. In fact, *Saccharomyces cerevisiae* was the first eukaryote to have all of its DNA sequenced, and studying it taught us a lot of what we know about how life works.[4]

Now that we've seen how humans have benefitted from beer, the next chapters will move into a detailed look at actually making the stuff, highlighting some of the scientific concepts along the way.

* * *

Enrolling in a few undergraduate classes can tell you a lot more about the beer-related topics introduced in this chapter. If life in ancient Mesopotamia and Egypt interests you, you might look for a history or anthropology course on the origins of civilization. If science is more your thing, Introductory Microbiology will teach you volumes about the fascinating world of living creatures too small to see (like yeast, for example). You'll learn about the structure and lives of different microorganisms, ways humans use and combat them, and look at how a host of pathogens like *Vibrio cholerae* cause disease. The course also includes a section on the history of the field, addressing the works of Louis Pasteur and John Snow. Finally, the two-semester Honors course titled Food for Thought takes a big picture look at humans' complex relationship with food, incorporating history, science, and sociology. The class typically spends some time discussing beer, complete with brewing demonstrations.

More course recommendations will accompany the brewing-related concepts introduced in the following chapters.

Bibliography

1. Hornsey, Ian S. *History of Beer and Brewing*. RSC Paperbacks. Royal Society of Chemistry, 2003.
2. Choi, Charles Q. Beer Lubricated the Rise of Civilization, Study Suggests. *LiveScience*, <http://www.livescience.com/10221-beer-lubricated-rise-civilization-study-suggests.html>.
3. Hayden, Canuel, and Shanse. "What was Brewing in the Natufian? an Archaeological Assessment of Brewing Technology in the Epipaleolithic." *Journal of Archaeological Method and Theory* 20, no. 1 (2012): 102-150.
4. Rogers, Adam. *Proof: The Science of Booze* Houghton Mifflin Harcourt, 2014.
5. Homan, M. M. "Beer and its Drinkers: An Ancient Near Eastern Lover Story." *Near Eastern Archeology* 67, no. 2 (2004): 84-95.
6. Ensminger, Marion and Audrey Ensminger. *Foods & Nutrition Encyclopedia, 2nd Edition, Volume 1. 2*, illustrated, revised ed. CRC Press, 1993.
7. Mark, Joshua J. "Mesopotamia," *Ancient History Encyclopedia*. <http://www.ancient.eu/Mesopotamia/>. (2009).
8. Mason, Betsy. "April 23, 1516: Bavaria Cracks Down on Beer Brewers | WIRED." (April 10, 2010), <http://www.wired.com/2010/04/0423deutsche-reinheitsgebot-german-beer-purity-law/>.
9. *Encyclopædia Britannica Online*, s. v. "Emile Christian Hansen", <http://www.britannica.com/EBchecked/topic/254578/Emile-Christian-Hansen>.
10. Palmer, John J. *How to Brew: Everything You Need to Know to Brew Beer Right the First Time*. 3rd ed. Brewers Publications, 2006.
11. Kramer, B., J. Thielmann, A. Hickisch, P. Muranyi, J. Wunderlich, and C. Hauser. "Antimicrobial Activity of Hop Extracts Against Foodborne Pathogens for Meat Applications." *Journal of Applied Microbiology* 118, no. 3 (2015): 648–657.
12. Harris, Stephen J. and Bryon Lee Grigsby. *Misconceptions about the Middle Ages*. Routledge Studies in Medieval Religion and Culture. Vol. 7 Routledge, 2008.
13. Schmelzer, Marilee. "Cholera Outbreak in 1854. an Early use of Statistical Methods." *Gastroenterology Nursing : The Official Journal of the Society of Gastroenterology Nurses and Associates* 27, no. 3 (May 1, 2004): 135.
14. Bauman, Robert W. *Microbiology with Diseases by Taxonomy (4th Edition)* Benjamin Cummings; 4 edition, 2013.
15. Nanninga, Nanne. "Did Van Leeuwenhoek Observe Yeast Cells in 1680?"

<http://schaechter.asmblog.org/schaechter/2010/04/did-van-leeuwenhoek-observe-yeast-cells-in-1680.html>.

16. *Encyclopædia Britannica Online*, s. v. "Justus, baron von Liebig",
<http://www.britannica.com/EBchecked/topic/339838/Justus-baron-von-Liebig>.

17. Shurtleff, William and Aoyagi, Akiko. "A Brief History of Fermentation, East and West."
<http://www.soyinfocenter.com/HSS/fermentation.php>.

18. "Søren Sørensen | Chemical Heritage Foundation."
<http://www.chemheritage.org/discover/online-resources/chemistry-in-history/themes/electrochemistry/sorensen.aspx>.

19. "Carlsberg Group - Vision." <http://www.carlsberglab.dk/vision/Pages/default.aspx>.

Two Sugar

Life is all about energy. And since brewing completely relies on living creatures (first grain, and later, yeast), it too tells a long story about energy. This can be a tricky concept, intuitive in some cases, but not all. Most of us are familiar with the notion that our bodies use the food we eat to fuel our activities. Physical activity uses up energy, and you feel hungry afterwards because your body needs to replenish it with food. What we are really talking about here is the transformation of energy between different forms, and because that's a very important concept with ties to brewing, we'll discuss it here.

The First Law of Thermodynamics states that energy cannot be created or destroyed, but can change forms. If we look at a situation inside a bubble, where nothing is allowed to leave or enter from the outside, the total amount of energy within will always be the same. (In science this is called a "closed system.") Regardless of how the energy might change form, the amount you start with is equal to the amount you end with.

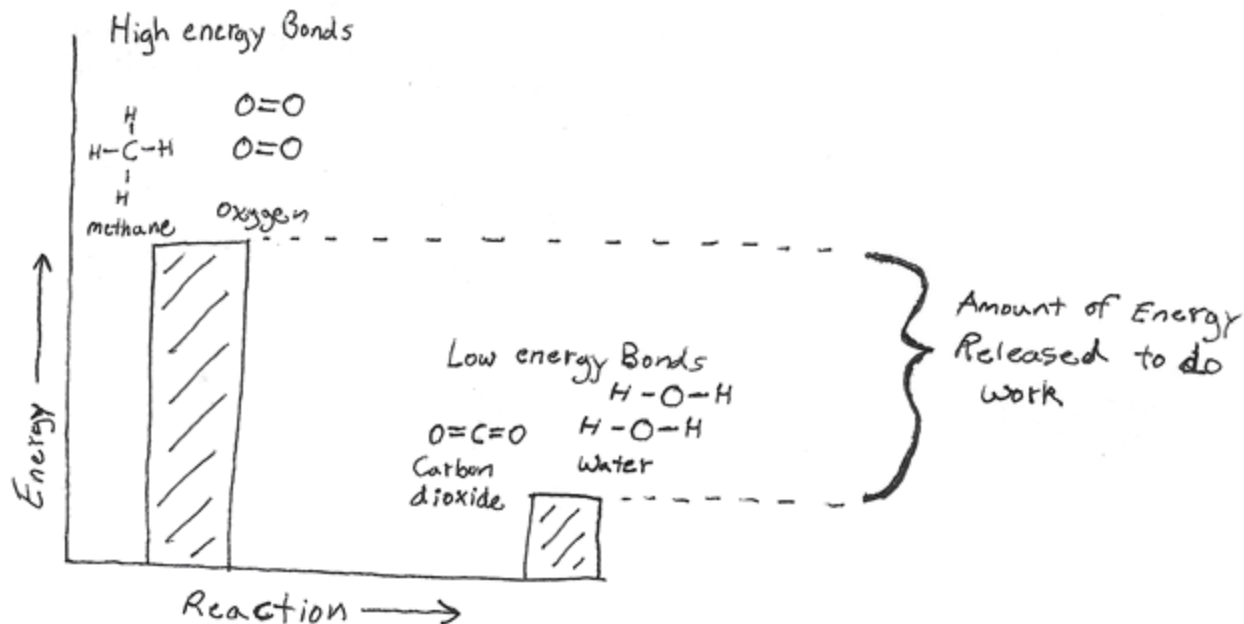
The two main forms of energy we usually use to illustrate this concept are referred to as kinetic and potential. Kinetic is the energy of movement: a golf ball whizzing through the air has more kinetic energy than one sitting on the ground. (Temperature is also related to kinetic energy, having to do with the movement of the molecules making up a substance. The individual molecules in, say, a hot glass of water are moving faster and have more kinetic energy than a glass at room temperature.) On the other hand, potential energy is energy that is stored, and can possibly be released to cause some sort of action.

The two types can be converted into one another. The classic, idealized example is a ball sitting at the top of a hill. The ball is stationary, so it has no kinetic energy. But because it's at the top of a hill (a "high energy" position), it has the ability or *potential* to roll down to the bottom. We'd say it has some stored energy. If it starts rolling down the hill, it now has movement, and thus has some kinetic energy. Because the ball couldn't gain or lose any *total* energy according to the First Law, the kinetic type it has while moving must have been transformed from some of the potential present at the beginning. And this makes sense: while the ball is rolling down, it isn't as high on the hill, and thus has a lesser distance that it's able to fall. At the bottom, it has no more potential (it's got nowhere else to roll down to), and that means all the energy has been converted to kinetic. In a perfect world ignoring friction and air resistance, the amount of kinetic energy the ball has at the bottom exactly equals the amount of potential it had at the top. Alternatively, the ball can be rolled back up the hill, requiring an input of kinetic energy, but converting and storing it again as potential.

In this example, the stored energy was due to the ball's position (at the top of a hill). But there are other ways we can store energy aside from just placing objects high off the ground. The type of stored energy most pertinent to brewing, and life in general, is called chemical potential energy.

All physical stuff in the universe is made up of atoms of different types: carbon atoms, oxygen atoms, hydrogen atoms, just to name a few. These particles can become bonded together to form the molecules that make up our world. For example, water, chemically represented as H_2O , is an oxygen atom (the “O”) bonded with two hydrogens (the “H”s). Oxygen gas, O_2 , is made of two oxygen atoms bonded to each other twice (called a double bond). There is potential energy stored in all of these bonds, and this type is specifically called *chemical potential energy*.^[1]

It turns out that not all chemical bonds are created equal: some have more energy stored in them than others. If you start with some molecules composed of high energy bonds, and perform some reaction allowing the atoms to rearrange into molecules with lower energy bonds, the total amount of stored energy has gone down (like the ball at the top of the hill versus the bottom). But because we can’t destroy any energy (First Law!), the difference had to go someplace - it gets released from the molecules in a form that can be harnessed to do useful work and make things happen. An illustration showing the conversion of oxygen and methane (a component of natural gas) into carbon dioxide and water might help to make it clearer:



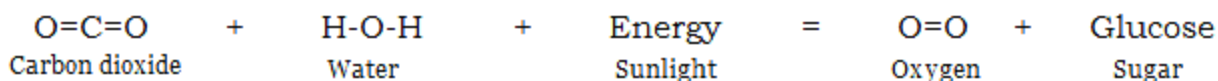
This concept is the basis of our food-fuel example: we take in food with high energy bonds, our bodies rearrange it into molecules with lower energy bonds, and harness the energy that gets released to fuel our lives. Reactions like the one above where useable energy is given off are referred to as exergonic, *ex-* meaning “out of.”

The process can also go in reverse: molecules with low energy bonds can be converted to ones with lots of energy (equivalent to pushing the ball back up the hill). In this case, we’d

need to put energy into the molecules, opposed to getting it out. Such reactions are endergonic, coming from the prefix *endo-* meaning “into.”

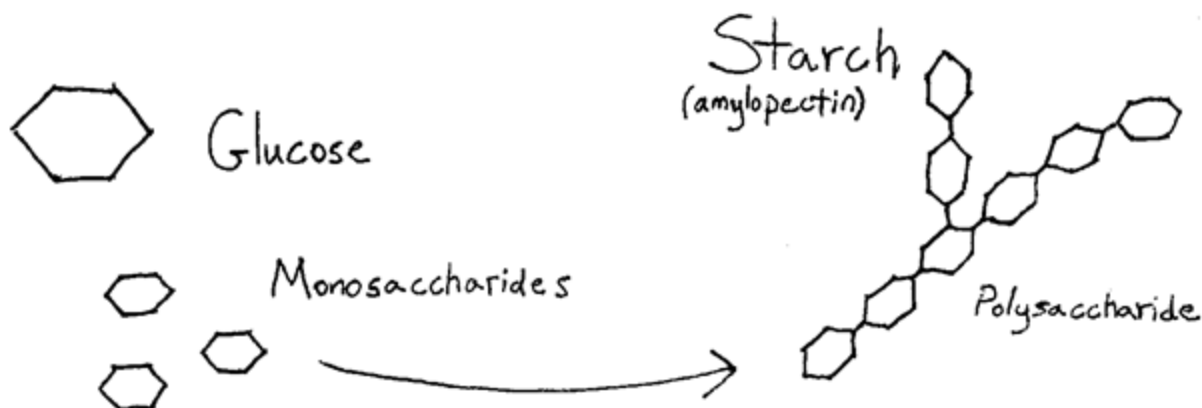
Light is also a form of energy, and it can be used in endergonic reactions to push low energy molecules uphill into energetically richer ones. This concept is the basis for most life on Earth: plants (like grain) use sunlight to build molecules with lots of stored energy. They keep those molecules until they need energy to perform their functions, in which case they break them down again, releasing the energy they stored earlier. If the plants are unlucky, other organisms (like yeast) can eat them, and those animals will harness the energy in those molecules instead. Alternatively, those animals may get eaten themselves by carnivores, and so it goes. It’s a big energy food chain, but it all starts with plants capturing light energy from the sun and converting it to chemical potential energy. The main high energy molecule we are talking about here is sugar, and the process of making it using sunlight is called photosynthesis.

Most people know that plants take in carbon dioxide (CO₂, one of the molecules that comes out of our cars as they burn gasoline) and release oxygen, O₂. It’s also well known that plants need water and sunlight to grow. It turns out that these are all players in photosynthesis, but one last piece is missing: the high energy sugar that is produced. We’ll focus specifically on one type of sugar called glucose. A simplified version of the photosynthesis equation is as follows:



(This gets a little technical, but photosynthesis is a process of “carbon fixation.” What this means is it takes an “inorganic carbon,” within the CO₂, and converts it to part of an organic molecule, the molecules of life. Also, a chemistry student who knows that the formula for glucose is C₆H₁₂O₆ will notice that the above equation is not balanced. In reality, six carbon dioxides will need to be taken in before the plant can make a full glucose. Glucose isn’t the only sugar made by plants either. Fructose is another one that can be made, plentiful in fruits. When a fructose combines with a glucose, it makes a type of sugar called sucrose, table sugar.)

We now need to look in detail at carbohydrates, the scientific name for sugars. Like many structures important in life, carbs exist as monomers and polymers. This sounds complicated, but all it really means is that many single units, the monomers (*mono-* meaning “one”), get connected together in a repeated fashion forming a polymer (*poly-* meaning “many”). It can be helpful to think of it like a chain: each individual link is a monomer and the whole chain is a polymer. Glucose is a type of sugar called a monosaccharide, and many glucose molecules linked together form starch, a polysaccharide.



Plants produce glucose via photosynthesis, but this isn't the end of the story. Glucose is the form of sugar that can easily be broken down to release energy, but it is also small and dissolves in water. For these reasons, singular glucose can get washed away in moist conditions and is hard for a plant to hang on to for long periods of time. To solve this problem, when a plant wants to store up energy for later, it connects many glucoses together into starch (linking monomers to form a polymer). Starch is big and doesn't dissolve well in water, making it a stabler, long term way to store a lot of energy. Specifically, grain forms a branched type of starch called amylopectin (shown above).[2] And this is where the story starts to relate directly to beer.

As barley and wheat grains store energy from the sun, much of the amylopectin gets kept in the grain's kernels. This makes sense if you look at it from the plant's point of view: The kernel is the seed that will hopefully make its way into the ground and eventually sprout (in plant language, sprouting is termed germination). The rapid growth that accompanies germination requires a lot of energy, and since the kernel is below ground, it wouldn't be able to get that energy from the sun. Instead, it needs to start using the chemical potential energy stored in its starch reserve. But amylopectin is the long term storage form, and first needs to be broken down into glucose before energy can be harvested. When the kernel senses that conditions are right to start growing, it will start producing the agents of starch breakdown, called enzymes.

Enzymes are the workhorses of life, they make things happen. They can link things together, break things apart, and convert one thing into another, performing the functions that make life possible. Enzymes help reactions occur, but don't get consumed in the process, meaning they can perform their function over and over again. Enzymes are usually named for the task they perform or the molecule they work on, called their substrate, and end in the suffix *-ase*. For instance, lactase breaks down lactose, a component of milk. DNA polymerase links the components of DNA into a long, polymerized chain. Each enzyme performs a highly specific task. This is because the substrate needs to physically fit into a certain spot on the enzyme before the job can be completed, referred to as a lock-and-key mechanism. We'll get

into more specifics on enzyme function in the next chapter. For now, we are focused on where the enzymes of starch breakdown come from: they are synthesized by the grain during germination.

It turns out that the polymer of glucose within the kernel is of little use to the beer brewer. Yeast can't eat these long chains, and therefore, we can't make alcohol from them. What the brewer is after are smaller, fermentable sugars that result from breaking apart amylopectin. Namely, yeast - and thus the brewer - desire maltose (composed of two connected glucoses), maltotriose (made from three), and singular glucose.[2] You may have noticed that the brewer and a sprouting seed want the same thing: the breakdown of amylopectin into smaller pieces. The grain wants them for energy, the brewer wants them for beer. This is used to the advantage of the brewer during the process referred to as malting.

Malting is a way of "tricking" the grain into thinking that it is time to start growing so that it will begin the process of exposing and breaking down its starches. This includes degrading the protective coating surrounding the amylopectin, as well as synthesizing the necessary enzymes that actually perform the breakdown. The malting process is usually accomplished by a professional maltster, long before the brewer ever sees the grain.

The maltster needs to give the grain the favorable growing conditions it's looking for to stimulate germination. This is accomplished by steeping the kernels in water, alternatingly submerging and draining them for around two days, until the grain has absorbed its own weight in water. During this stage, tiny rootlets begin to sprout from the kernel. The grain continues to germinate for four to five days, and the starches become more and more exposed.[3] But most importantly, the enzymes are synthesized.

Here comes the genius of the process: If germination was allowed to continue, and the grain kept on growing, it would use up all of those sugars that the brewer needs to make beer. So the maltster halts the grain mid process by drying it out. This is usually performed in a device called a kiln, at a temperature around 180° F.[3] After being dried, all of the enzymes are present, but the germination process has been frozen in time. From here, the grains get tumbled to knock off the rootlets.[2] Once the entire process has been completed, the partially germinated grain is referred to as malt. By varying the level of moisture in the grain after steeping, as well as the conditions of drying, the malt can be manipulated into a variety of colors and flavors from pale to black and bready to coffee-like.[2,3] The dried malt can then be stored until the brewer is ready to actually make the beer.

* * *

The concept of energy is discussed extensively in second semester General Chemistry, giving you all the tools to quantify and track it as it changes form during reactions. General Physics I and II also teach you ways to mathematically describe the conversion between potential and kinetic energies. First semester General Biology looks at photosynthesis in great detail, showing you exactly how energy from the sun gets stored in chemical bonds. The course also teaches the structures and functions of many monomers and polymers vital to life, including carbohydrates as well as DNA and proteins.

Bibliography

1. Reece, Jane B. and Neil A. Campbell. *Campbell Biology* [Biology]. 9th ed. Pearson Education, 2011.
2. Palmer, John J. *How to Brew: Everything You Need to Know to Brew Beer Right the First Time*. 3rd ed. ed. Brewers Publications, 2006.
3. "Briess Processes - the Malting Process." <http://www.briess.com/food/Processes/malttmp.php>.

Three Mashing

Now that we have our malt, the next step is to get the starches inside it broken down into smaller, fermentable sugars, and dissolve those into our brewing water. This is the process brewers call mashing. Before the brewer begins the mash, the grain is crushed, making the starches more exposed and accessible. After crushing, the malt is placed into hot water, and the starch breakdown becomes the task of the enzymes produced during malting.

As mentioned in the previous chapter, enzymes are highly specific, each acting in one way, accomplishing one job. The specificity comes from the fact that the substrate must perfectly fit into a certain spot on the enzyme (called the active site), like a key into a lock, before the enzyme can perform its job. This requires that both pieces come together in precisely the correct spatial orientation, which is only true for a fraction of collisions between the two. Perhaps you recall from the last chapter that temperature is related to the kinetic energy of molecules. When a substance is hotter, the molecules move faster. It follows that more collisions between the enzyme and substrate will occur when the pieces are moving around more (in other words, when the temperature is hotter). More total collisions means more successful ones as well. This has been observed in experimental data: enzyme activity increases as temperature increases, but only to a certain point. If the temperature gets too hot, enzymes will denature (essentially melt), completely losing their shape and thus their function. Every enzyme has a specific temperature it works best at, and this fact will come into play later.

Another factor besides temperature that affects the activity of enzymes is the pH of the solution. pH has already been addressed briefly, but we will recap: this is a measure of the acidity of a liquid, referring to the amount of hydrogen ions present, abbreviated as H^+ . H^+ is very reactive and has a positive electrical charge. If there is lots of H^+ around, the solution is called acidic, with a pH below 7. On the other hand, if there is very little H^+ around, it means there is a lot of hydroxide ion present, abbreviated OH^- . (The amounts of the two move in opposite directions; increasing one decreases the other.) OH^- is also very reactive and has a negative electrical charge. It's found in large quantities in basic solutions, with pH greater than 7.

These two species play a role in enzyme activity because they can change the nature of the active site or the substrate, preventing the two from fitting together, and ceasing enzymatic reactions. One way they can do this is by affecting the electrical charge on portions of molecules. Because H^+ is so reactive, it can attach itself to certain parts of molecules (usually nitrogen atoms), giving that region of the molecule a positive charge. Additionally, OH^- can rip away hydrogen atoms attached to molecules, leaving behind negatively charged regions.

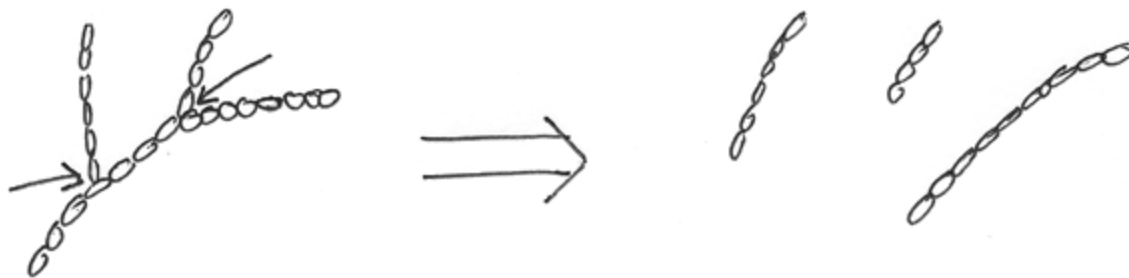
Most people are aware that similar charges repel each other, while opposites attract

(like with magnets). Therefore, altering the charge on parts of a molecule can change its shape when these charges attract or repel each other. For example, if two regions on the active site of the enzyme both become negatively charged from OH^- , they will bend away from each other slightly. This shape change can potentially ruin the fit between the active site and substrate. Alternatively, if the enzyme and substrate both acquire a similar charge, they will repel each other, also preventing them from fitting together nicely. Just like temperature, each enzyme has a specific pH where it works best.

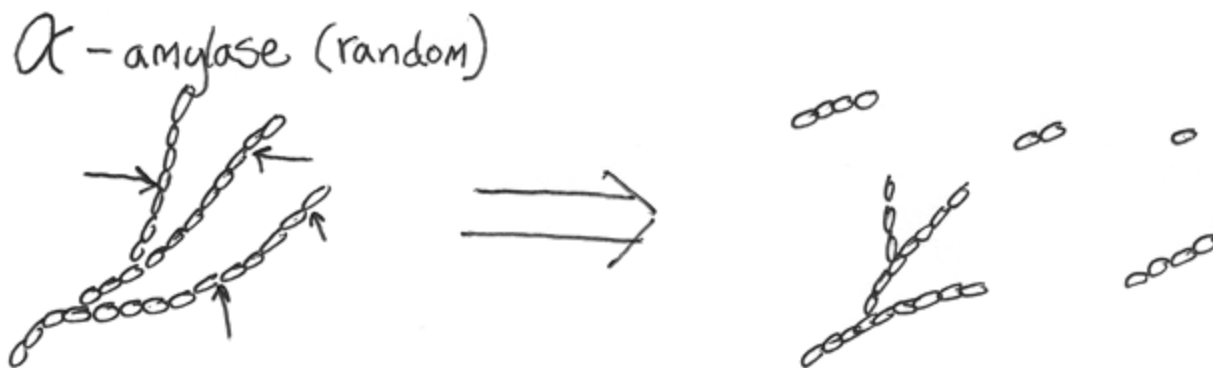
We will now examine the enzymes of mashing, keeping in mind that each will have a preferred temperature and pH. After we have seen their functions and contributions to the mash, we will discuss how the brewer can manipulate mash conditions to achieve different results, tailoring a beer to their desires.

Each starch-breakdown enzyme fits perfectly onto one particular part of amylopectin, dictating the specific way that that enzyme can break it apart. This phenomenon results in the production of sugars with varying lengths: dextrins, the longest products of starch breakdown, are greater than four glucose segments long. They are unfermentable (too big for yeast to eat), and contribute somewhat to the “thickness” of a beer. Maltotriose and maltose are made up of three and two glucoses, respectively, and are both fermentable. Maltose is the main carbohydrate in beer, representing about 45% of the dissolved sugar.[1] Singular glucoses can also be produced, and are eaten by yeast as well. We will address the most important starch-cutting enzymes: limit dextrinase, alpha-amylase, and beta-amylase.

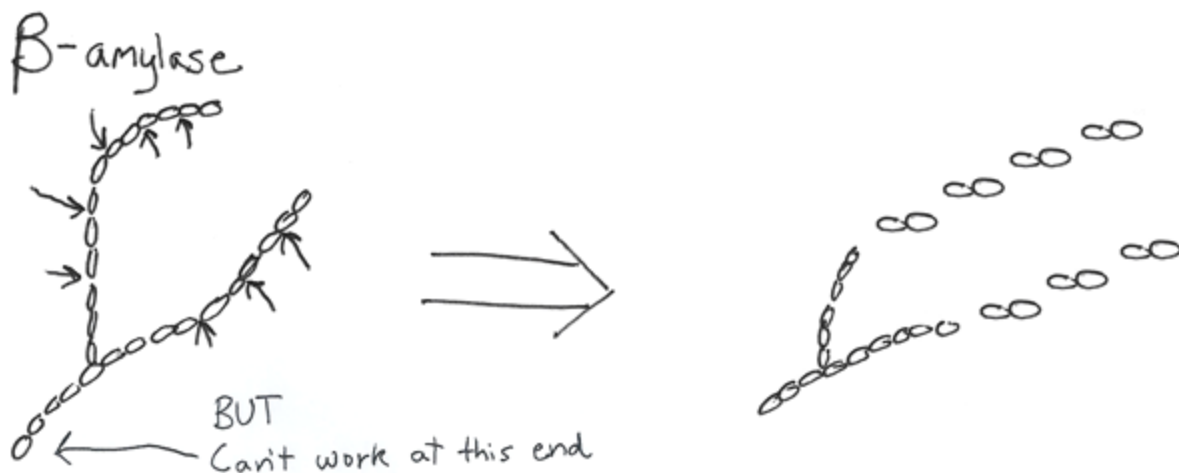
Limit Dextrinase (Branch points only)



The type of chemical bond at the branching points of amylopectin is different than the kind between the glucose molecules in the straight portions. (The bond type that makes up the straight portions is the same in both the trunk and the branches, it's only the single bond that connects a branch to the trunk that is different.) Breaking this bond requires an enzyme that perfectly fits onto the branch point, and one such enzyme is limit dextrinase. Since this enzyme only works on the bonds at the branch points (indicated above), it is referred to as a debranching enzyme.[2] The long straight chains that result are dextrinous and unfermentable, but may be broken down further by the next two enzymes.



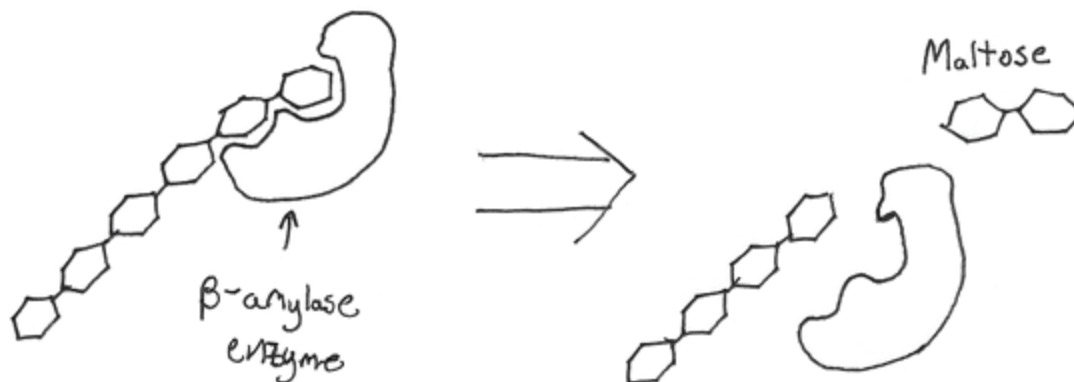
Alpha-amylase, abbreviated with α , can't break down the branch point bonds. It may work only within the straight portions of amylopectin and the long dextrans produced by limit dextrinase. However, α -amylase cuts at random points along a straight starch. If it happens to work near the end of a chain, it's possible for it to produce fermentable sugars, as shown above. But because it's randomly chopping, it's more likely that the enzyme will make a cut somewhere near the middle of a long chain, resulting in proportionally more unfermentable dextrans than fermentables. Imagine a string stretched out in front of you. If you close your eyes and cut it at a random spot, you're more likely to wind up with two relatively long pieces (dextrans), rather than one very long and one very short piece (a dextrin and a fermentable sugar).



Beta-amylase, on the other hand, is much pickier about where it cuts. The only place that it works is at specific ends of the starch. This is because amylopectin has directionality to it and only one type of end fits into the enzyme correctly. To borrow an example from Palmer, the starch is like a row of batteries, and the enzyme can only start cutting at the "positive" end, working in only one direction. β -amylase cleaves off two glucoses at a time, producing maltose, the main fermentable sugar in beer. It can keep cutting from that end, moving down the chain like Pac-Man. However, once it gets close to a branch, it can't work anymore, and

must find a new end of amylopectin or dextrin to work on.

Action of β -amylase



As mentioned earlier, each of the three enzymes has a favorite temperature and pH. However, since they are all in the same solution, it's impossible to make each one of them perfectly happy at the same time. Thus, the brewer aims for mash conditions that maximize the total *combined* happiness of the three, achieving the highest possible enzymatic activity. (No one is at their very happiest, but at least everyone is moderately content.) This turns out to be a mash temperature of 150 to 155° F and a pH of 5.1 to 5.6.[1] (The conditions just given are used in the simplest method of mashing, called single-temperature infusion, where one temperature is held for the duration of the mashing process. More advanced methods involve changing the mash temperature over time to optimize different enzymes at different stages. Single-temperature is easiest, and perfectly adequate for many beer styles.[1])

It turns out that the optimal temperatures are higher for both limit dextrinase and α -amylase (which primarily produce unfermentable dextrans) than β -amylase (which produces the fermentable maltose). Using this information, the brewer can begin to fine-tune the mash temperature to produce certain characteristics in the beer. Still staying within our range, a higher temperature mash results in a heavier, more dextrinous beer that is less fermentable. A lower temperature mash, with β -amylase favored, results in a more alcoholic, lighter-bodied beer.[1]

Temperature has a bigger effect on the mash than pH on how the mash goes,[1] and this is convenient because temperatures is the easier of the two to control. However, sometimes the particular conditions of the water being used for brewing can prevent the mash from reaching the target pH. This brings us into a discussion of buffers.

Buffers are vital to life. They are systems of related chemicals that minimize the effects when acid or base gets added to a solution. Like we have mentioned, both highly acidic and highly basic solutions can be corrosive and dangerous, especially if they are within our bodies. To prevent this, humans have a blood buffer system that keeps our blood from getting too

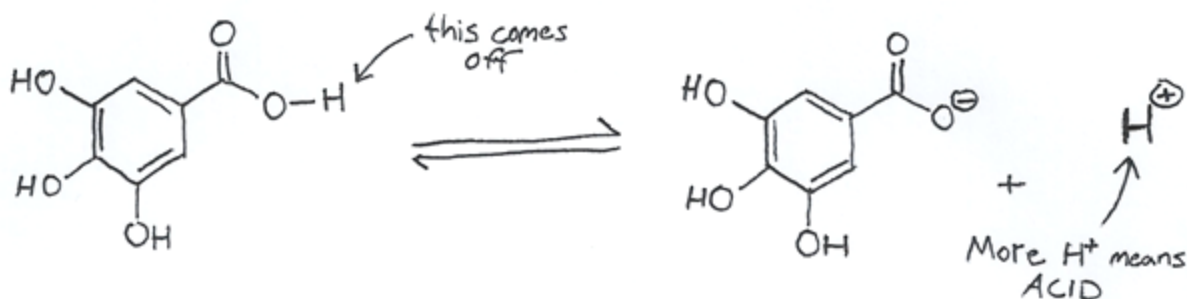
acidic or too basic, which could cause major damage.

Buffer systems can accept H^+ to lower acidity, or release it when things get too basic. Their ability to do so comes from the fact that there is both a weak acid and a weak base present in the same solution. The weak acid will neutralize the effect of added base, and the weak base will counteract any added acid, but neither of the weak species is very powerful on its own. This setup prevents drastic changes in pH, which is great for inside our bodies, but can pose a problem for the brewer when they are trying to mash.

Because most drinking water has a pH between 6.5 to 9.5,[3] and we are looking for a pH near 5 for our mash, the brewer needs it to drop quite a bit. All malt naturally releases some acid during the mash, and usually takes care of the pH on its own.[4] However, in extreme cases where the water supply is very good at buffering, the pH drop will be minimized, and might not get into our desired range. This can screw up our enzymes' functions.

The biggest contributor to a water supply's buffering capacity is a component called bicarbonate, naturally found in varying levels in drinking water.[1] (Our blood buffer system also utilizes bicarbonate.) A lot of bicarbonate in brewing water can prevent the pH from dropping sufficiently in our mash. In situations like these, a large amount of acid needs to be added to get to the desired pH. To get around the problem, we can utilize the varying acidity of different malt types: dark malts are more acidic than pale ones.[1,4] Part of the reason is that the amount of extractable phenolic acids increases with kilning,[5] and one example, gallic acid, is shown below.

Gallic acid



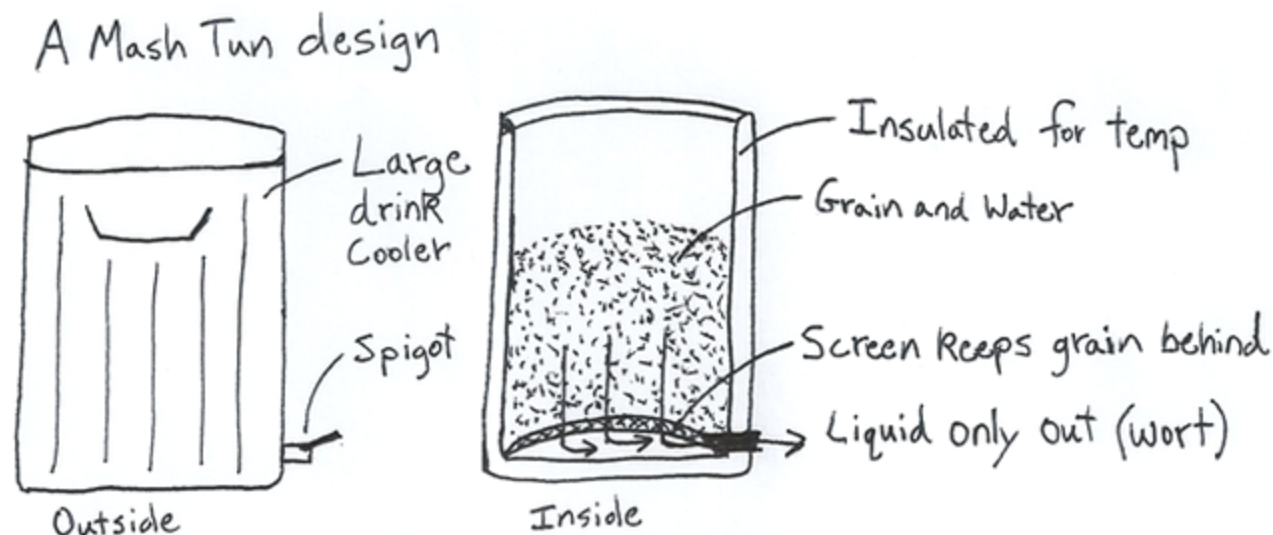
Differing malt acidities can be useful in geographical areas where water buffering is an issue. Back before a lot was known about water chemistry, people figured out that certain styles of beer turned out better when made in specific areas of the world. In Dublin, Ireland, where the water is high in bicarbonate (and thus requires a lot of added acid to drop to pH 5), it was realized that highly roasted, highly acidic malts made better beer. Hence, Guinness Stout. In contrast, Pilsen, Czech Republic (birthplace of the famous Pilsener) has very low

buffering capacity. There, dark malts drop the pH too much, and beers made with pale, lighter malt turned out best.[1]

Bicarbonate is not the only thing in our water that is important to brewing. A host of other ions (chemicals with positive or negative charges) are present in water, and can play a role in both beer flavor and health of the yeast. Some notable examples are sodium, which can accentuate malt flavors, and sulfate, which adds to crispness of hop flavor.[1] Also, just like us, yeast require certain nutrients to live well. Calcium, magnesium, and zinc must be present in our brewing water, as they are essential to yeast wellness, a healthy fermentation and successful production of alcohol.[6]

(It should be noted that there are a host of ways to mess with your brewing water's chemistry to try and get it just right, including additions of acids, bases, buffers, or ions. This requires reading a water report and can involve complicated calculations. If that doesn't sound interesting to you, a homebrewer who is concerned about their water can simply use jugs of drinking water from the grocery store.)

Now, let's bring it all together and look at how the mash is performed. The grain and water are mixed in a special container that keeps the mash temperature hot and constant. The vessel also provides a way to separate the liquid from the solid grain matter once the mash is completed (a process called lautering). Homebrewers frequently use large, insulated picnic coolers that have been adapted with some sort of filter to keep the solids behind, illustrated below. Such a vessel is called a mash tun. (Technically, it's a combined mash/lauter tun, but the "lauter" part of the name frequently gets dropped.)



In the mash tun, hot water is mixed with the grain in a ratio of 1.5 to 2 quarts for every pound of grain.[1,4] The water should be about 10 degrees warmer than our desired mash temperature (to account for heat lost to the grain and mash tun).[1] If the brewer gets the

conditions in the mash correct, all that is left to do is let the enzymes work. The mixture is allowed to sit for about an hour as the starches get dissolved and converted to sugars. After the time is up, the spigot is opened and the sugary water, now referred to as wort, is drained from the mash tun through the screen. Like a sieve or strainer, this keeps the solid husks and spent grain behind, allowing us to drain only the wort.

The first liquid to come out of the mash tun will be cloudy and full of grain particulate too small to be caught by the screen. But as the wort drains, the grain itself will settle and form a natural filter, leading to progressively clearer liquid exiting the vessel. Therefore, the cloudy first portion can be collected in a pitcher and added back into the mash tun once the grain filter has been established and the wort is running clear. This process is referred to as vorlaufing. Afterward, all of the clear wort is drained into a large pot.

The grain gets another rinse with fresh water, called sparging, to ensure that all the sugars get washed into the pot. Just like mashing, there are a few different styles to sparging, but the simplest is called batch sparging. In this method, fresh water is added to the mash tun and is allowed to sit for about 10 minutes.[4] The target temperature for this water is 170° F. This is high enough to allow for good draining fluidity and extraction of all the sugars, but not so hot that it extracts tannins from husks.[1] Tannins are compounds that add astringent flavor to the beer, giving it a mouth-puckering feel.[4]

The wort from the sparge is vourlafed in the same manner as the mash, and is drained into the same pot as before, mixing the two. Now that we've successfully gotten the sugars out of the grain and into the pot, we are ready to move to the next step: the boil.

* * *

As already discussed in the previous chapter, enzymes are explained terrifically in first semester General Biology. You'll learn enzymes' general structure, how they function, various jobs of different enzymes, and ways to enhance and inhibit their activity. Once that class is under your belt, Biochemistry will take enzymes to a whole new level, bringing mathematics into the picture to describe their activity. Enzyme kinetics are extremely pertinent to this step of brewing, and a biochem course will help you more fully understand what's happening inside your mash tun. Biochemistry also teaches you the detailed chemical structures of carbohydrates. These include the sugars and starches important to brewing, but also ones found in other foods and your body (yes, sugar derivatives play important structural roles within us). Second semester Gen Chem thoroughly explains pH and buffers, and the concepts introduced there are utilized frequently in every subsequent chemistry course. After that class, you'll be able to predict how your specific brewing water will behave during the mash, and will understand the tools to manipulate it.

Bibliography

1. Palmer, John J. *How to Brew: Everything You Need to Know to Brew Beer Right the First Time*. 3rd ed. ed. Brewers Publications, 2006.
2. Fix, George. *Principles of Brewing Science: A Study of Serious Brewing Issues* Brewers Publications; 2nd Edition edition, 1999.
3. World Health Organization, *pH in Drinking Water*. Guidelines for drinking-water quality, 2nd ed. Vol. 2. Geneva, 1996.
4. Strong, Gordon. *Brewing Better Beer: Master Lessons for Advanced Homebrewers* Brewers Publications, 2011.
5. Cechovska, L., M. Konecny, J. Velisek, and K. Cejpek. "Effect of Maillard Reaction on Reducing Power of Malts and Beers." *Czech Journal Of Food Sciences* 30, no. 6, 2012.
6. Janson. *Brew Chem 101: The Basics of Homebrewing Chemistry* Storey Publishing, LLC, 1996.

Four Boiling

Once the sugary wort has been drained from the mash tun into a pot, it is placed over a heat source. Typically, the liquid has a set boiling length, around an hour. This step is important for a number of reasons: It helps to remove undesirable flavors from the beer, and plays a role in cleanliness and clarity. It is also vital to the flavoring action of hops, which will also be discussed in this chapter.

As the liquid warms, dissolved proteins that came from the grain begin to clump together, causing the beer to foam. This is referred to as the hot break. If it happens all at once, the foam can boil right out of the pot, so a watchful eye needs to be kept on the kettle. Once the protein globs get big and heavy enough, they will sink back into the liquid and the foam will subside. A good hot break is critical to a clear (not hazy) beer. Most homebrewing experts recommend letting the hot break happen before proceeding to the next steps involving hops.[1,2]

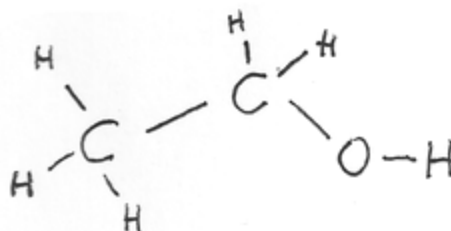
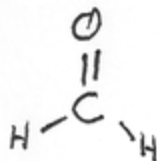
Hops are the conical flowers from the vines of the *Humulus lupulus* plant. They are added to the beer during the boil, and play a huge role in the final product. In fact, hops frequently receive the most attention of all the ingredients in beer. (Highly hopped styles such as India Pale Ales, IPAs, are extremely popular, and many beer drinkers proudly identify themselves as “hopheads.”) It’s somewhat surprising, therefore, that hops did not begin to be used in beer until relatively late in brewing history. As we have seen, beer making has been going on since 6000 BC, but the first written mention of using hops for brewing purposes came in 822 AD.[3] (Prior to that, a spice mixture called gruit was used to flavor beer. Flavoring with fruits like dates was also employed in ancient times.[4]) The hops contribute three qualities to the beer: bitterness, flavor and aroma. Many different varieties of hops are grown, each with unique characteristics relating to these qualities. Some are best for adding bitterness, some are better for flavoring, and some are decent for both purposes. We’ll address hop bitterness first.

Every modern beer has some degree of bitterness. This quality adds to the refreshingness of beer and helps to combat the sweetness imparted by the grain sugars. Bitterness is the result of hop compounds called alpha-acids, but the story isn’t as simple as just tossing in the hops and being done with it. The boiling process induces critical changes to these molecules, which significantly alter their properties for the better. A good understanding of hops requires some knowledge of basic organic chemistry. (Your heart may have just sank, but don’t worry. Our discussion will be kept simple.)

The vast majority of chemical structures important to living things are called organic molecules, simply meaning that they are made up of a lot of carbon. Carbon atoms can attach

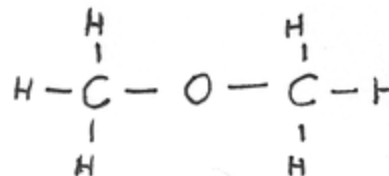
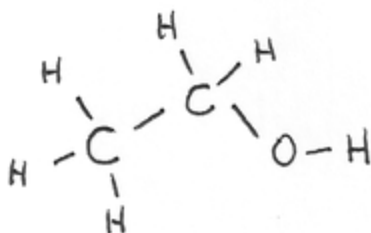
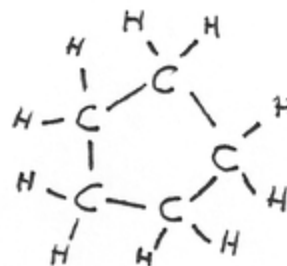
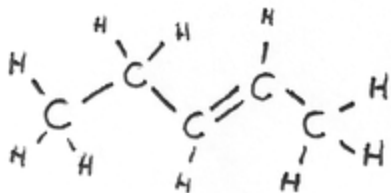
to each other in a variety of fashions, making them great building blocks for the large, complex molecules of life. Except for very rare occasions, carbon always has a total of four chemical bonds, but it does have some variety in how it arranges them. Carbon can form four single bonds, two double bonds, two singles and a double, or one single and one triple.

Always Four Bonds:



Because carbon has a variety of bonding patterns, it's often possible to make a handful of different molecules using all of the same starting atoms. This concept is no more complicated than taking a Lego mansion, disassembling it, and using all the same pieces to build a skyscraper instead. Such structures are called isomers, molecules with the same chemical formula but different arrangements of atoms. Below, the top molecules have the formula C_5H_{10} , and the bottom are both C_2H_6O .

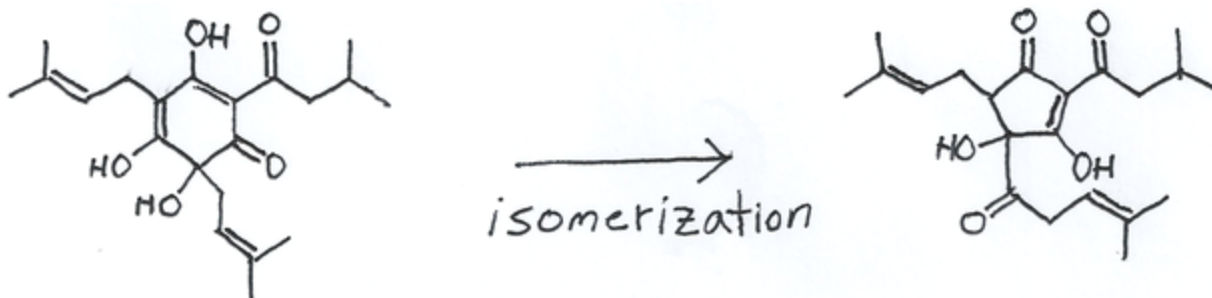
Some Isomers:



As you might imagine, even though isomers are made up of exactly the same atoms, they can behave quite differently from one another. (We have already seen how important shape is to enzymes, and the same is true for most molecules. In fact, one of the overarching themes of chemistry and biology is that “structure determines function.”) The process of rearranging the shapes of molecules is called isomerization, and it happens to hop compounds during boiling, drastically altering their chemical properties.

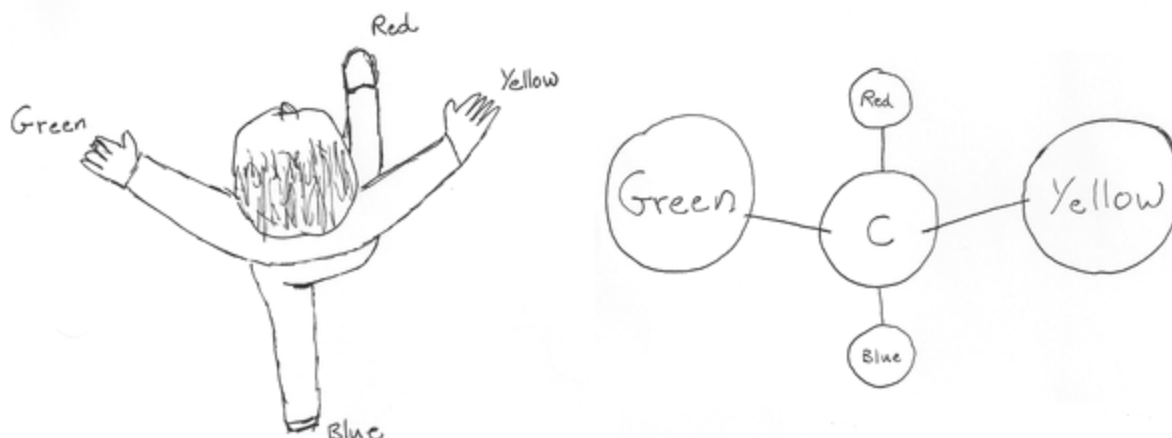
When the hops are first added, the alpha-acids do not taste all that bitter, nor do they dissolve into our wort (when something won't dissolve or mix, scientists call it insoluble). The

heat from the boil cause the alpha-acids to isomerize into a different shape that tastes more bitter to us, and is soluble. The longer the hops are boiled, the more alpha-acids become converted to this form. Therefore, hops that are added early get boiled for longer, and are responsible for the bitterness in the final product. The conversion of an alpha-acid, named humulone, to isohumulone, is shown below.[5]

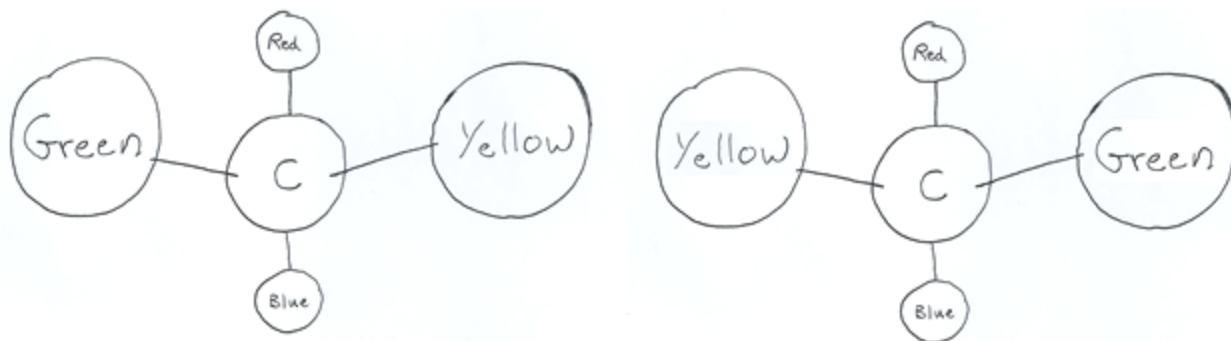


The difference in structure of the alpha-acids before and after boiling is quite apparent. But even subtler shape changes can drastically affect a molecule's properties. This next example, though not directly applicable to beer, is a really cool demonstration of how a very small variation in structure gives two isomers completely different perceived flavors. The change is an alteration of the molecule's stereochemistry, a topic that deals with the three-dimensional orientation of the bonds around carbon. In a special case where a carbon has four single bonds to four different things, we have some interesting things that can happen.

Imagine that your torso is a central carbon, and your hands and feet each represent a different atom, symbolized by different colors. Your arms and legs each represent a single bond that connects the atom back to your carbon torso. Now imagine standing with your right foot planted in front of your body, left foot behind, with your arms raised and out to the side (pictured below). This is very similar to how a carbon atom has its bonds positioned in space. (The name of this shape is a tetrahedron. It's also important to know that the whole bond positioning changes when the carbon has anything other than four single bonds.)



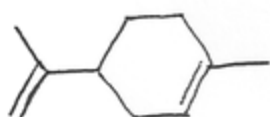
Now imagine swapping the colors on your two hands, and doing the same for the corresponding molecule. It is only a minor change, but with some mental rotation, you will see that these two molecules are now different. No matter how you twist or rotate them, they will never match up perfectly again.



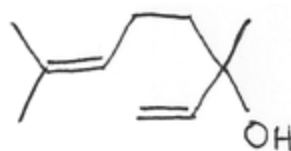
In organic chemistry terms, the situation we've just described is stereochemistry around a chiral carbon, and the two versions of the molecule are a special kind of isomer, called enantiomers. Similar to the difference in taste between isomers of hop acids, the flavor of a natural compound called carvone varies greatly between its two enantiomers. Although the shape difference is subtle - swapping the arrangements of just two bonds - one form of carvone tastes like wintergreen, while the other tastes like anise, the flavor of black licorice. Compared to alpha-acids, the shape difference between carvone enantiomers is much less, but the flavor change more drastic. (Sorry for the sidetrack, now back to beer.)

Hops also contain compounds called beta-acids, but these behave differently than the alpha-acids just discussed. Rather than being isomerized by boiling, beta-acids become bitter by interacting the oxygen gas. Their bitterness is described as being harsher and less desirable in beer than that of alpha-acids. With proper storage and technique, avoiding excessive contact between beer and air/oxygen limits the isomerization of beta-acids, sidestepping development of harsh flavors.[2]

Aside from just contributing bitterness, hops also add flavors and aroma to the beer. However, the compounds which are responsible for these characteristics are quite different from the hop acids. They come in the form of oils, and rather than getting more powerful with boiling, the opposite is true. Because they are volatile (meaning they evaporate pretty easily) they get carried out of the wort as it boils. For this reason, hops that are intended to impart hoppy flavors should be added toward the end of the boil. Different varieties of flavoring hops can have descriptions like "citrusy," "spicy," or "earthy." [1] A couple of these compounds are shown below. Limonene contributes a citrusy aroma to beer,[7] and linalool is described as floral.



Limonene



Linalool

In summary, hops for bittering need to be boiled for a long time in order to isomerize, and hops for flavor can't be boiled for too long because the compounds will be lost. Therefore, the brewer typically makes multiple hop additions at different times throughout the boil, according to the recipe. (So the next time you see a national television ad where a company brags that its beer is superior because it's "triple hopped," don't be fooled. Three hop additions is nothing special and standard for imparting bitterness, flavor, and aroma.[8])

Even though boiling might remove some of the desirable hop compounds, it also gets rid of molecules that hurt our beer. Making sure that these compounds get removed is imperative to a good tasting end product. Certain harsh hop oils, particularly those containing sulfur, need to be boiled off.[6] Dimethyl sulfide, a compound that imparts a taste of cooked vegetables, also needs to be removed for most beer styles. The precursor to this compound is S-methylmethionine, a sulfur-containing amino acid derivative that arises during germination.[1] (Like glucose, amino acids are monomers that can be joined to form polymers. Proteins, the central substances necessary for life,[9] are made up of many linked amino acids.) In order to ensure these compounds leave the beer, the pot lid should never be left completely on during the boil.[1,10]

Another set of important reactions that occur during the boil (and also during malting and mashing) are Maillard reactions. These occur between sugars and amino acids, and the products depend on the amino acids involved, temperature, and how much sugar is in the wort (referred to as wort gravity).[1] Some of the compounds produced contribute highly prized malty flavors,[6] however, these can be inappropriate in light beers. To minimize these reactions for lighter beers, Palmer recommends a lower-gravity wort, containing less dissolved sugars. These reactions also cause darkening in the color of the wort (and because of this, are sometimes mistakenly referred to as "caramelization" reactions).[1]

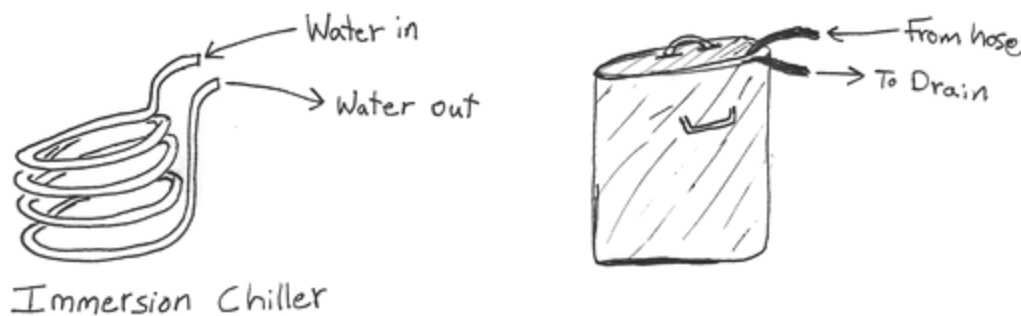
The final contribution of the boil is sterilization of the wort. We have already seen how contaminating microbes were ruining beer in the days of Pasteur, and the same can happen today. Unappetizing flavors like vinegar and medicine can occur when beer gets infected with microorganisms other than our yeast (though they will rarely make us sick).[1] To avoid losing a whole batch of beer to these tiny culprits, cleanliness is of the utmost importance to the brewer. (Good brewing is clean brewing.) We now need to define some terms on the topic: clean, sanitized, and sterile. Clean simply means free of dirt and crud. *Everything* that ever makes contact with the beer should be clean. Sanitized means that the object has been treated with some sort of chemical sanitizer to reduce microbes to negligible levels.[1] To be sterile means that every living organism on an object has been killed.

Obviously, sterilizing every piece of brewing equipment would be most effective in preventing an infection in our beer, but it is not practical. Bleach or chemical sanitizers for the foodservice industry are used instead, reducing microorganisms to insignificant amounts. But not everything needs to be sanitized: because the wort will be boiled for an hour, any piece of equipment employed before the boil (mash tun, thermometer, vourlaf pitcher, etc.) need only

be clean. Boiling will kill any microbes that got into the wort from these objects. However, all equipment that touches the beer *after* the boil should be sanitized.

The next step is cooling down the wort to an appropriate temperature so we can add our yeast (called pitching). The quicker it's cooled down, inoculated with yeast, and put away to ferment, the less likely it is that contaminating microbes can get into it. Rapid cooling also helps precipitate more haze-causing proteins, this time called the cold break.[1] Fast cooling has advantages from a chemistry standpoint as well. Dimethyl sulfide will continue to be produced while the wort is hot, and we would like to minimize its production.[10] Also, excessive contact with oxygen in the air while the wort is hot will lead to oxidation of fatty acids, giving beer a taste of wet cardboard. Cooling to below 80° F should prevent oxidation.[1] According to Palmer, oxidation is the most common problem with beers, including the ones you buy at the store.

Methods of cooling include placing the pot in a sink or bathtub filled with ice water, or simply setting it outside if it's winter. A faster, more advanced method is the immersion chiller, a copper coil with cold water running through it (usually from a garden hose spigot). The sanitized chiller is placed in the pot, cold water enters one end of the tubing, goes through the coil, and flows out the other end. The water never makes direct contact with the beer, but carries away the heat from the wort as it flows through the coil.



In the next step, we introduce yeast to our beer. Because yeast are living creatures, it helps to have some knowledge of basic biology. Therefore, we will save them for our next and final chapter: Fermentation.

* * *

Hops are all about organic chemistry, the field that focuses on the carbon-based structures of life. Two semesters of Orgo class will allow you to take one look at a once intimidating organic compound (like those found in malt and hops) and predict its properties and chemical behaviors. In this chapter, we also discussed ways to keep our beer from being infected with microbes, requiring good *aseptic technique*. Introductory Microbiology Lab teaches you methods to avoid contamination, knowledge that can be directly applied in the brewhouse. The lecture portion of Microbiology also discusses the strengths and weaknesses of many methods to inhibit microbes, including different sanitization methods and sterilization.

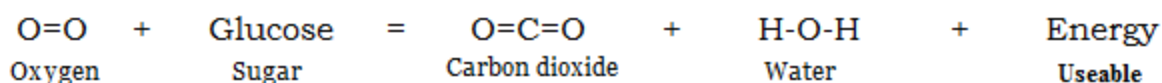
Bibliography

1. Palmer, John J. *How to Brew: Everything You Need to Know to Brew Beer Right the First Time*. 3rd ed. ed. Brewers Publications, 2006.
2. Strong, Gordon. *Brewing Better Beer: Master Lessons for Advanced Homebrewers* Brewers Publications, 2011.
3. Esslinger, Hans Michael. *Handbook of Brewing* Wiley-VCH, 2009.
4. Hornsey, Ian S. *History of Beer and Brewing*. RSC Paperbacks. Royal Society of Chemistry, 2003.
5. Lord, Richard. "The Science of Hop Bitterness." Presentation slides, emailed to author. 2015.
6. Fix, George. *Principles of Brewing Science: A Study of Serious Brewing Issues* Brewers Publications; 2nd Edition edition, 1999.
7. Steinhaus, Martin, Wolfgang Wilhelm, and Peter Schieberle. "Comparison of the most Odour-Active Volatiles in Different Hop Varieties by Application of a Comparative Aroma Extract Dilution Analysis." *European Food Research and Technology* 226, no. 1-2, 2007.
8. Palmer, John. "Hop Bitterness and Aroma Development in Beer." *HopUnion Hop and Brew School 2014*. https://www.hopunion.com/library/John%20Palmer_HopBitternessAroma.pdf
9. Reece, Jane B. and Neil A. Campbell. *Campbell Biology* [Biology]. 9th ed. Pearson Education, 2011.
10. Janson. *Brew Chem 101: The Basics of Homebrewing Chemistry* Storey Publishing, LLC, 1996.

Five Fermentation

In the last stage of brewing, the story of beer comes full circle. We started off the process with a discussion of energy: grains captured light energy from the sun within the sugars they produced. The sugars were made accessible to the brewer during malting. The brewer extracted the sugars from the grain during mashing. Here, the sugars finally fulfill their destiny: they are eaten by yeast, releasing the energy that was initially stored in them. But the process is a little more complicated than yeast simply going to town on the fermentables and making alcohol. To really understand it, we need to talk a little bit about how living organisms function and different methods of releasing energy.

Everyone knows that humans need oxygen to live. This is because the gas is part of the main chemical reaction that keeps our bodies going. It's a reaction that releases energy in a useable form to fuel life, and we've actually seen it before (just in reverse). The process is called cellular respiration, and it turns out that it is the exact opposite of the photosynthesis equation:



So when oxygen-breathers like us and most of the things we think of as “animals” break down sugar, this is how it's done. (It's also important to note that sugar is not the *only* substance that living things can use as fuel: others like fat and protein can be converted to sugar-like intermediates in order to be processed in the pathway above.)

But our yeast (and a lot of other microbes too) aren't necessarily limited to this method for releasing energy. Some creatures are also capable of getting energy without oxygen. Organisms of this kind are referred to as *facultative anaerobes*, simply meaning that they can live with or without oxygen. This is where fermentation comes into the equation (no pun intended). Fermentation is another process that allows an organism to release glucose's energy, but it does not require the presence of oxygen and makes alcohol as a byproduct. The simplified fermentation equation is shown below:



It turns out that a lot more energy is released when glucose is broken down by respiration versus fermentation, about 15 times as much.[1] We've already discussed that the basis for extracting energy from sugar is a rearrangement of the bonds from high energy ones to lower energy ones. It turns out that the chemical potential energy “drop” from glucose and O₂ to CO₂ and H₂O is *greater* than the drop from glucose to CO₂ and ethanol (the specific kind

of alcohol that is produced). If you think back to the diagram from Chapter 2, a greater drop means that more useful energy is released to be harnessed by the yeast.

Since yeast are capable of performing both methods, and cellular respiration yields a lot more energy than fermentation, it seems like they would prefer to use respiration whenever possible (in other words, whenever oxygen is present). However, this is not the case: brewer's yeast actually prefers alcoholic fermentation, even in the presence of oxygen.[2] The reason is that a typical wort has so much sugar available, the yeast don't feel the need to squeeze every last bit of energy out of it. In short, they're being wasteful,[2] but since they wouldn't be making any alcohol if they were using respiration, the brewer doesn't complain.

Even though yeast do not use oxygen to respire, the molecule is still helpful to them in another way. Yeast cells reproduce in a process called budding, where a daughter cell grows from the parent cell, and they eventually split.

Budding yeast



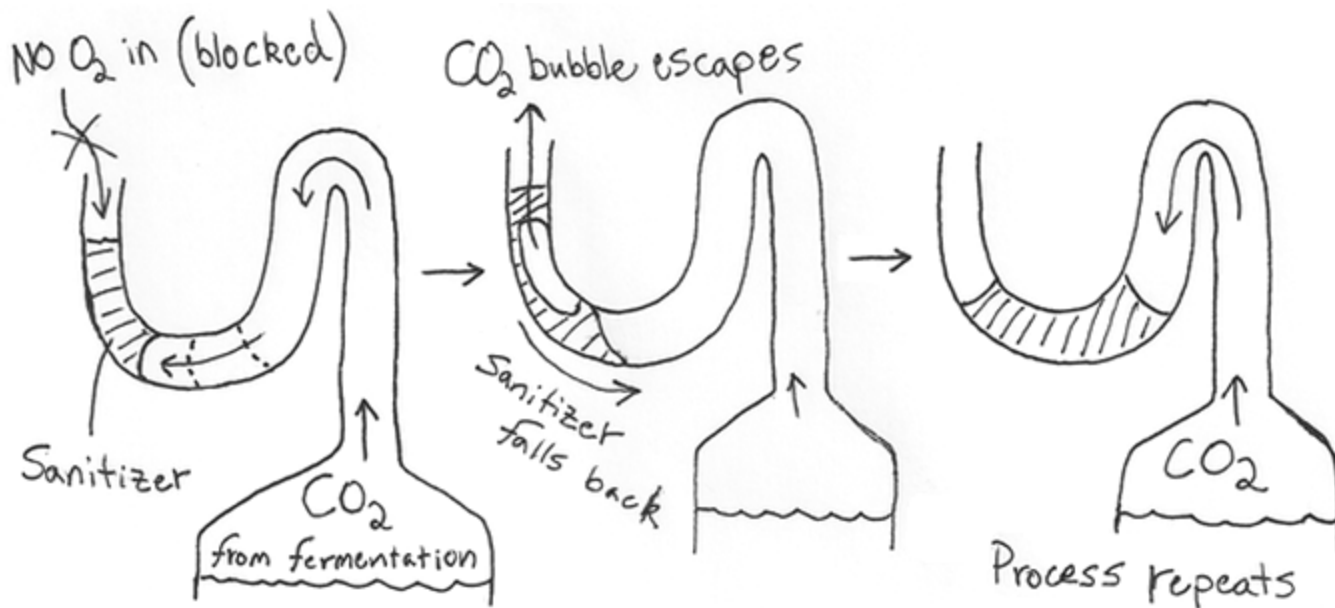
In the process of budding, the surface area of the cell needs to increase quite a bit. The surface of the cell, or the cell membrane, is made of molecules called fatty acids and sterols. Thus, it requires a lot of these compounds to bud and reproduce. It turns out that oxygen is very helpful to yeast for the synthesis of these compounds.[2,3]

We want a lot of yeast reproduction to occur so that there are many cells around to carry out the fermentation of the wort. In order to aid in that reproduction, a lot of O_2 is introduced by the brewer. Once the wort has been cooled to a temperature appropriate for adding yeast (called pitching), the liquid is aerated. (As mentioned in the last chapter, exposure to air while the wort is still hot can lead to oxidation. Aeration is good, oxidation is bad.) Aeration can be performed by simply pouring the wort back and forth a few times between two sanitized buckets.[3]

Once the beer has been sufficiently aerated, it gets transferred to a fermenter. The fermenter is the container where the beer will sit for a matter of weeks while the yeast do their thing. The most popular fermenter styles for homebrewers are large plastic buckets with airtight lids, or giant glass jugs called carboys. As soon as the wort is inside the fermenter, it's time to pitch our yeast. The organisms come in a couple different styles: liquid yeast cultures that are poured directly into the wort and dry packets that may be sprinkled in. (Dry yeast can also be "rehydrated" in sugar water for an hour before pitching, and then poured into the wort. Rehydration is crucial according to some homebrewing experts.[3])

While the wort is fermenting, we do not want oxygen or other microbes getting into it.

(Oxidation and infections both cause off flavors.) But the chemical equation for fermentation tells us that CO_2 gas is produced in addition to alcohol, and this gas needs to be allowed to escape. Thus, brewers employ a genius, yet simple device called an airlock, the concept of which is shown below. The airlock works as a one way valve, allowing the carbon dioxide to escape, but preventing anything else from getting into the fermenter.



A little sanitizer is poured into the device and settles at the bottom of the “U” shaped tube. This blocks any oxygen or airborne microbes from getting through to the wort. As the CO_2 is produced, it pushes against the sanitizer until it rounds the bend and bubbles up. As soon as the bubble is released, gravity causes the sanitizer to fall back into place and the process can repeat. The outside world is never able to make contact with the fermenting wort. (A couple different styles of airlocks are used by brewers, but this is the simplest to visualize.)

Fermentation will continue for a couple of weeks. But yeast are not robots that solely take in sugar and release ethanol. Different yeast varieties have character and personality, and produce compounds that add to the distinct flavor of a beer. Notably, yeast make organic molecules called esters during fermentation, various levels of which are required for certain beer styles. Esters are typically associated with fruity flavors, like banana and apple.[1] The temperature of fermentation plays a big role in the production of these compounds.[3] Additionally, phenolic compounds produced by yeast can give beer a peppery character, among other flavors.[3] The key thing here is that just like malt and hops, brewers have access to a wide variety of yeast strains which can each impart different characteristics to the beer. Most recipes explicitly state what type of yeast best suits the intended style (in the opinion of the recipe author).

In an earlier chapter, we noted that some distinct beer styles have become associated with specific geographical areas based upon water chemistry. Another way that a particular

style can develop in a certain area is from the specific yeast strains preferred there. For example, Belgian beers owe their uniqueness to the ester-producing yeasts of the region.[3] On the other hand, the strains from the Pacific Northwest are known for accentuating maltiness.[4] Over time, traditional beer styles developed due to the area's local yeast strain. (These strains can be so important to producing a specific beer that the brewery keeps them highly protected, even patented.[5]) What is really cool is that the homebrewer has access to many diverse strains from around the world through their local homebrew shop.

As mentioned throughout the book, wild yeast strains also exist, but their results when used for brewing can be unpredictable. However, some brewers do rely on them to ferment their brews with great results, not bothering to add yeast themselves. Recently, kits have been sold that allow homebrewers to capture yeast from the environment and grow up a lot of them (called culturing). These environmental yeast cultures can be used to ferment beer instead of store bought yeast brands.

Once fermentation has completed, it is time to bottle the beer. (Advanced homebrewers may have the ability to keg their beer, in which case the following steps are not employed.) In this process, beer is transferred slowly from the fermenter into a spigoted bucket using a siphon. Special care is taken to avoid splashing the beer, as contact with oxygen can (again) cause oxidation, giving the beer bad flavors like wet cardboard.[3] In the bottling bucket, a little more glucose sugar is added, and we will address why in a moment. Sanitized bottles are filled with the young beer and capped using a bottle capper.

Now that the yeast have been given some new sugar, they perform the same fermentation reaction as before. In this case, however, there is no airlock allowing the escape of the carbon dioxide gas produced - the bottle is sealed with a cap. Instead, the CO₂ dissolves into the beer, giving it "carbonation" and fizziness. This step relies on the presence of living yeast in the bottle. As the beer carbonates and ages, these yeast will slowly sink and form a layer on the bottom of the bottle. When the beer is carbonated and ready to be enjoyed a few weeks later, the beer can just be poured off this yeast layer, leaving it behind. Of course, that yeast is perfectly safe (and healthy) to drink if you want, but may give you some gas.

* * *

The topics of cellular respiration and fermentation are a big focus of General Biology I. This class gives you the big picture: you'll learn the general processes and why each is performed in the context of life. Then, after Organic Chemistry has taught you how to handle the structures and reactions of the molecules of life, Biochemistry gives you the detail. You'll learn the specific structures and enzymes involved in both respiration and fermentation. Introductory Microbiology will teach you the process of how single celled organisms (like yeast) divide to reproduce, as well as the environmental conditions that certain ones prefer. This can help you understand how to tailor a wort to yeast's biological needs.

Bibliography

1. Janson. *Brew Chem 101: The Basics of Homebrewing Chemistry* Storey Publishing, LLC, 1996.
2. Aquilla, Tracy. "The Biochemistry of Yeast: Debunking the Myth of Yeast Respiration and Putting Oxygen in its Proper Place." *Brewing Techniques* 5, no. 2, 2013.
http://www.morebeer.com/articles/how_yeast_use_oxygen.
3. Palmer, John J. *How to Brew: Everything You Need to Know to Brew Beer Right the First Time*. 3rd ed. ed. Brewers Publications, 2006.
4. "WLP041 Pacific Ale Yeast | White Labs."
<http://www.whitelabs.com/yeast/wlp041-pacific-ale-yeast>.
5. "Pacman Yeast from Rogue - Wyeast 1764 - Rebel Brewer Rebel Brewer."
<http://www.rebelbrewer.com/shop/ale-yeast/pacman-yeast-from-rogue-wyeast-1764>.

Conclusion

It has been a long journey, but the beer is finally ready to be enjoyed, a well-deserved reward for your hard work. But we have only taken a brief glimpse at beer. Many more resources exist, from books, classes and conferences to college professors or the homebrewing heros at your local supply store. If beer and brewing has piqued your interest, I strongly encourage you to pursue it further. I hope that this has been an educational and approachable read, offering you an introduction the brewing process and the science behind the steps. And I hope that like me, brewing has made you smarter.

* * *

I want to thank Grand Valley State University and the Frederik Meijer Honors College for allowing me to complete this exciting project; particularly, the Food for Thought Honors class for the opportunity to present and brew with them. I would also like to specifically thank Dr. Richard Lord for his gracious advisement on this project, and also for his continued support of the art and science of brewing at this institution. Finally, I want to thank all of the top-tier professors throughout the years who have made my time at this university an immensely educational and truly grand experience.