BICEP #7

This session covers yeast and fermentation, acetaldehyde, diacetyl and estery off-flavors and Style Categories 15 & 16 - German Wheat & Rye Beers and French & Belgian Ales.

Key to Abbreviations and Text

Bolded Text (except for headers) is important information which you should know for the exam.

Italic Text is "just for fun" and won't be covered on any of the exams.

***** This material might appear on the Online Qualifier Exam.

† This material might appear on the Tasting Exam.

‡ This material will be (or might be) tested on the Written Proficiency Exam.

Part 1: Yeast and Fermentation*‡

What It Is: Yeasts are Class of unicellular organisms within the Kingdom of Fungi. Brewers are most interested in yeasts of the genus Saccharomyces (Greek for "Sugar Fungi"); especially S. *Cerevisiae and* S. *Uvarum*. The differences between the various species of Saccharomyces are slight and they can easily hybridize, leading to some dispute over whether a particular species constitutes a truly different species or is just a strain or hybrid.

History: *Humans have been using yeast, without knowing it, since prehistoric times. Yeast naturally occurs on fruit skins and grain husks and in honey, and, under the right conditions, will spontaneously convert the sugars in these products into ethanol. Neolithic people eventually figured out how to produce intoxicating beverages by soaking mashed-up fruit, honey or grain in water and waiting. In essence, brewing was the first form of biotechnology. Vessels containing traces of liquids containing honey, fruit and grains have been dated to approximately 5,000 BCE and fossilized yeast spores have been found remains of Egyptian bread dating from approximately 2,000 BCE (Since leavened bread uses S. Cerevisiae, bread-making and brewing were related industries until early modern times). While vintners could rely on natural yeasts found on grape skins to ferment their grape must, brewers had to rely on naturally occurring yeast found in their brewery or in the local bread or beer. As a result, until the advent of industrial brewing, every village must have had its own unique strain of beer yeast. Medieval English brewers called the "something" that turned wort into beer "Goddesgoode" (God is Good). Scientists first suggested that microbes were necessary to fermentation in 1680, but Louis Pasteur was the first to prove this idea (1876). Emil Christian Hansen was the first to isolate brewing yeast (S. uvarum, 1883) and the first to recognize it as the necessary agent in fermentation (1888).* Since then, brewers have attempted to isolate and use pure strains of yeast. Since yeast is the most important ingredient in determining a beer's flavor, breweries carefully protect their "house" yeast from infection, contamination or genetic drift. Some protect their yeast just as carefully against their competitors!

Meet the Family: Brewing strains of S. *Cerevisiae* are used to ferment ales, while other strains are used to leaven bread or to ferment wine (S. *Cerevisiae*, *var.* Epsiloidins). Even though they are all the same species, however, wine yeast strains produce undesirable esters (recalling solvents or rotten fruit) when used to ferment beer, while beer yeast used to ferment wine gives off flavors and attenuates poorly. Likewise, bread yeasts are poor attenuators and produce distinct bready flavors when used to ferment beer or wine. *Ale yeast* strains of S. *Cerevisiae* are often referred to as "top fermenting" (i.e., top-flocculating) yeasts.

Lager yeasts (variously called S. *Uvarum*, S. *Carlsbergensis*, or S. *Cerevisiae var.* Uvarum) are hybrids of S. *Cerevisiae* and S. *Bayanus* and **are often referred to as "bottom fermenting" (i.e., bottom-flocculating) yeasts.** George Fix describes S. *uvarum* as "a largely undesirable" mutant of S. *carlsbergensis*. It is sometimes found in champagne yeast mixtures because it attenuates well.

There is some evidence that lager yeast was actually introduced to Europe from Patagonia in South America in the 15th century, (possibly on barrels made of wood from South American trees, which returned with ships exploring the New World).

Wild yeasts in the Saccharomyces genus include S. *Bayanus* (a wild wine yeast), S. *Diastaticans* (a superattenuating wild yeast that produces phenolic off-flavors) and S. *Pastorianus* (a contaminant in wine and beer yeasts). All of these produce off-flavors.

Specialty yeasts include S. *Florentinus* (an alcohol-tolerant champagne yeast) and S. *Ludwigii* (developed for "no alcohol beers; it ferments sugars but it doesn't produce ethanol!).

A. Yeast Life Cycle

The yeast life cycle can be divided into five main phases: Lag Phase, Growth Phase (AKA Respiration or Exponential Phase), Fermentation (with sub-phases called low kräusen, high kräusen and late kräusen), Flocculation Phase (AKA Sedimentation) and Dormancy. Different texts might use different terms to describe these phases.

1. Lag Phase

Time: 0 to 24 hours after pitching, usually about 8 hours for ales, longer for lagers.

What's Happening?: Yeast acclimatizes to its environment (assessing dissolved oxygen levels, amino acid, Free Amino Nitrogen, sugar levels, etc.), begins to make enzymes needed to grow and ferment the wort and begins to import some peptides (short chains of amino acids) and sugars to start cell division. During this time, it relies on internal reserves of glycogen, which it converts to glucose. Normally, the lag phase is very brief (as short as a few hours), but if the yeast isn't healthy this period can be very protracted, ultimately causing problems.

Effect on Wort: Wort pH drops. Dissolved oxygen begins to drop. Low glycogen levels mean higher VDK (diacetyl) levels and longer lag time. **An extended lag phase can allow bacterial or wild yeast infection to take hold, and can cause the beer to develop off flavors or to mutate as it adjusts to its new conditions.**

2. Growth/Respiration/Exponential Phase

Time: 12-24 hours after pitching.

What's Happening?: This phase begins when the yeast has built up its internal food and enzyme levels up to sufficient levels. Yeast absorbs and uses oxygen, sugars (which it converts to glycogen) and nutrients and oxidizes acid compounds. The cell absorbs oxygen and amino acids to produce sterols, which it uses to enlarge its cell walls. **It uses aerobic respiration to grow during this phase. When a yeast cell reaches sufficient size it begins to divide, reproducing itself by budding.**

Cell division occurs by budding until yeast reaches maximum population density, exhausting available dissolved oxygen and true fermentation begins. If the yeast culture is healthy, has been pitched in sufficient quantity, and has sufficient levels of nutrients and dissolved oxygen, it should only double itself one to three times before reaching maximum density. **If enough yeast is pitched to reach maximum population density, the growth phase will be very short or entirely absent.**

Effect on Wort: Wort pH drops further. Dissolved oxygen depleted. Foam appears on wort at sides of fermenter. Action of aerobic and acid-sensitive bacteria inhibited. Some alcohol production begins due to the Crabtree Effect (AKA Glucose Repression - where production of alcohol in an aerobic environment when sufficiently high sugar levels are present).

The situation where the yeast starts to ferment in the presence of high glucose levels is called glucose repression, or the Crabtree Effect. The yeast produces carbon dioxide (CO_2), water (H_2O) and flavor and aroma compounds, the latter as a result of minor metabolic pathways.

Excessive yeast levels can lead to a distinct off flavor called "yeast bite."

Insufficient levels of dissolved oxygen inhibit growth, leading to sluggish fermentation and increased production of minor metabolic compounds due to insufficient yeast cell count.

3. Fermentation Phase

Time: Up to 3 to 7 days after pitching.

What's Happening?: When the yeast culture has exhausted all the dissolved oxygen in the wort, or if the wort contains more than 0.4% glucose, the yeast begins to use a form of anaerobic respiration called Fermentation. Fermentation produces about ~45% ethanol, ~50% carbon dioxide, ~5% new cells, and trace amounts of higher alcohols and other flavor/aroma compounds (e.g., acetylaldehyde, esters, fusel alcohols, ketones, phenols and vicinal diketones - VDK - such as diacetyl).

There are three sub-phases:

I. Kräusen (AKA Low Kräusen): Yeast scrubs remaining oxygen from wort and begins anaerobic respiration (fermentation). Yeast are fully adapted to wort conditions; transport of amino acids and sugars into the cells for metabolism is very active. Minor metabolic products, such as acetaldehydes, diacetyl and esters are produced.

II. High Kräusen: Most vigorous fermentation. Top-cropping of ale yeast (for reuse) is most productive at this phase. Yeast metabolizes most sugar present in the wort. Lager yeast may still be in growth phase while also reducing the extract by four gravity points per day (Crabtree Effect).

Ale yeast will have metabolized most of the sugars present in the wort and begins to scavenge fermentation byproducts excreted during low kräusen, such as diacetyl and acetylaldehyde. Lager yeast might still be multiplying and metabolizing sugars during this period, slowly reducing the wort's Specific Gravity by up to 0.004 points per day.

S. Cerevisiae & Cousins

Kingdom: Fungi
Phylum: Ascomycota
Subphylum: Saccharomycotina
Class: Saccharomycetes
Order: Saccharomycetales
Family: Saccharomycetaceae
Genus: Saccharomyces
Species:

S. cerevisiae (Ale, bread & wine yeast)
S. Carlsbergensis (Lager yeast)
S. bayanus (wild wine yeast)
S. diastaticans (superattenuating wild yeast)
S. florentinus (champagne yeast strain)
S. ludwigii (no-alcohol beer yeast strain)
S. pastorianus (wild wine & beer yeast)
S. uvarum (mutant lager yeast)

The Weird 2nd Cousins

Genus: Brettanomyces
Species: B. *anomalus*, B. *bruxellensis*, B. *custersianus*, B. *lambicus*, B. *naardenensis*, B. *nanus* (all responsible for the unique flavors of lambics and sour beers).

Two Evil Families of 2nd Cousins

Genus: Hansensula (wine & beer spoilage)
Genus: Kloekera (wine & beer spoilage)

A Really Evil 2nd Cousin

Genus: Candida
Species: C. *albicans* (yeast infections, wine spoilage)

III. Late Kräusen: Some reproduction and flocculation, and some fermentation byproducts (VDK, acetylaldehyde) are metabolized.

Effect on Wort:

- **Kräusen:** A "wreath" of foam develops on the top of the fermenting wort, migrating from the sides of the fermentation vessel to the center.
- **High Kräusen:** Tall, rocky foam on head, vigorous fermentation. Suspended trub can be carried out of solution by carbon dioxide and foam.
- **Late Kräusen:** Fermentation slows, foam begins to fall. Some flocculation of yeast.

Higher temperature fermentation promotes the production of off-flavors and off-flavor precursors (esters, higher alcohols). Low temperature fermentation might slow or inhibit fermentation and keep yeast from reducing off-flavor compounds (acetaldehyde, VDK) during Late Kräusen. To aid reabsorption, some lager brewers use a Diacetyl Rest during Late Kräusen (see below).

In some cases, the yeast might preferentially uses oxygen to produce glycogen rather than ethanol, even in the presence of high glucose levels or after fermentation has begun. This is called the Pasteur Effect. It can occur if oxygen is introduced into the wort after the yeast reaches primary fermentation.

Another risk to yeast during primary fermentation is cold shock, where the wort is chilled too quickly. This causes the yeast to prematurely flocculate (see below), before fermentation is complete and before it can reabsorb all its fermentation byproducts. As a rule, fermenting wort should be cooled at no more than 5° F per day.

4. Flocculation/Sedimentation Phase

Time: Usually 3 to 12+ days after pitching.

What's Happening?: The yeast has exhausted all its food sources and starts to go dormant. Yeast finishes scrubbing metabolic byproducts (VDK, etc.) out of wort and forms glycogen. It then flocculates and sinks to the bottom of the fermentor. Flocculation rate depends on yeast strain. Some highly flocculent yeast strains might need to be roused to finish fermentation. Other strains don't flocculate well, meaning they must be filtered out or else the beer must be conditioned for long periods of time to get sufficient sedimentation rates.

Effect on Wort: Wort clears as yeast falls out of suspension. Yeast cake begins to form on the bottom of the fermentor. Some strains of yeasts form clusters called "flocs" and associate with CO2 bubbles to rise to the surface of the green beer. Other strains just fall to the bottom of the fermenter. Once they fall out of solution, many yeast cells die and begin to decay (autolyse).

5. Dormancy Phase

Time: More than 3 to 12+ days after pitching, once flocculation occurs.

What's Happening?: Metabolism slows. Yeast becomes inactive and eventually dies (weeks or months, but sometimes years). At death, compounds within the yeast cell break it down (autolysis), releasing unwanted byproducts into the beer (enzymes, off-flavor chemicals. Enzymes produced during autolysis attack other compounds in the beer, accelerating staling. Starches, amino acids, etc. produced by the decaying yeast provide food for new generations of microorganisms.

Effect on Wort: A solid yeast cake forms on bottom of fermenter. Yeast autolysis can impart off flavors if beer is allowed to sit on the trub for extended periods of time (1+ month).

B. Pitching Yeast

The act of adding yeast to freshly chilled wort is called pitching. It is one of the most important phases in yeast propagation.

Wort Chilling: Before yeast can be pitched, the wort must be chilled to proper pitching temperature - typically 5 °F above the yeast's preferred fermentation temperature. The yeast culture must also be warmed or cooled to approximately the same temperature range, lest the sudden change in temperature shock the yeast.

Nutrient Levels: In addition to sugars, yeast requires a sufficient supply of nitrogen, phosphorus, vitamins and trace minerals, although exact nutrient requirements vary by yeast strain. All malt wort is typically high in nutrients, with sufficient levels of FAN and other nutrients for yeast health, with the exception of oxygen and zinc. For extra yeast nutrition, some brewers use diammonium phosphate (DAP) and ammonium sulfate. Vitamin for yeast health are biotin (AKA vitamin B_7), niacin (AKA nicotinic acid or vitamin B_3) and pantothenic acid (AKA pantothenate or vitamin B_5).

Minerals required are calcium, potassium, magnesium, zinc and other trace metals (e.g., chromium copper, iron and manganese). Yeast requires least 50 ppm of calcium and 0.1 to 0.15 ppm of zinc. Calcium can be added during mash pH adjustment. Zinc can be added by adding zinc sulfate or zinc chloride at a rate of 0.2-0.3 mg/L of these compounds near the end of the boil. Commercial products such as Servomyces™ can also supply sufficient yeast nutrients. Homebrewing systems which incorporate some copper or brass fittings can also impart some copper and/or zinc to the wort.

Overuse of metallic salts or vitamins can impart unpleasant metallic notes to the finished beer, however.

Pitching Rates: To get the proper cell count, a brewer needs to make a starter, reuse fresh yeast slurry or pitch one or more packets of liquid or dry yeast. A rule of thumb for pitching rates is 1 million cells per 1 milliliter of wort per degree Plato. Multiply this by 0.75 for ales or 1.5 for lagers.

To convert this to cells per gallon per point of specific gravity, multiply by cell count by 14.7 (where there are 3785.4 ml per gallon, and the conversion formula for degrees Plato to points of specific gravity is °Plato/(258.6-((°Plato/258.2) x 227.1))+1).

There is no hard and fast rule on pitching rates, however. Some yeast strains, or the same yeast stain under different conditions require slightly higher or lower levels, down to a minimum of a 0.5 multiplier for German wheat beer strains and some British style ales.

Cell counts at 1 million cells or above make a culture visibly turbid. Cell densities are 5-15 cells/ml at the beginning of fermentation to 25-60 million cells/ml at the end. Top- or bottom-cropped yeast slurry is likely to have 0.8-2 billion cells/ml. Dry yeast contains 7-20 billion cells per gram.

A simpler rule of thumb is to pitch 0.5-1.5 quarts of healthy yeast starter per 5 gallons of wort for low to medium-strength ales, 4 quarts for strong ales, 3 quarts for lagers and 7 quarts for strong lagers. When using pure yeast cultures, like smack packs or yeast slurry, read "cups" or "packs" for quarts. For dry yeast, read "packs" for quarts.

Aerating the Wort: Since freshly-boiled wort doesn't contain any oxygen the brewer must add it by aerating the wort. The proper level of dissolved oxygen is (1 ppm dissolved O_2) x (°Plato), to a maximum of 10 ppm. Ideally, the wort will be oxygenated to 8-10 mg/l of dissolved oxygen.

Rates of up to 14.0 ppm dissolved oxygen can be achieved by aerating the worty by passing pure oxygen through a sintered air stone for 120 seconds; 30 seconds results in about 5 ppm and 60 seconds results in about 9 ppm. Shaking the fermenter for 5 minutes results in about 2-3 ppm dissolved oxygen. Wort splashing devices used by homebrewers don't allow more than 4 ppm. Extended stirring or shaking, or extended periods of passing filtered air through a sintered airstone result in a maximum of 8 ppm.

Wort should be aerated after it is cooled to pitching temperature, but before the yeast is added.

Very high gravity beers might benefit from an addition of 7-12 ppm of oxygen 12 hours after fermentation has started, after the yeast have completed at least one cell division.

C. Considerations During Fermentation

Primary fermentation is when the yeast produces most of the alcohol and secondary fermentation products found in the finished beer. The most important factor in primary fermentation is temperature, although commercial brewers also have to take

Kräusening in Detail

While it is an obscure brewing technique seldom used by homebrewers or commercial brewers, for some reason the BJCP insists on testing judges' knowledge of the subject on the BJCP Written Proficiency Exam. Therefore, anyone prepping for that exam should understand exactly what kräusening is, how it works and what it brings to the finished beer.

Describe: **Kräusening is a German technique where a portion of actively fermenting wort (from another batch of beer at the high kräusen phase of the Fermentation stage of the yeast's life cycle) is added to green beer which has finished fermenting (where the yeast is at the Sedimentation stage of the yeast life cycle), just prior to packaging. This provides active, healthy yeast to supplement dormant/dying yeast lost during extended lagering. It is typically used when making German lagers or wheat and rye beers in order to comply with the *Reinheitsgebot* and to provide sufficient healthy yeast to properly bottle condition the beer.** (Brewers who force carbonate their beer comply with the Reinheitsgebot by using carbon dioxide collected during yeast fermentation.)

Kräusening is often used by German commercial brewers who brew the same varieties of beer on a regular schedule. Even for those brewers who don't bother with the Reinheitsgebot, the practical benefit of kräusening is that they can top up the headspace in their conditioning tanks with kräusen once fermentation subsides, increasing the volume of beer in their tanks, reducing headspace and possibly freeing up tank space.

Typically, 10-20% of fresh wort is added depending on desired level of carbonation and batch size. For a 5 gallon batch of homebrew, this works out to 2-4 quarts. When homebrewers use this technique, they generally make a second yeast starter, sometimes using canned wort from the batch of beer to be kräusened, and add that to the green beer.

The practice of adding unfermented wort (speise) to carbonate finished beer is related to kräusening, but technically isn't the same thing.

Effects on Beer: **For brewers who wish to comply with the Reinheitsgebot, kräusening provides natural carbonation** for beer without adding sugar or artificial carbon dioxide. **Actively fermenting yeast helps scavenge VDK (diacetyl) & acetylaldehyde** still present in the packaged beer, **and also helps fully attenuate high gravity lagers.** Conversely, yeast in the **kräusen can also impart these off flavors** if they can't complete their fermentation in the bottle. **Kräusening can also result in infection** of the bottled beer, or the beer from which the kräusen came, if the brewer doesn't practice proper sanitation procedures. Finally, if the wort used to kräusen isn't identical to the beer to be kräusened, **the brewer must recalculate vital statistics** like ABV, IBU and SRM.

into account factors such as fermenter geometry, pressure levels and levels of dissolved carbon dioxide.

Different yeasts have different preferred temperature ranges, and the same yeast strain might perform differently at different temperatures.

Some yeast strains also benefit from fermentation temperatures which start off on the cool side of the preferred temperature range and which finish at a slightly higher temperature. This is particularly true of lager yeast strains, since it minimizes acetaldehyde and VDK production during the initial phases of fermentation and helps the yeast scavenge those products during the lag phase.

When fermenting, the rule of thumb is to not change the fermenting temperature by more than 5 °F per day to avoid shocking the yeast and making them flocculate prematurely. For this reason, fermenters must be located in a location where the temperature is relatively steady and where there are unlikely to be any major temperature swings. In the absence of artificial heating or refrigeration, homebrewers can use water baths (e.g., a keg cooler bucket or a garbage can) to buffer temperature swings. Cold weather fermentations might benefit from an aquarium or pond heater. In warm, dry weather, brewers can wrap moist towels around the neck of the carboy to create an improvised "swamp cooler" which will help cool the fermenting beer.

Homebrewers must also be aware that the temperature indicated by thermometers outside the fermentation vessel is likely to be several degrees lower than the temperatures within the fermenter. This is because yeast generates heat as it ferments.

If fermenting using a refrigerator or converted freezer and a temperature control, you can compensate for the slightly low temperature reading by setting your temperature control several degrees lower or somehow inserting the temperature probe into the fermenting wort so you get a true temperature reading.

D. Conditioning & Secondary Fermentation

When the yeast begins to flocculate, the beer is generally conditioned by racking to a secondary fermenter (also known as a conditioning or brightening tank) to allow the yeast to finish fermentation and flocculation while preventing the beer from developing unpleasant yeasty, sulfury flavors from prolonged contact with autolyzed yeast in the trub.

Ale yeasts can finish conditioning in just a few days, while lagers usually may require 4-6 weeks, or up to 6 months in the case of some strong lager styles. During conditioning, it is vital that the green beer not be aerated, since exposure to air can cause off flavors due to oxidation and may cause infection by wild yeast or bacteria.

Bottle Conditioning and Kräusening: During packaging, fresh yeast may be introduced to the beer, particularly if the beer has been lagered for an extended period, or if the beer is strong. In such cases, the existing yeast is likely to be dead or in very poor health, making it impossible for it to properly bottle condition the finished product.

It is also common for breweries to filter their beer before packaging in order to speed production, control access to proprietary yeast strains, or to produce a more stable or attractive product. In some cases, breweries which filter their beer will introduce a different strain of yeast to the beer during packaging in order to bottle condition their beer.

The two methods of naturally carbonating packaged beer are bottle conditioning or kräusening.

Bottle conditioning consists of adding a fresh yeast starter and/or sugar, usually corn sugar (glucose), to the beer. This is common practice for most homebrewers, but is also common for Trappist-style Belgian ales.

Homebrewers typically introduce 1/3 to 1/2 cup of corn sugar in 1-2 cups of boiled water per 5 gallons of beer. For beers where the yeast is likely to be in poor condition due to long lagering times or high ABV, homebrewers should also add a 250 ml yeast starter culture along with the priming sugar.

Kräusening consists of adding a quantity of fermenting wort (at high kräusen) to the beer. This is common for traditional German lagers, mostly as a method of complying with the historical German beer purity laws (the Reinheitsgebot). Adding actively-fermenting wort both carbonates the beer as well as reducing off flavors generated from the previous fermentation, but if improperly done it can introduce off aromas associated with incomplete fermentation, particularly acetylaldehyde.

The volume of kräusen added should be about 10-20% of the volume of the beer being primed.

E. Considerations When Choosing Yeast Strain

Each yeast strain differs in preferred fermentation temperature, its ability to metabolize sugars and starches, preferred environmental conditions, flocculation (ability to settle out of solution after fermentation) and byproducts it produces during fermentation. Some styles of beer depend on special yeast strains in order to produce their unique flavor characteristics (e.g., Hefeweizens, Belgian ales).

Different yeasts produce very different flavor and aroma characteristics, and any yeast can vary its character if it is fermented at a higher or lower temperature.

1. Preferred Conditions

Each yeast strain has its preferred environmental conditions, both at the start of fermentation and at the end. Environmental conditions include oxygen requirements, pH, sugar concentration and alcohol tolerance.

Oxygen Requirements: These differ by strain; some need much more oxygen than others. **At the very least, yeast needs 5 ppm of dissolved oxygen for optimal function, while some lager yeasts only reach optimal function at 10-12 ppm of dissolved oxygen.**

Fortunately for homebrewers, who can seldom achieve even the minimal 5 ppm recommended, yeast can function with much less oxygen and can slowly develop even if there is no dissolved oxygen. Extremely high or extremely low oxygen levels can result in increased ester levels.

Preferred pH levels: These are fairly constant between yeast strains. Not surprisingly, beer yeasts prefer pH of 4-5.5 (the pH of finished beer and cool wort, respectively). It can still ferment between ranges of pH 2.4-3.5, but rapidly dies at pH below that point. Commercial breweries use "acid washing" (reducing pH of a yeast solution to 2.2 for 2 hours) in order to kill off bacteria while still retaining some live yeast.

High Sugar Concentrations: These can also inhibit yeast growth. At O.G. above 1.072 increased osmotic pressures can damage yeast cell walls (high sugar concentrations are the reason that honey and jam don't spoil). Because of this, wort of 1.056 or greater needs more yeast. Double the yeast amount for every 0.008 S.G. above 1.048. High concentrations of sucrose or fructose can interfere with yeast's uptake of maltose and maltotriose, making it more difficult for yeast to ferment in worts composed of 25% or more simple sugars.

2. Apparent Attenuation

Apparent Attenuation is commonly expressed as a percentage, where the numerator is the difference between final and original gravity (O.G. - F.G.) and denominator is the original gravity (O.G.) of the wort.

Some yeast strains don't metabolize certain sugars (e.g., maltriose), leading to lower levels of attenuation when the wort has higher concentrations of those sugars. Wild yeasts are notorious for being able to metabolize dextrins, thinning beer body until it is watery.

Apparent attenuation for ale yeasts can range from 69 to 80%. Apparent attenuation for lager yeasts usually ranges from 67-77%. Higher attenuation means more alcohol, less body and less residual sweetness.

Typically, attenuation is about 75%. Poorly attenuating strains typically only ferment to about 70%. Highly attenuating strains ferment above 75%, sometimes as high as ~80%.

3. Alcohol Tolerance

Higher original gravities and high ABV (9%+) can inhibit yeast activity. Alcohol tolerance describes how well a yeast strain continues to ferment as the ethanol concentration increases. This is particularly important to brewers since it is one of the factors determining F.G. and % ABV of the finished beer.

When producing a high alcohol beer, you must choose an alcohol tolerant yeast strain and pitch greater quantities of yeast. Most lager yeast strains can ferment up to alcohol concentrations of up to 8% ABV, while some ale strains can ferment up to 12% ABV. Wine and champagne yeasts can ferment up to 18% and distiller's or "turbo" yeasts can ferment at up to 21% ABV. Yeasts with higher attenuation produce drier, thinner-bodied beers. Yeasts with lower attenuation produce sweeter, fuller-flavored beers.

4. Flocculation

Although all yeast strains must develop and ferment in solution, when they go dormant they do one of three things: fall the bottom of the beer, form a cluster and float to the top, or stay in solution. **The process of dropping out of solution or rising to the top is referred to as flocculation.**

Some yeast strains are more flocculent than others. Highly flocculent strains take less time to clear, leading to clearer beer, less need to filter and better bottom cropping (if reusing yeast). Such strains might fall out of solution too soon, though leaving behind VDK and acetaldehyde. They might also need to be roused in order to finish their work. Other strains are poorly flocculent, and must be filtered out if you want clear beer.

Top-flocculating strains form a thick "scum," supported by surface tension, on the top of the green beer. They are often referred to as "top-fermenting" strains, because they were traditionally cultivated by "top cropping" the foam from the top of open ale fermentation vessels.

Bottom-flocculating strains don't form clusters, but quickly drop to the bottom of the fermentation tank. They are traditionally referred to as "bottom-fermenting" because they were normally obtained from the bottom of lagering tanks. Bottom-flocculating lager yeasts can be further subdivided into the Frohberg type (also called dusty or "powdery") which ferments quickly but flocculates poorly and the Saaz (also called S.U. or "break") type which flocculates more quickly but has lower attenuation.

Non-flocculating ("powdery" or "dusty") yeast strains tend to stay in solution and must be removed by filtration unless the brewer wants his finished beer to be cloudy and yeasty. "Powdery" yeasts are often better attenuators, since yeasts that flocculate too soon can produce incomplete fermentation.

Historically, some brewers who used quickly flocculating yeast had to "rouse" the yeast by physically shaking their fermentation vessels. Sometimes unintentional rousing of the yeast during transport had the same effect, as in the case of traditional IPAs, which were more attenuated than standard pale ales due to the rocking motion during the long ocean voyage from England to India. On the other hand, yeasts that flocculate well are desirable since they produce relatively clear beer without the need for filtration. For this reason, home brewers prefer more flocculent yeasts.

These days, the dichotomy between "top fermenting" ale yeast and "bottom fermenting" lager yeast is largely moot. It is possible to have top-flocculating, bottom-flocculating or non-flocculating strains of yeast which are active at any temperature range. For example, since cylindroconical fermentation tanks became the norm for commercial breweries (allowing brewers to reculture yeast taken from the bottom of the tank), many microbreweries use bottom-flocculating ale yeast strains. Some large commercial brewers prefer non-flocculent strains which produce a more attenuated product, since filtration will remove the yeast from the finished beer even if it doesn't flocculate.

5. Fermentation Temperature

Higher fermentation temperature typically produces more esters, phenols and fusel alcohols, but reduces fermentation times. Lower temperature fermentation temperatures generally produce "cleaner" aromas and flavors, but take longer to finish work. Also, stress on yeast at lower temperatures can lead to production of VDK and acetaldehyde.

<u>Ale yeast</u> (S. Cerevisiae) usually prefers room-temperatures (65-70 °F), although some Belgian strains prefer temperatures from 75-85 °F and some Scottish strains prefer temperatures of 60-65 °F and can remain active down to 55 °F. **Ale yeasts are used to ferment American, Belgian, British and French Ales as well as German Hefeweizen beers.**

<u>Lager yeast</u> prefers cool temperatures (45-55 °F), but can function at temperatures up to 68° F and down to 32 °F, it is used to ferment all types of lagers.

<u>Hybrid yeast strains</u> prefer temperatures between those preferred by typical lager and yeast types, typically 55-60° F but can function at temperatures up to 70° F. For example, the yeast use to ferment California Common beer has a preferred temperature range of 58-68° F, while the yeasts used to produce Altbier and Kölsch have preferred temperature ranges of 55-70° F.

6. Flavor Characteristics

Certain beer styles are defined by the special yeasts used to make them (e.g., German wheat and rye beers, strong Belgian ales). Certain yeast strains are "clean" - producing minimal byproducts (or actively scavenging fermentation byproducts), while others produce higher levels of esters (fruity, floral notes), phenols (spicy, peppery, clove) and/or diacetyl (buttery, butterscotch). Not all yeast strains are appropriate for all styles of beer.

During yeast fermentation, yeast produces various minor byproducts which can have a profound influence on the flavor and aroma of the finished beer. As a rule of thumb, the higher the fermentation temperature, the greater the level of byproducts, which is why lager beers have a "crisper, cleaner" taste than ales. Byproducts include esters, fusel alcohols ("higher" alcohols), phenols, saturated fatty acids, ketones, acetaldehyde, glycerol and sulfur compounds.

Acetylaldehyde is a precursor of ethanol that is also scavenged by yeast during the later stages of fermentation. Above detectable levels, it can produce distinct "green apple" or "grassy" aromas which can be unpleasant or out of place. It is a sign of weak or incomplete fermentation.

Esters are a combination of an organic alcohol and acid. They are produced by yeast during the Growth and Fermentation phases, especially in the presence of high gravity worts, high temperatures, or low oxygenation levels. While over 90 different esters have been identified in beer, ethyl-acetate, isoamyl-acetate and ethyl-hexanoate are the most common compounds, imparting sweet, fruity aromas (fruity, banana, and apple scents, respectively). Ale yeasts are particularly noted for their production of fruity, flowery esters, but lager yeasts can also produce esters if fermented at too-warm temperatures. For example, raising fermentation temperature from 60-68 °F results in a four-fold increase in ester production. Poor wort aeration can also cause excessive esters, since the ester production pathway competes directly with the absorption of oxygen and metabolism into sterols during yeast growth. French Bière de Garde is a lager style noted for its production of esters due to high fermentation temperature, while Belgian Trappist/Abbey beers produce their characteristic esters partially as a result of high-temperature fermentation, but also due to their high-gravity wort.

Fusel Alcohols contain more carbon atoms than the most common alcohol, ethanol. They are sometimes referred to as higher alcohols due to their higher molecular weight compared to ethanol. They are formed during primary fermentation from aldehydes (formed from amino acids) which react with enzymes to become alcohols. As with most other fermentation byproducts, fusel alcohol production increases with higher fermentation temperature and higher wort gravity, and wild yeasts produce higher levels of fusel alcohols. Most higher alcohols produce "rough," solventy flavors and aromas, although a few (Amyl alcohol, Isoamyl alcohol, Phenolethyl alcohol, Tyrosol) produce other flavors (bananas for the first two, roses & bitter, chemical flavors for the latter two).

Glycerol is formed when there is insufficient oxygen in high-gravity/low-malt wort via the Crabtree Effect. If present above threshold levels, it can have an unpleasant taste.

Ketones are produced by all yeast stains, via various metabolic pathways, during primary fermentation, although some yeasts are more prone to ketone production than others. Aroma-producing ketones include acetoin (fruity, musty), 2, 3-

pentanedione (honey), alpha-acetohydroxy-butyric acid (rubber), and **especially diacetyl (butter, vanilla, caramel, butterscotch).**

All yeast strains produce diacetyl, but the amino acid valine helps turn diacetyl precursors into other products. Brewing yeasts also have enzymes which scavenge diacetyl towards the end of fermentation.

Diacetyl aromas in beer are attributable to one of these causes: excess oxygen (extremely unlikely), high-gravity/low-malt worts, yeast strain (high diacetyl ale yeast), too-high/too-low fermentation temperature, infection (by gram-positive lactobacillus bacteria or wild yeast) or incomplete fermentation. To reduce diacetyl, and related 2,3 pentanedione, some lager brewers use a "diacetyl rest" during late kräusening, where they temporarily raise the temperature of their lagering tanks to up to 68° F (but usually 55-60° F) for several days before packaging.

Phenols are closely related to fusel alcohols and some phenolic compounds are fusel alcohols (e.g., Phenolethyl alcohol, Tyrosol). Like esters, they are produced during the growth and primary fermentation phases as a result of high temperature fermentation or infection by wild yeasts.

Most phenolic compounds produce medicinal, chemical or burnt-plastic aromas, but one yeast-derived phenolic, 4-vinyl guaiacol, is responsible for the distinct clove-like aroma of German hefeweizen beers. It is produced by a special strain of S. Cerevisiae, from its precursor amino acid, ferulic acid. This phenol may be controlled by the amount of precursor amino acid produced in the mash during a protein rest at 111° F.

Wine yeast, if used to ferment beer, will produce strong "winey" phenolic odors.

Fermentation scientists sometimes refer to yeast strains which produce phenols as "POF+ strains, where" POF stands for "phenolic off flavor."

Saturated Fatty Acids are formed by some wild yeast strains. They are responsible for Caproic acid, Caprylic acid, and Capric acid, three flavor compounds which impart "goaty," sweaty, fatty and soapy aromas to beer.

Sulfur Compounds such as dimethyl sulfate (DMS, "corny" or cooked vegetable aromas) are usually produced by malt rather than yeast, but yeast action plays an important part in scrubbing these compounds out of solution. Malt-derived DMS occurs when S-methyl methionine (SMM) in malt is turned into DMS by heat during mashing and wort boiling. Different types of barley have different SMM levels, hence imparting higher or lower DMS levels to the wort.

High-temperature fermentation tends to scrub more DMS from the wort, which is one of the reasons that ales tend to have lower DMS levels than lagers. Furthermore, some strains of yeast are more efficient at removing DMS than others.

High levels of DMS indicate one or more of: high sulfate levels in water, improper malt selection, improper mashing or wort boiling technique, improper yeast selection or improper fermentation temperature. Hydrogen Sulfide (H_2S, "rotten egg" or "sewer gas" aromas) are a sign of bacterial infection.

Very weak fermentation, especially in the absence of sufficient levels of FAN, can make some yeast strains produce hydrogen sulfide at detectable levels. This is more of a problem for cider-, mead- and wine-makers, but it can occur in very badly made beers, especially those made using excessively high levels of honey, syrup or sugar.

Yeast autolysis can impart rubbery sulfur-like or brothy sulfury aromas to the beer.

Judging Tip: Green Apples and Butter

Acetaldehyde and Diacetyl often appear together in the same beer. Both chemicals are produced during the lag phase of fermentation and both should be metabolized by the yeast in the late fermentation/dormancy phases. Green apple and butter aromas and flavors might arise in beers, especially lagers, where the yeast has precipitated or been filtered prematurely, or otherwise produced a lot of acetaldehyde and diacetyl initially and then didn't have the ability to clean it up later (e.g., weak or mutant yeast).

Lager brewers deal with these problems by giving their beer a "diacetyl rest" (which also deals with acetaldehyde) by warming it to ~50-55 °F for a few days before filtering or packaging. See VDK for more information.

7. Sugar Metabolism

All yeasts (in fact, any organism capable of aerobic metabolism) metabolize glucose, a monosaccharide. They can also use enzymes to turn fructose (another monosaccharide) into glucose, and can use other enzymes to digest maltose and sucrose (disaccharides), breaking them down into glucose.

Both ale and lager yeasts can also slowly digest maltotriose (a trisaccharide) and the trace sugars xylulose, mannose, and galactose, but only lager yeasts can completely metabolize raffinose and maltotetrose (polysaccharides consisting of four monosaccharides). The ability to metabolize maltotetrose is what sustains lager yeasts during long periods of lagering.

Some superattenuating wild yeast strains have the ability to metabolize polysaccharides (longer chains of simple sugars, including dextrins) and amylose (AKA starch - extremely long, branching chains of simple sugars). This typically results in thin body and explosive levels of carbonation in bottle conditioned beers which have been infected with wild yeast.

Part 2: Off-Flavors

Acetaldehyde

Detected In: Aroma, flavor.

Described As: Aldehydic, bready, bruised apples, cidery, fruity, grassy, green apple, green leaves, latex paint (AKA emulsion paint), raw apple skin, "rough." Sometimes mistaken for cellar-like, musty or sour notes, sweet apple esters and/or acetic sourness (and vice-versa).

Typical Origins: Yeast activity, Microbial contamination.

Typical Concentrations in Beer: 2-15 mg/l.

Perception Threshold: 5-20 mg/l. At 6-8 g/ml it is perceived as a "fruity" flavor. At higher levels it has a distinctive "green apple" aroma flavor and aroma.

Beer Flavor Wheel Number: 0150.

Discussion: Acetaldehyde is the most important aldehyde (carbonyl compound) in beer, although there are others. Acetaldehyde is found in all beer, although detectable levels are considered to be a defect in most beer styles.

* It is typically produced as a precursor to ethanol produced during fermentation: glucose is metabolized into pyruvic acid which is then converted to acetaldehyde and then to ethanol. During fermentation some acetaldehyde escapes from

the yeast cell. During the final phases of fermentation, the yeast scavenges free acetaldehyde and finishes converting it.

* In young beer or fermenting wort, acetaldehyde levels range from 20-40 mg/l, decreasing to 8-10 mg/l in finished beer.

* Oxidation of finished beer might convert ethanol back into acetaldehyde. In this case, acetaldehyde is usually accompanied by other oxidation and/or age-related defects.

* The combination of bacterial action and oxidation can reduce acetaldehyde to acetic acid (vinegar) due to the chemical reaction of ethanol and acetaldehyde. In this case, acetaldehyde is usually accompanied by acetic acid and other contamination defects.

Some Aldehydes Found in Beer

Aldehyde	Descriptor	Detectable range
3-Methylbutanal	Unripe banana	0.01-0.3
Acetaldehyde	green apples	2-20 mg/l
Benzaldeyde	Bitter almonds, burnt almonds, cherries	0.035-3.5
Butyraldehyde	melon, varnish	0.03-0.2
Hexanal	Bitter, vinous	0.003-0.07
Trans-2-nonenal	Papery, cardboard	0.00001-0.002

Increased By: * Yeast management: Yeast strain (highly flocculent strains). Poor yeast health. Underpitching. Fermentation at temperature too cool for yeast. Vigorous fermentation. Incomplete/stuck fermentation. Removing yeast from wort prematurely (e.g., fining, filtering, crash cold conditioning). Insufficient conditioning time. Increasing fermentation pressure (whether atmospheric or liquid pressure - although this is mostly a problem for large breweries, not homebrewers). * Aeration of green beer during conditioning or packaging. * Bacterial infection by Zymomonas or Acetobacter species (but usually accompanied by other off-flavors in such cases, such as sulfur compounds or acetic acid, respectively).

* Acetaldehyde concentrations are increased by rapid fermentation, higher fermentation temperatures and increased yeast cell count, although these factors also promote reduction of acetaldehyde.

To Avoid or Control: * Proper Yeast Management: Proper fermentation temperature. Longer fermentation and/or conditioning times. Proper yeast health/quality. Proper yeast strain. Proper pitching rate (at least 0.5 quarts per 5 gal. for ale, more for lager and high gravity beers). "Diacetyl rest" at ~50 ° F for 1-3 days at end of lagering period. Increasing yeast concentration during conditioning period. (Also see VDK for more detailed discussion of diacetyl rests.) * Reduce head pressure during fermentation and conditioning to allow acetaldehyde to blow off. * Avoiding aeration of green beer or fermenting wort. * Proper sanitation to avoid bacterial infection. * Proper packaging and storage. Oxygen introduced during packaging can oxidize alcohol back into acetaldehydes, especially when catalyzed by heat and light.

* Scavenging of acetaldehyde by yeast is increased by promoting vigorous late primary and secondary fermentation, by conditioning at warmer temperatures and increasing yeast cell count during late primary and secondary fermentation (i.e., by adding more yeast or by rousing existing yeast).

Judging Tip: "Yeast Management"

The saying that "brewers make wort, yeast makes beer" is absolute truth. Proper yeast selection and treatment makes the difference between great beer and undrinkable swill. Problems with yeast management are probably the biggest systemic fault that judges are likely to encounter in competition. Here is a selection of yeast-related problems:

Improper Fermentation Temperature: This probably the single biggest homebrew fault (with infection ranking a close second). Ideally, fermentation occurs on the lower side of the recommended fermentation range for the yeast strain (although there are exceptions), with steady temperatures or a slight temperature rise as fermentation progresses. Temperature changes should occur gradually (no more than ~0.3 °F or ~0.15 °C per hour) to avoid shocking the yeast.

Excessively cold temperatures lead to an excess of diacetyl and acetaldehyde. Excessively warm temperatures produce more phenols, esters, fusel alcohols and ketones.

Beers made without temperature control during Spring and Autumn, when weather is often unpredictably hot or cold, often suffer from this fault.

Insufficient Yeast: The higher the O.G. of the wort, and the cooler the fermentation temperature, the more yeast are needed. Otherwise, the yeast produces excessive esters, higher alcohols and ketones during its overly long growth phase.

Improper Wort Aeration: Yeast needs oxygen when it is first pitched in order to synthesize fatty acids and sterols, which are necessary for yeast reproduction. Failure to aerate the wort properly inhibits the yeast's growth phase, with the same effects as insufficient yeast. Insufficient yeast and improper wort aeration combine to give the distinct "homebrew twang" often found in beers made by novice brewers.

Poor Yeast Health: Old smack packs or old dry yeast sachets have reduced yeast cell counts, and might have other problems. At the very least, you will need to make a starter if you use old yeast. The effects of poor yeast health are the same as if you pitched insufficient yeast. This is another common rookie mistake.

Poor Yeast Nutrition: Generally, all-malt worts supply yeast nutrients in proper amounts, but poor yeast nutrition can be a problem in ciders, meads, or beers made using more than 20% adjunct sugars or syrups. Poor yeast nutrition results in slow, weak fermentation and can give beer a "cidery" or "vinous" character.

Improper Yeast Strain for Style: Some strains of yeast are notable for producing high levels of acetaldehyde, diacetyl, esters, fusel alcohols and/or phenols. Others are notable for not flocculating well (causing haze), not working well in high alcohol or high O.G. environments (resulting in poor attenuation) or not working well at higher or lower temperatures (poor attenuation or off-flavors and aromas).

This is a rarer problem, but might be encountered if the brewer is making a new style of beer, is trying to make an unusually strong beer, is experimenting with a new variety of yeast or has recently changed his brewing technique or system.

When Are Acetaldehyde Notes Appropriate?: For most styles of beer, detectable level of acetaldehyde is a fault. The exception is that Lite and Standard American Lagers may have very low levels of acetaldehyde. This is because Budweiser has very slight acetaldehyde notes, since Anheuser-Busch uses beechwood slats in their conditioning tanks to encourage the yeast to flocculate and settle prematurely, before it reduces all the acetaldehyde to ethanol.

Esters

Detected In: Aroma, flavor.

Described As: Bubblegum, butter, candy (e.g., Artificial fruit, bubblegum, Circus Peanuts, Froot Loops™, Juicy Fruit™ gum, pear drops, Trix™ cereal), cream, citrusy (e.g., lemon, lime, orange, tangerine), floral (e.g., feijoa, flowery, geranium, jasmine, lavender, perfumy, rose, ylang-ylang), herbal (e.g., pine, sage), honey, plant-like (e.g., "green," green banana, new-mown hay, parsnip, waxy), soft fruit (e.g., grape, raspberry, strawberry), spicy (e.g., aniseed, cinnamon, wintergreen, liniment), tree fruit (e.g., apple, apricot, cherry, peach, pear), tropical fruit (e.g., banana, canned pineapple, coconut, mango, papaya, passion fruit, pineapple, "tutti-frutti"), "sweet" (aroma only) and/or vinous (e.g., wine-like, rum, sherry). Bitter, solventy or glue-like in very high concentrations.

Typical Origins: Yeast.

Typical Concentrations in Beer: variable.

Perception Threshold: 5-15 µg/l.

Beer Flavor Wheel Number: Variable.

Discussion: In beer, esters are formed by the esterification of fatty acids by Ethanol, and also in small amounts by the esterification of Fusel Alcohols.

Ester precursors are produced as minor elements of yeast metabolism: Alcohol Acetyl Transferase (AAT) and Acetyl Coenzyme A (aCoA); aCoA is normally used for the synthesis of lipids, which the yeast cell needs to build cell membranes. Esters are formed under conditions when aCoA isn't needed for synthesizing cell components. So factors which promote yeast growth (e.g., high levels of aeration) lower ester production. Also see Solventy.

Esters are mostly produced during the main (fermentation) phase of primary fermentation, but can increase slowly during the late phases of fermentation and during secondary fermentation. During long secondary fermentation, the level of esters might double.

Acceptable thresholds for esters in bottom fermented beers are up to 60 mg/l. Top fermented beers can contain up to 80 mg/l of esters.

Type and character of esters produced depends on the exact chemical reaction. Perception thresholds vary depending on the exact molecule. While there are about 60 different esters found in beer, the most important are: ethyl acetate, isoamyl acetate, isobutyl acetate, β-phenyl acetate, ethyl hexanoate, and ethyl caprylate.

*** Ethyl Acetate:** The most common ester in beer, most typically described as smelling like ripe apples, pears or pear drops. Typical Concentration in Beer: 5-30 mg/l. Perception Threshold: 25-30 mg/l. See Solventy/Solventy Esters for full discussion.

* **Ethyl Butyrate:** Canned pineapple, mango, papaya, pineapple, tropical fruits. One of a family of butyrate esters found in beer. Imparts a welcome fruity ester character to some beer styles (e.g., Belgian ales), but can also be an indicator of poor sanitation, since it is formed from worts which have higher levels of butyric acid (see Butyric). Typical concentration in beer: 0.05-0.25 mg/l. Perception Threshold: 0.04-0.4 mg/l. Beer flavor wheel number: n/a.

Ethyl Caprylate (AKA Ethyl Octanoate): Floral, Fruity (apple, apricot, banana, pear, pineapple), soapy, sweet, vinous (brandy, wine-like), waxy. Present in all beers, although concentrations vary widely. Concentrations are higher in Belgian beers. Typical Concentration in Beer: ?. Perception Threshold: 0.01-1.5 mg/l. Beer flavor wheel number: n/a.

*** Ethyl Hexanoate (AKA Ethyl Caproate, Ethyl Pentanoate):** Aniseed, apple, banana, brandy, floral (roses), fruity, "green," honey, pineapple, rum, sherry, strawberry, "sweet" (aroma), wine-like. Present in all beers, although concentrations vary widely. A defect at high concentrations. Typical Concentration in Beer: 0.07-0.5 mg/l. Perception Threshold: 0.15-0.25 mg/l. Beer flavor wheel number: 1032. Also see 0142 Apple

* **Isoamyl Acetate**: Banana, Circus Peanuts candy, pear, pear drops. Present in all beers, although concentrations vary widely. Part of the signature of German wheat and rye beers. Typical Concentration in Beer: 0.8-6.6 mg/l. Perception Threshold: 0.6-4.0 mg/l. Beer flavor wheel number: 0131.

* **Isobutyl Acetate**: Papaya, apple. Present in all beers, although concentrations vary widely. Concentrations are higher in Belgian beers. Typical Concentration in Beer: 0.1-0.3 mg/l. Perception Threshold: 0.4-1.6 mg/l. Beer flavor wheel number: n/a.

Also see Solventy.

Other Esters

Ester	**Description**	**Threshold**
Butyl acetate	Banana, sweet	0.04-0.4 mg/l
Ethyl caprate	Goaty	0.01-1.0
Ethyl caprylate	Apple, sweet, fruity	0.01-1.5
Ethyl dodecanoate	Soapy, estery	3.5
Ethyl lactate	Fruity, strawberry	250
Ethyl myristate	Vegetable oil	0.4
Isoamyl propionate	Aniseed, pineapple	0.015
Phenylethyl acetate	Apples, honey, roses	0.05-3.8

Increased by: * Yeast strain. * Improper Yeast Management: Wild yeast infection. Insufficient or excessive yeast growth. FAN/Amino Acid deficiency. Mineral (Zinc, Calcium, etc.) deficiency. Underpitching yeast. Low dissolved oxygen - low oxygen levels limits rate of yeast reproduction due to limited sterol in cells. Incorrect fermentation temperature for strain, especially high temperature fermentation. * Aeration of green beer during growth phase of fermentation. * High gravity wort (above 13-15 °P, 1.052-1.060 O.G.) - going from 10 °P to 20 °P (1.040-1.080 O.G.) results in fourfold ester production. * High ethanol concentration (>9%). Dehydration of yeast. Excessive trub. * Moving green beer or fermenting wort during fermentation or maturation. * Wild yeast infection. * High pressure, either due to hydrostatic pressure due to fermentation vessel design or high pressure due to CO2 buildup (this is mostly a problem for large commercial breweries).

Decreased by: * Overpitching yeast. * Proper Yeast Management: High dissolved oxygen. Adequate oxygen levels for wort strength. Increased lipids in wort - carrying over more cold break into fermenter. Correct fermentation temperature for strain - especially fermenting at the cool end of the proper temperature range. * CO_2 buildup in fermenter. * Aging - esters are degraded by esterases produced by yeast; they are also volatile and will evaporate or degrade into other compounds over time.

To Avoid or Control: Choose appropriate yeast strain. Pitch correct amount of yeast (less for higher fusel levels, which translates into higher esters levels) at 0.5 to 1 quarts of yeast slurry per 5 gallons. Maintain proper fermentation temperature for strain (higher temperature means more fusel alcohols, meaning more esters). Match starter to wort gravity & temperature.

Adequately oxygenate wort after pitching yeast (O_2 is used by yeast to make unsaturated fatty acids, using up aCoA and increasing thickness of cell membranes, thus preventing ester formation). Don't aerate wort once fermentation starts. Proper separation of trub from wort. High-pressure fermentation decreases yeast growth, hence fusel precursors - it is used by some large lager breweries. Aging will decrease or eliminate esters (over the course of 1+ year).

When Are Esters Appropriate? Esters are expected low to medium concentrations in American ales and hybrid styles.

They can be present in low to high concentrations in Belgian, English & German Ales. Younger, fresher ales will have higher ester concentrations.

German wheat and rye beers are noted for isoamyl acetate (banana) esters.

Belgian ales often have for bubblegum, tutti-frutti, pineapple & "tropical fruit" notes.

Sugar: Amino Acid Ratio on flavor production by yeast

Compound	**Flavor**	**Impact of C:N Ratio**
DMS	sweet corn	Higher ratio = more DMS
Esters, e.g., iso-amyl acetate	Banana	higher ratio = more ester
Higher alcohols, e.g., methylbutanol	Solvent	Too low or high a ratio = more alcohol
VDK e.g., diacetyl	Butterscotch	Higher ratio = more VDK
Organic acid, e.g., citric	Sour	Higher ratio = lower pH through reduced buffering
Fatty acids, e.g., decanoic	Various	Higher ratio = less fatty acid.

Vicinal Diketones (AKA Diacetyl, VDK) (Fatty Acid)

Detected In: Aroma, flavor, mouthfeel.

Described As: Butter, buttered popcorn, buttery, buttermilk, butterscotch (at higher levels), honey, milky, movie/theater popcorn, toffee, vanilla. Oily, slick or creamy mouthfeel. Can give illusion of fuller body.

Typical Origins: Yeast, microbial contamination.

Typical Concentrations in Beer: 8-600 µg/l.

Perception Threshold: 10-40 µg/l. The ability to detect diacetyl is higher in light-flavored, low-alcohol beers, lower in more full-flavored beers. The ability to sense diacetyl is also genetic. Some people are sensitive to it down to 10 µg/l, others are insensitive to it. The typical threshold is 20-40 µg/l.

Beer Flavor Wheel Number: 0620.

Discussion: Vicinal diketones (VDK) consist of diacetyl & pentanedione. Since they are virtually indistinguishable by typical chemical tests, they are grouped together. Both are natural byproducts of fermentation, formed from minor metabolic products produced during the initial stages of yeast growth and fermentation, which leak out of the yeast cells into the beer. The highest concentrations are found in the initial stages of fermentation, during the reabsorbed by yeast in final phases of fermentation and are metabolized to relatively flavorless diol compounds.

High temperature fermentation both produces higher levels of VDK, but does an even better job of reducing them as long as the yeast remains active until the end of fermentation.

Bacterial infections, notably Pediococcus and Lactobacillus, can produce VDK in high concentrations, usually in conjunction with numerous other off-flavors and aromas as well. This is a common problem in infected (dirty) draught beer lines.

* **Diacetyl:** Produced during fermentation as a byproduct of valine synthesis when yeast produces α-acetolactate, which escapes the cell and is spontaneously decarboxylated into diacetyl. The yeast then absorbs the diacetyl, and reduces the ketone groups to form acetoin and then 2,3-butanediol. Healthy yeast has about 10 times the ability to absorb diacetyl as to produce it.

Diacetyl is typically detectable at 0.5 to 0.15 mg/l, although the ability to taste diacetyl is genetic. Some people can taste diacetyl down to 0.2 mg/l, while others are insensitive to it! It is described as tasting like artificial butter, butter, butterscotch, toffee or vanilla.

* **Pentanedione:** 2, 3-pentanedione is produced during fermentation as a byproduct of isoleucine synthesis when yeast produces α-ketobutyrate, which escapes the cell and is spontaneously decarboxylated into 2, 3-pentanedione. The yeast then absorbs the 2, 3-pentanedione and reduces the ketone groups to form relatively flavorless compounds.

Compared to diacetyl, pentanedione is much less important, since the perception threshold is 10 times higher than that of diacetyl and most yeast strains produce far less pentanedione than diacetyl. It is detectable at 0.90 mg/l. It is detectable in aroma and flavor as honey or honey-like perfume.

Some Vicinal Diketones and reduced derivatives in beer

Material	**Description**	**Detectable range**
2, 3-hexanedione	Strawberry	<0.01
2, 3-pentanedione	Honey	0.1-0.15
3-hydroxy-2-pentanone		0.05-0.07
Acetoin	Fruity, moldy, woody	1-10
Diacetyl	Butterscotch	0.01-0.4 mg/l

Increased By: * Yeast strain selection - some produce more VDKs, especially those which flocculate well and those which produce respiratory-deficient mutants.

* Improper yeast management. Insufficient or excessive yeast growth. Yeast mutation. Reusing yeast collected too early in previous fermentation cycle. Poor yeast health (e.g., Mineral deficiency, overpitching, low dissolved oxygen, high gravity wort, >9% ethanol concentration, delayed yeast collection, insufficient cooling of fermentor cone, incomplete mixing in

fermentor, excessively high or low pH). FAN/Amino Acid deficiency, especially insufficient levels of valine in wort (needed for diacetyl reduction). Underpitching yeast. Aeration of green beer after yeast growth phase. Slow/weak fermentation. Incomplete mixing in fermentor. Dehydration of yeast. Incorrect fermentation temperature for strain, especially low temperature fermentation. Swings in fermentation temperature. Insufficient fermentation time. Prematurely removing yeast from the wort (e.g., filtering, fining, reducing fermentation temperature).

* Improper Sanitation. Wild yeast infection (bacterial contamination can produce high levels of 2, 3- pentanedione). Pediococcus Damnosus infection produces large amounts of diacetyl, which isn't reduced with time. Lactobacillus infection during storage.

* Configuration & size of fermenting vessels can affect VDK production - but only for large commercial tanks where there is high pressure at the bottom of the tank.

* VDK precursors are increased by yeast strain, higher oxygen levels and higher yeast pitching levels, but the latter two factors also help yeast reduce VDK in the final stages of fermentation.

* Conversion of VDK precursors to VDK is increased by drop in pH (optimal at 4.2-4.4 pH), high levels of oxygen and temperature increases, especially during the fermentation stage of primary fermentation. These factors also help yeast reduce VDK, however.

Decreased By: * CO_2 buildup in fermentor. * Keep adjuncts low (<40%) or add yeast nutrient. * Use good quality malt extract (with good nitrogen and amino acid composition). * Good yeast management. Aerate wort well after pitching yeast. Use yeast starter (at least 0.5 quart per 5 gallons for ale, more for lager and high gravity beers). Use optimum fermentation temperature for yeast strain (not too cold). Use good quality moderately flocculating yeast, which is not susceptible to mutation or contaminated by wild yeast. Allow fermentation/diacetyl reduction to finish before racking off, lowering temperature or adding finings. Sufficiently age beer on yeast (rouse yeast if necessary, while avoiding aeration). Minimize aeration during transfer. * Use good sanitization practices to avoid bacterial infection.

* Yeast will naturally reduce VDK as fermentation progresses, so healthy, vigorous yeast activity during primary fermentation (down to about 90% of terminal gravity) will reduce most diacetyl.

* The yeast's ability to remove diacetyl drops during secondary fermentation (i.e., lagering). It is increased by a "diacetyl rest." Typically, this consists of increasing the temperature of lagering beer to ~50-55 °F for 1-3 days at end of lagering period. In some cases, however, more or less extreme rests might be required. Diacetyl uptake by yeast is slightly increased at 6 °C (43 °F) to a maximum activity at 20 °C (68 °F)) for up to 34 days (maximum VDK reduction occurs at 3-4 days with very little additional reduction after about 16-24 days).

* Higher yeast concentrations and increased contact between yeast and fermenting beer (i.e., adding new yeast or rousing existing yeast into suspension) also increase yeast's natural ability to reduce VDK.

When Are VDKs Appropriate?: Low levels of diacetyl are acceptable in Bohemian Pilsner, English Pale Ales, Scottish Ales, English Brown Ales, Brown Porters, Robust Porters, Sweet Stouts, Oatmeal Stouts, Foreign/Extra Stouts, English IPA and Strong Ales. They are a fault in other styles of beer, especially most lagers.

Low (sub-threshold) levels of diacetyl can give the illusion of richness or body in any beer style, although this is undesirable in thin-bodied beers.

Part 3: BJCP Category 15 - German Wheat and Rye Beers

History: *People have been brewing beers from wheat since antiquity, but, since wheat is better adapted to making bread and barley is better adapted to brewing beer, wheat beers were less common. In some times and places, brewing beer from wheat was prohibited as being wasteful of vital foodstuffs. Due to the prestige associated with wheat beer, throughout the Middle Ages and Renaissance it was considered a premium product. There were many different medieval styles of wheat beer, although these probably would have been sour beers, much more like lambics or Berliner Weisse. Modern-style weissbier probably originated in Bavaria in the 16th century, as a summer beer brewed when it was too warm to brew lagers.*

Traditionally, wheat beers were referred to as "weisse" (white) beers, possibly due to the cloudiness of the beer imparted by the wheat malt. Conveniently, this name is similar to the German word for wheat ("weizen") so weissbier and weizenbier became synonymous.

In Bavaria, the home of modern German wheat beers, in the 16th century the Degenburger family held a monopoly on brewing wheat beer until they died out, at which point the exclusive right to brew "white" beer reverted to the Dukes (later Princes) of Bavaria. Originally, the Hofbrauhaus in Munich was the Duke's wheat beer brewery. The famous Reinheitsgebot was, in part, promulgated to protect the noble monopoly on brewing wheat beer, since it restricted commoners to just brewing barley beer. People who wanted wheat beer had to buy it from the von Degenburgs (or, later, the duke)!

By the 18th century, due to changing tastes, the noble monopoly on brewing weizenbier was almost worthless, so the princes of Bavaria relinquished their monopoly, relegating Bavarian wheat beer to the status of a local curiosity. In 1859, the crown sold seemingly worthless right to brew weizenbier to a brewer named George Schneider, and the family has been brewing weizenbier ever since. The Schneider family is responsible for the (re-)invention of Dunkelweizen and Weizenbock.

After the unification of Germany, the Bavarian Reinheitsgebot was applied to all of Germany, but an exception was made for wheat beers. By law, a wheat beer had to be made from at least 50% wheat (most modern hefeweizens are 70% wheat). By the end of the 19th century, the production of pale malt, the advent of refrigeration and the concomitant rise in popularity of light-colored lagers almost forced Hefeweizen into extinction. At that time, the most popular forms of wheat beer were sour beers like Berliner weisse. This decline continued until the early 1960s, when the market share of Weissbier fell to less than 3% of Bavarian beer production. After 1965, however, hefeweizen suddenly became extremely popular, and remains popular to this day. Weissbier is particularly popular among physically active young adults. Today Weissbier holds about 11.5% in market share in Germany, 35% in Bavaria.

(Personally, I think that the vicissitudes of late 20th century international politics partially accounts for the rise of

Hefeweizen and the decline of Berlinerweisse. After World War 2, Bavaria was spared the massive destruction and social disruption inflicted on Prussia and Berlin by the Soviets, was in the relatively prosperous American zone of occupation and was close to the other nations of Western Europe.

By contrast Berlin and the remnants of Prussia were almost entirely within the Soviet zone of occupation and were adjacent to other Communist-controlled nations. The severe effects of German reparations to the USSR and the destruction of private enterprise by due to Soviet Communist ideology had disastrous effects on eastern Germany and the rest of communist-controlled Central and Eastern Europe.)

Modern Hefeweisse: Weizenbier has a distinct flavor produced by the interplay between the special Hefeweizen yeast and the large proportion of wheat malt. Hefeweizen should have banana, phenolic, spicy, sour and even bubblegum aromas and flavors. To emphasize these characteristics, hops are kept to a minimum.

Most weissbiers have raw wort added to the beer at packaging, to give the beer a high level of carbonation and a fresh, yeasty flavor. In Germany, there are several variations in the way in which hefeweizen is served. Kristallweizen is a filtered and artificially carbonated hefeweizen with a less pronounced wheat flavor and a lighter taste. Hefeweizen "mit hefe" is hefeweizen served with the yeast roused from the bottom of the bottle or with added yeast added at the bar. Wiepie (pronounced VeePee) is an extremely popular mixture of half light lager and half hefeweizen.

Hefeweizen (unfiltered "yeast wheat" beer) is typically served in a "masse" glass to hold the head and concentrate the beer's aroma. In Germany, hefeweizen isn't served with lemon – the citrusy or sour notes should come from the beer itself. It is common for Germans to add fruit flavorings to summer beers, however (e.g., Berliner Weisse mit schusse).

Dunkelweizen is a hefeweizen made with amber-colored malted wheat and barley malt. It can have distinct "banana bread" (i.e., clove, vanilla, banana, caramel and biscuity) notes.

Weizenbocks (properly divided into Weizenbock, Weizendoppelbock and Weizeneisbock) are merely dunkelweizens or hefeweizens brewed to bock, doppelbock or eisbock strength. These specialty beers are commonly brewed as winter warmers. The BJCP only recognizes weizenbocks based on the dunkelweizen style, however. They should have some degree of dark fruit esters and smooth alcohol notes in addition to the phenol and ester profile reminiscent of a dunkelweizen.

Spicy phenols in German wheat beers are variously described as being reminiscent of clove, cinnamon, nutmeg, ginger or slightly smoky.

"Bubblegum" esters represent some mixture of apple, raspberry, peach, cherry, strawberry, banana and vanilla aroma and flavor.

Some authentic commercial examples of hefeweizen, especially dunkelweizen, lack the typical "clove and banana" aromas and flavors typical of the style, since some strains of weizen yeast produce noticeable "apple and cinnamon" notes, sometimes reminiscent of baked apples or apple strudel. Per the BJCP Guidelines, however, high scoring German wheat beers should have some combination of clove, banana, bubblegum and vanilla notes.

Brewing German Wheat Beers: Prize-winning weizenbiers are brewed using at least 50% to 66% wheat malt, with the remaining grist being mostly pale pilsner malt. Wheat/barley malt extract can be substituted for some or all of this. Hops should be Hallertau, Saaz or similar noble hop. For dunkelweizens and weizenbock, dark grains such as crystal, Munich, chocolate and Special B should account for 15-30% of the grist.

Mash should take place at about 152 °F to produce wort of about 1.052. Dunkels and Bocks mash at higher temperatures of 154 °F or more, to produce O.G. of 1.051 and 1.069, respectively. The yeast should be pitched at approximately 54 °F and fermentation should take place at moderate ale temperatures (67 °F or lower). Weissbiers should be carbonated to 3.6 to 5.1 volumes of CO^2 about double the level for most lagers. Beer should be cold-conditioned for about 5 days after carbonation.

To develop clove character, German wheat beers benefit from a Ferulic Acid Rest where the mash is held at a temperature of 111-113 ºF for 15-20 minutes. Conveniently, the ferulic acid rest is also in the same temperature as the beta-glucanase rest, which is also desirable when brewing such beers.

A ferulic acid rest promotes the formation of ferulic acid, a precursor of the 4-vinyl guaiacol which produces the clove phenol aroma and flavor.

German wheat beers, especially hefeweizens, also benefit from some degree of yeast stress. For this reason, it is actually good practice to underpitch hefeweizen yeast and to not fully oxygenate the wort. These techniques help force the yeast to develop more ester and phenol character. Proper yeast management can result in hefeweizens which have yeast profile which is too "clean."

Roggenbier: Roggenbier is a very rare beer, even in Germany. *It was never a premium beer, usually being produced by peasants from rye beer grown on land not suitable for growing wheat or barley.*

Modern roggenbier was first produced in the Bavarian city of Regensburg by the defunct Thurn und Taxis brewery in 1980s. It was considered novel enough at the time that the brewery actually got a patent for the brewing process. Subsequently, the British beer writer Michael Jackson described this beer in his World Guide to Beer. On the strength of his description, Roggenbier was dutifully included in the BJCP Style Guidelines.

Subsequently, Thurn und Taxis was bought out by the Paulaner group, which then transferred the brand to Wolnzacher Burgerbrau. Although the beer was produced as late as 2011, as of 2013, the brand no longer appears on the company's web site, nor on the Paulaner website, which is a dire sign in these modern times. If Paulaner has really discontinued production of roggenbier, it will have gone the way of Classic American Pilsner – limited to homebrew and rare brewpub specials.

While the original modern roggenbier was brewed using just 10-50% rye, the homebrewed interpretation of the style is made using a much higher proportion of rye malt. This gives it a character similar to a dunkelweizen but with distinctive rye character, fuller body and more prominent flavor and aroma hops.

Malt character is generally more prominent than in a comparable weizen. Rye has its own distinctive flavor which stands on its own. Some American brewers will add caraway seeds to their beer, but this isn't "traditional" and is generally unnecessary. Noticeable caraway character will turn the beer into a Spice, Herb or Vegetable beer (Category 21).

As with dunkelweizen, roggenbier can be served "mit hefe" - with yeast - by gently rolling or swirling the bottle before it is opened or by inverting the bottle as the last of the contents are poured. Also like hefeweizen, this is a style which doesn't age well and is best consumed young.

Roggenbier is typically made using about 50% rye malt and 25% Pils malt, with some additions of crystal malt. Other aspects of the brewing schedule are the same as for a hefeweizen or dunkelweizen.

Since rye produces an extremely gummy mash use lots of rice hulls and expect long sparge times. Without filtration, a brownish protein haze remains in the finished beer, which can coagulate into brown chunks over time. If you get a chance to try a homebrewed roggenbier, don't be put off by nasty-looking floaters!

Part 4: BJCP Category 16 - French and Belgian Ales

There are an indescribable number of French and Belgian Ales. In effect, each product from each brewery in Belgium is its own "style," so the BJCP guidelines for French and Belgian Ales represent a best attempt to classify the unclassifiable. Within this category, Belgian Pale Ale, Saison and Bière de Garde are probably the most closely related. Witbier is effectively its own style and "Belgian Specialty Ale" isn't so much a style as a dumping ground for any Belgian-style beer which can't be crammed into some other style.

Witbier: Witbier once meant any beer brewed with wheat. The protein and starch hazes from the wheat gave the beer a cloudy, whitish cast, while sourness from the wheat and from wild fermentation gave the beer a sour tang. Historically, many Belgian Witbiers were probably similar to Berlinerweisse, but each city would have had its own version of Witbier, with its own unique flavor.

Witbiers were designed to be brewed fairly quickly and consumed very young, typically within just a few weeks after primary fermentation ended. *Most local versions of Witbier vanished by the end of 19th century, surviving only in the province of Brabant in, especially the city of Leuven and the town of Hoegaarden. The beer we think of as Witbier originates there. In Leuven, however, Witbier went extinct in the 1950s or 1960s. It survived only in the nearby town of Hoegaarden, where it was revived as a commercial style by Pierre Celis at the Hoegaarden (pronounced HU-ghar-dun) brewery in 1965.*

Part of the reason for the commercial extinction of Witbier was is because it was very difficult to brew, since the brewing process resulted in four different worts, which were boiled separately before being blended. Modern Witbier brewing technique is simpler.

Brewing Witbier: Witbier mash consists of up to 40% unmalted wheat, plus some oats. Pilsner malt makes up the majority of the grist. Chamomile flowers, coriander and Curacao orange peel are added to the wort. A special yeast is used to ferment the wort, and it is infected with lactobacillus bacteria (or lactic acid is added) to give it a slight lactic sourness. The resulting beer is highly carbonated, hazy, thin-bodied and very refreshing.

When brewing Witbier, be sure to use fresh coriander, and to be careful to avoid getting any of the white orange pith into the beer along with the outer peel. Stale coriander, or the wrong variety of coriander, can produce vegetal, soapy or ham-like notes, while orange pith can impart a bitter flavor.

It is best to use a potato peeler or lemon zester to remove the outer peel of the orange. Use the most strongly-flavored oranges you can find; Seville or sour Caribbean oranges are best. Alternately, you can add a bit of Curacao liqueur in the secondary or just before packaging.

Coriander and chamomile should be added in the last 5 minutes of the boil, as should the other spices. Alternately, you can add them to secondary. It is essential to not boil the spices too long, or to allow herbs or spices to sit in the fermenting wort lest the beer pick up astringent notes, however.

Hops should be mild, European hops, such as Saaz or Tettnanger, and should be used only for bittering or flavor, not aroma. Avoid making the beer too spicy, any additions should be very subtle.

To give the beer its distinctive cloudy appearance and "creamy" mouth texture, some brewers throw some soft white wheat flour into the wort boil (about one cup per 5 gallons).

Some brewers add a tiny bit of ginger or other delicate herbs or spices as a secret ingredient. These additions should be extremely understated, however.

Yeast should be Belgian Witbier yeast.

The beer should be bottle conditioned or force carbonated to at least 2.5 volumes of carbonation.

Witbier is a very delicate beverage and is best consumed young. Aged witbier is a sad, withered thing with minimal esters and oxidized malt character.

Belgian Pale Ale: *Belgian pale ale is a traditional Belgian beer style, native to the Flemish provinces of Antwerp and Brabant. It has been produced since the mid- 1700s, but since the late 19th century it has been influenced by English Pale Ale. Most modern brands date to after WW2 and often use English yeast and/or hop strains. Since the 1960s, this style has lost ground in its homeland to the ubiquitous industrial lagers.*

Belgian pale ales are about as "mundane" as Belgian beers get. Since they are associated with the French-speaking portions of Belgium, they are all-malt (or mostly barley malt) beers, since the Walloons are more restrained in their use of adjuncts than the Flemish. Historically, they were associated with the coal-mining regions of Belgium - Mons, Charleroi and Namur - and with the city of Antwerp.

They are a somewhat broad category which covers many Belgian "Category 1" beers. Compared to their stronger "Category S" cousins, Belgian pale ales are "session beers" or "table beers." They are intended to be balanced and drinkable, without any one ingredient being too pronounced or dominant.

For this reason, yeast character (i.e., fruity esters, spicy phenols) is more restrained than in other varieties of Belgian beer. Due to thinner body and filtration, the head may fade more quickly than other Belgian ales and might not leave the typical "Belgian lace" within the glass as it fades. Many are similar to Saisons, except that the yeast strains used to make them are different.

Belgian pale ales should be easy to drink, with a moderate initial sweetness and spicy and fruity notes due to yeast. They are not high alcohol beers, nor should they be excessively fruity, spicy or sweet. Balance is crucial.

Keep in mind, that, despite the similar names, Belgian Pale Ales are not Belgian Blonde Ales, nor are they Belgian Strong Golden Ales. Balance is the key. They are brewed using Pilsner malt, English or German hops, and special yeast (White Labs WLP515 Antwerp Ale or Wyeast 3655 Belgian Schelde).

Some homebrewers find that they inadvertently brew an excellent Belgian pale ale if they attempt to make an English Pale Ale but ferment the beer at too high a temperature.

Saison and Bière de Garde: Saison and Bière de Garde are both Northern French and Wallonian Belgian farmhouse ales. As with other Belgian beer styles, they suffered when industrial brewing was introduced, but revived after World War 2. *They are the two historically French beer styles to have survived from pre-industrial times and are associated with Southern (Wallonian) Belgium, particularly eastern Hainault province, and the departments (provinces) of France nearest the Belgian and German borders: Alsace, Nord and Pas de Calais.*

Saison is a winter beer which finishes very dry. Bière de Garde is the "big brother" to Saison. The name literally means "beer to be kept" i.e., a "keeping beer" designed to be aged. Both evolved out of the same tradition and they represent aspects of the same overall style. As with any other Belgian-style beer, however, each version of Saison or Bière de Garde has its own house flavor.

Saison: Historically, Saison was a low-gravity beer, which was probably very "rough," with earthy, funky and sour flavors due to wild fermentation, which was partially balanced by bittering hops. Some Saisons are still brewed using wild yeast, but most have evolved to be "cleaner" in flavor, and much sweeter.

Saison varies widely in color and might be slightly hazy. It will have fruity and spicy notes, reminiscent of pepper, clove, apricot, tropical fruit (mango, passion fruit), bubblegum, bananas in the aroma and the flavor. Hop aroma can vary widely. Hop flavor and aroma can be noticeable, but hop bitterness should be low. Hints of spice, due to yeast character or actual spice additions, are present in some styles. "Rustic" versions can have very low lactic tartness, although excessive sourness is a fault.

Overall, Saisons should have complex aroma and flavor, but low phenol levels. They should be very well attenuated and can be very thin and dry. While they are more highly hopped than other Belgian-style ales, the emphasis is on flavor and aroma, rather than bitterness. They can also have a mild "cellar" funkiness similar to that found in Bière de Garde.

The grain bill for Saison consists mostly of Belgian Pilsner malt, plus some mixture of Vienna malt, malted or unmalted spelt or wheat, up to 10% sugar, and possibly a small percentage of unmalted or malted oats and color malt. A single temperature infusion mash is typically used, although some breweries use a step infusion mash. Starch conversion occurs at 143-147 °F in order to produce highly fermentable wort.

Hops for Saison are typically locally-grown continental hop varieties, particularly Goldings. Imported varieties include Styrian Goldings, Hallertauer or Saaz. These varieties are used for bittering, flavor and aroma additions. Saison brewers don't currently use dry hopping, although they have in the past. Many brewers add low levels of spices, similar to those found in Witbier.

Fermentation can take place at a range of temperatures. In particular, Brasserie Dupont ferments their Saison at 86 °F! Proper fermentation temperature, however, depends on the strain of yeast you use. The trick is to get spicy and estery notes without getting unpleasantly high levels of phenols, and without getting high levels of higher alcohols. Some brewers use several different strains of yeast, and since Saison yeast can occasionally get "stuck," it is sometimes necessary to use a different yeast strain, or even champagne yeast, particularly if making a strong saison.

Many brewers age their beer in secondary for 3-4 weeks at temperatures of 65-75 °F. Suitable yeast styles include White Labs Belgian Saison, Belgian Ale, Wit and Belgian Golden Ale yeasts and Wyeast Belgian Saison, Belgian Ardennes, Forbidden Fruit and Canadian/Belgian yeasts. After conditioning, Saisons are typically bottled-conditioned to at least 2.5 volumes of carbon dioxide.

Bière de Garde: Bière de garde was historically made in autumn and aged in bottles until spring. It was sometimes kept for several years.

Bière de garde initially tastes sweeter than Saison, but is balanced by dryness from thinner body and possibly higher alcohol levels. Some versions can have some caramel flavor or hints of alcoholic warming. It can also have stronger "cellar" flavors than a Saison. In particular, it can have a small degree of musty and earthy notes as a result of being corked. While "corked" character is considered a serious fault in wine, some tasters consider its presence in bière de garde to be pleasant.

Since it is cold-conditioned and aged, bière de garde has fewer fruity esters due to yeast action. On the other hand, it can have some "yeasty" notes as part of its "cellar" flavor.

Bière de garde is brewed using mostly Pilsner malt, although artisanal brewers use a mixture of Pilsner, Munich, aromatic, Biscuit™ and Cara-Vienna™ malts, with just a tiny bit of black malt to darken the color. White or brown sugar can compose up to 5% of the grist. Infusion mash is typical.

Hops are Continental or British aroma hops, which are mostly added as bittering hops, with a very small addition in the last half hour of the boil for flavor. Two unique varieties used in bière de garde are French Strisselspalt or Alsatian-grown Goldings hops.

Fermentation occurs at 52-68 °F using any appropriate ale strain (e.g., White Labs or Wyeast European Ale) and the beer is then cold-conditioned for 3-4 weeks at 32-35 °F). Some ale strains will stop fermenting prematurely, requiring you to restart fermentation using a different strain of ale yeast or champagne yeast.

Aging is critical for this style – it should be stored for at least 3 months before opening.

Belgian Specialty Ales: *This is an arbitrary category used to describe artisanal Belgian and Belgian-style beers which don't fit into any other category. Very roughly, Belgian specialty ales can be divided into four categories:*

Spiced ales, often made as Christmas beers. These will often have names such as Noel, Hiver, Pere Noel, etc.

Unusually strong or weak Trappist and Abbey-style ales, such as "Quad" or Orval. Some will have spices, other ingredients, or might be fermented using microflora other than brewing yeast.

Wild Fermented beers which don't fit into the lambic category, such as spontaneously fermented unblended beers, sweet, fruit-flavored lambics (like the various Lindeman's products), spiced sour beers, sour beers made with unusual ingredients.

Belgian interpretations of other beer styles, such as English, Scottish or American ales. These often feature American or English hops and American or British malts, but are fermented with Belgian yeast (i.e., Chouffe McChouffe, Scotch Silly, Urthel Hop-It).

Note: Belgian Specialty Ales are not covered by any of the BJCP exams.

Part 5: Brewing Belgian Specialty Beers

Belgian History: *Once upon a time, the beer-brewing regions of Belgium and France were a single country – the Kingdom of Flanders. Due to war and dynastic marriages, the Kingdom of Flanders was divided and ultimately ceased to exist by the end of the Middle Ages. From the late middles ages through the Renaissance, these areas were thrived economically. In particular, the region was known for its textiles (lace and woolen cloth). Due to the prosperity of the textile trade, Belgium was the center of the so-called Northern Renaissance of the 15th and 16th centuries.*

Unfortunately, by the late Middle Ages, the provinces of the former kingdom of Flanders were under the control of France and Spain, who ruled as indifferent, sometimes brutal, "absentee landlords." As border areas controlled hostile powers, Belgium was the site of many battles from the Renaissance onwards. During the 19th century, Belgium was dubbed "the cockpit of Europe" – a place where other nations fought their wars. Following the French Revolution, modern Belgium and Holland were merged into a single state, but in 1830, the people of the French-speaking territories revolted and gained their independence. In 1831, they founded the Kingdom of Belgium. Even so, so parts of the former Kingdom of Flanders (the Departments of Alsace, Nord and Pas de Calais) remained under French control.

The people of Belgium formed two distinct ethnic populations, the Flemish Dutch-speaking Flemish in the north of the country along the border with Holland, and the Wallonian French-speaking Walloons in the south, making Belgium an officially bilingual state. Following the revolution, Belgium industrialized rapidly, but it was never a great European power and was economically and politically dependent on the great powers which surrounded it: the United Kingdom, France and Germany. During World War I, Belgium was almost entirely overrun by the Germans from 1914 until 1918, and the part of the country which wasn't overrun formed an almost static portion of the Western Front, the scene of some of the bloodiest fighting in history. During World War II, the Germans occupied Belgium again from 1940 to 1944, and Belgium was the site of the Battle of the Bulge.

Following World War II, Belgium was one of the founding members of the European Union (now the European Economic Community) and its capitol was chosen as the site of NATO headquarters. Today, Brussels is the administrative capitol of the EEC and NATO, making Belgium an important diplomatic and administrative center. The rise of Belgian beers, in part, is related to the rise of Brussels as the capitol of united Europe.

Belgian Brewing History: *Beer is the national drink of Belgium, but perhaps because Belgium was never a great power it never developed a national "style" of beer – like English Ales or German lagers. Instead, until the early 20th century, every city had its own local beer style[1]. Commercial pressures and the ravages of war have pared down the number of Belgian breweries, but vestiges of local beer styles still remain.*

In the Middle Ages, Flanders was a great beer-brewing center, and it is the Flemish who were responsible for introducing hops into England in the late 15th century. As in other countries, local guilds controlled the price of beer and the types of ingredients which could be used in brewing. Flemish beer was brewed with barley malt as well as malted or unmalted wheat, buckwheat, oats or rye. The beer was bittered with hops as well as other locally-grown herbs. By the 19th century, Belgium was dependent on other European countries for its hops, so Belgian beers traditionally use British, Czech and Serbian hops and Belgian beers aren't known for their strong hop flavors or aromas. Likewise, Belgian beers use a high proportion of imported (British or German) malt, although Belgian maltsters are renowned for their crystal and caramel malts. Since the 19th century, Belgian brewers have also been using sugar in their beer, to create light-bodied, dark, highly alcoholic beverages.

Unlike other countries, Belgian brewers only started sparging in the 19th century and they never collected the runnings from the mash into a single wort. Instead, they used the "parti-gyle" system of brewing, or a modified form of it, to make their beer. The strong first runnings were used to make stronger "double" or "dubbel" beers, while the thinner second runnings were used to make "simple" or "table" beers. In some cases, Belgian brewers used a variant of the decoction mash to brew their beer. Essentially, this was a step mash where the liquid portion of the mash was pulled and heated (but not boiled) before being added back into the main mash tun.

As with every other brewing tradition, local laws also influenced the character of Belgian beer. Historically, Belgian brewers had to pay excise tax based on the strength of their wort in the mash tun, so Belgian brewers went to extreme lengths to preserve as much of their wort as possible. Wort was centrifuged to separate the hot break, and hops were pressed to squeeze out as much of the wort as possible. The raw beer was centrifuged to remove the yeast, which was then used to ferment a new batch of beer. Because the law allowed up to 40% adjuncts to the mash, but doesn't specify what those adjuncts must be, Belgian brewers routinely added unmalted wheat or oats, or sugar syrups to their beer. Finally, because Belgian tax classifications skip beers of certain gravities, brewers must start with wort which falls into a certain classification. From there, however, they can attenuate the wort as much as they wish.

Due to tax classifications, however, it is unusual to see Belgian beers of 6.7% ABV unless it is poorly attenuated beer with a starting gravity of 1.062+.

Belgian Beer Tax Classifications

Class	*O.G. (°P)*
S (Superior)	*1.062+ (15.5+)*
Illegal	*1.055-1.061 (13.5-155.5)*
I	*1.044-1.054 (11-13.5)*
Illegal	*1.039-1.043 (9.5-11)*
II	*1.016-1.038 (4-9.5)*
III	*up to 1.016 (up to 4)*

[1] The cities of Antwerp, Diest, Hoegaarden, Leuven, Liege and Mechelen all had distinct local beer styles, as did the regions of Flanders, Hainault and the Senne Valley. See Pierre Rajotte's ***Belgian Ale*** or Randy Mosher's ***Radical Brewing*** for more information.

While industrial lager represents at least 75% of the Belgian market, Categories S and I represent 70% of traditional Belgian craft beers.[2]

Belgian Brewing Techniques: *This section is, of necessity, a brief overview of Belgian brewing techniques, other than the historical brewing methods listed above. The key to brewing a particular style of Belgian or French ale is to understand the particular style and the ingredients used to produce it.*

1. Style Guidelines, not Rules: *Commercially, there is no such thing as an "out of style" Belgian beer, as long as the ingredients are wholesome, the techniques used to make it are "honest," and the resulting beer is good. Rather than attempting to mimic their competitors, Belgian brewers strive to achieve a unique "house flavor" within a broader category. For example, all of the Trappist ales (which we will be sampling next month) have their own house flavor.*

2. Use the Right Yeast and Treat it Right: *The right yeast, and proper management of it, is crucial to get the proper flavor. Belgian brewers repeatedly state that the right yeast strain is crucial to producing the distinct flavors of their products. They frequently use the same wort, fermented with different yeasts, to produce different styles of beer. In particular, much of the difference between Saison and Belgian Pale Ale depends on the yeast strains. Hefeweizen yeast is not appropriate for Belgian ales. In particular, Belgian ales don't produce the clove-like aromas associated with hefeweizen.*

In some cases, brewers use a blend of yeasts, or use one yeast for primary fermentation and another for secondary fermentation. Sometimes bottle-conditioned beer is filtered to remove the first yeast, and then a second yeast is added at bottling. This isn't so much out of a desire to preserve a house flavor as to achieve the proper flavor and carbonation level.

Some Belgian Ales are fermented at very high temperatures (up to 86 °F), but this is not always the case, however. In any case, fermentation at too high a temperature, insufficient yeast starter, or poor yeast health due to lack of yeast nutrients can produce unwanted and higher alcohols. Belgian beers be can be highly alcoholic, but they shouldn't taste like paint thinner and give you a headache. High gravity wort and a high sugar percentage demands a big yeast starter and proper yeast nutrition to get optimal flavor.

3. Avoid Dark Malt: *Except for British style beers brewed under contract, and a few specialty beers, the Belgians don't use Chocolate or Patent malt. Instead, they darken beer using either caramelized sugar or crystal malts.*

4. Know Your Water: *Water chemistry varies widely across Belgium. Some styles depend on extremely soft water, while others require somewhat hard water. Belgian Pale Ale requires soft water, while Saison and Bière de Garde can use either soft or high-hardness water. Alls water used for brewing Belgian or French style ales should have a low sulfate content (less than 300 ppm), however.*

5. High Carbonation: *Most Belgian ales are highly carbonated, to 1.5-3.5 atmospheres of carbon dioxide pressure (approximately 20 to 50 p.s.i.). Highly carbonated Belgian ales are typically packaged in champagne-style wine bottles capped with caged champagne corks. "Gushing" bottles are common.*

6. Good Head: *Most Belgian ales have a tall, fine, white head which falls slowly. As it falls, the fine bubbles which compose the head cling to the glass, producing a classic "Belgian lace" effect. Some of the head is due to high carbonation levels, but head retention depends on some proportion of wheat or crystal malt.*

7. Sugar: *When brewing some styles of beer, Belgian brewers use sugar the way that American industrial brewers use rice and corn, and in approximately the same percentages. Sugar has the advantages of being cheap, producing maximum attenuation from lower gravity wort and lightening body. Caramelized sugar darkens color without imparting much flavor. Belgian brewers don't use "rock candy" sugar, nor do they use plain white sugar. Instead, they use liquid sucrose, dextrose or invert sugar.*

Invert sugar consists of ordinary sugar which has been treated with acid to break sucrose disaccharide molecules into two monosaccharides – one molecule of glucose and one molecule of fructose. It is possible to create your own invert sugar syrup by adding half a gram of citric or ascorbic acid to 1 kilogram of white sugar. Practically, this means 1 tsp (10 ml) of lemon juice, or a pinch of cream of tartar per pound of sugar. Add enough water to dissolve the sugar and then boil the mixture for 20 minutes to create invert sugar. Boiling a concentrated sugar solution will also cause Maillard reactions as the sugar caramelizes, giving a darker color and more highly flavored syrup.

Should you wish you can create rock crystals by suspending lengths cotton twine in a solution of concentrated invert sugar and letting the water evaporate.

Alternately, you can use caramel syrup (without further additives) or lightly caramelized sugar or sugar syrup.[3]

8. Spices: *Many Belgian beers incorporate some herb, spice or fruit flavor. These spices should be subtle, however, much of the spiciness of Belgian beer comes from the yeast strain and mouthfeel perception due to carbonation levels. There are no rules as to when to add these additions, some are added during the wort boil, others during primary or secondary fermentation and some at packaging. Use the usual techniques for producing a spiced beer, but keep overall spicing levels low.*

9. Unmalted grains: *Most Belgian ales incorporate some proportion of unmalted oats and/or wheat. These ingredients can produce a very gummy mash. Belgian brewers historically solved this problem by dropping a fine mesh basket into the mash tun, letting the liquid portion of the mash percolate into the basket and siphoning it off of the top of mash. Modern brewers use either force filtration or rice hulls to avoid a stuck mash. Rice hulls should make up 1-5% of the total grain bill when working with a large proportion of unmalted wheat or oats. Alternately, for beers which are supposed to be full-bodied and hazy, such as Wit, it is possible to just add a bit of white flour to your wort kettle.*

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[2] Legal information is taken from Rajotte and is 20 years out of date. EU regulations, or just plain common sense, might have forced changes to Belgian excise laws.

[3] Randy Mosher suggests using unrefined sugar, such as Piloncillo, for up to 10% of the grist in Strong Belgian Ales. This isn't "traditional," but will add flavor and complexity, and is in keeping with the spirit of Belgian brewing.