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The Industrial Revolution tremendously impacted all areas of European life in the nineteenth century. The continent became more urbanized and more commercially connected via rails and canals. Industries once located in homes and small workshops moved to factories, and science was increasingly utilized to provide the technologies needed for the production of goods. Not only did these momentous changes radically alter the lives of Europeans, it also affected their most prominent beverage, beer.

I

In order to understand the changes that took place in the manufacturing and consumption of beer, a generic explanation of the brewing process and terminology will be helpful. Brewing, in effect, begins in the farmer's field. Barley, and occasionally wheat, is the basis for most beers. Europe's climate offers an exceptional cradle for these cereal grains, which lend themselves so naturally to brewing and fermentation.

After leaving the farmer's field, the barley and wheat are malted. Malting involves soaking the harvested kernels in water until germination begins. During germination, enzymes capable of converting the starchy endosperm into sugars develop. When the grain reaches the appropriate level of modification, it is kilned (lightly roasted) to kill the plant and to stop further modification. Some barley is also kilned at higher temperatures to create specialty malts that can include caramel, toasted, dark coffee, and chocolate flavors. At this point, the grains are called malt and are ready to be utilized by a brewer.

Brewers crush the malt and then mix the crushed malt with water. Water is actually the main ingredient in beer, and access to quality water sources is a major concern for all breweries. The mixture of water and crushed malt is referred to as the mash. The heating of the mash and the duration of the mash's rests vary according to each brewery's needs. However, all mashes include a starch conversion rest, where the mash is allowed to rest at a temperature between 145°F and 155°F while the enzymes created in the malting process convert the malt starch into various sugars. These sugars go into solution forming a syrupy liquid known as wort. At the end of the mash, the wort is drawn off the malt debris (lautered), and the malt debris may be rinsed (sparged) with hot water to capture residual malt sugars.

Next, the wort is boiled. During the boil, hop flowers are added, which impart bitterness and a floral bouquet. Almost every style of beer is hopped to some degree. Hops, like barley, favored the climes of Europe and were introduced as a beer seasoning by at least the twelfth century.[1] Beer also benefits from the preservative quality given by hops. After the boil, the bitter wort is cooled and then mixed with yeast for fermentation.

In many ways, yeast is the most important ingredient. Yeasts ferment the malt sugars and create alcohol and carbon dioxide. They also determine the character and complexity of the finished beer. Yeasts used for brewing are divided into two general categories. The first is ale yeast (*saccharomyces cerivisiae*), and the second is lager yeast (*saccharomyces uvarum or carlsbergensis*). Ale yeasts ferment at relatively warm temperatures (55°F – 65°F). They work quickly creating a frothy head (top fermenting) and produce distinctive fruity esters. Lager yeasts, on the other hand, ferment at cold temperatures (40°F – 50°F). Lager yeasts work more slowly than ale yeasts, and lager styles require an additional holding period (lagering) at near freezing temperatures. This allows the lager yeasts to clean up unwanted fermentation by-products, leaving a very round and clean tasting beer.

II

Now that we have an understanding of the brewing process, let's take a look at pre-industrial brewing. Prior to the Industrial Revolution, beer was a local affair brewed in homes, monasteries, and small guild-regulated breweries. The malt and hops used came from fields tended by manual labor. The maltings prepared the barley and wheat by hand and kilned it with direct heat. Old-fashioned maltings created darker base malts that retained smoky characteristics of the kiln's fuel (peat or wood). Dark smoky base malts produced dark smoky beers. German Rauchbiers, which utilized smoked malt, hearken back to this old tradition.[2]

Pre-industrial malts were mashed similarly to modern practice except that mashing was done on a much smaller scale since the mash had to be stirred by hand. Additionally, achieving the appropriate mash temperature was virtually guesswork. "In traditional British brewing, the brewer is said to have overcome this difficulty by using brewing water (liquor) whose temperature was such that his face was best reflected by the water surface. Below the temperature of 65-71°C (150-160°F), the ability of the water to reflect is less, while above this temperature water vapour fogs the air."[3] In his 1796 brewing treatise, E. Hughes recommended the reflection method as well as blending "about one gallon of cold water to eighteen gallons of hot."[4] On the continent,

brewers developed a system of boiling a portion of the mash (decoction) and then mixing it with the cold remainder to achieve more consistent temperatures.[5] In either instance, achieving consistent and predictable results was nearly impossible before the introduction of the thermometer to the brew house in the eighteenth century.

Another factor contributing to the great variability of pre-industrial brewing was the inefficiency of most lautering procedures. Wort was often drawn off with ladles or strainer-baskets or even poured over a network of tree branches, and sparging was not universal. This left a great deal of malt sugar wasted in the spent grains. Inefficient lautering necessarily led to variable concentrations of malt sugars in the wort from batch to batch, which in turn affected the flavor and alcohol content of each beer produced.

However, the most important elements determining the quality of pre-industrial beer were the mixed cultures of wild yeast and bacteria that fermented the wort. After boiling, bitter wort cooled in shallow vessels where wild yeast and bacteria present in the air inoculated the wort. After cooling, the wort was transferred to wooden barrels. These barrels contained many living microorganisms that also contributed to the fermentation. In addition to the alcohol and carbon dioxide generated by the yeast, some bacteria would produce lactic sourness and other off flavors. Pre-industrial brewers had no knowledge of these microorganisms and viewed fermentation as a miraculous and fickle process.

Brewing at this time was a crapshoot depending on which microorganisms dominated the fermentation. Since the temperature of fermentation could not be controlled, warm-fermenting ale yeasts tended to dominate successful fermentations. The end result of pre-industrial brewing was usually a dark and cloudy beer with sour notes and a very complex aroma. Wildly fermented lambic beers produced in Belgium may furnish the best modern examples of old-style beer flavors.[6] Due to the presence of a multitude of microorganisms, pre-industrial beers had very limited shelf lives and therefore, very limited distributions. Almost all brewing served the home or local community.

Eventually, some brewers achieved more consistent and palatable results by retaining the yeast slurries left over from successful fermentations and adding them to successive brews. This practice favored the dominance and selection of appropriate brewing yeasts. Unfortunately, this practice was neither wide spread nor understood. Other remedies to avoid spoilage included brewing strong, heavily hopped beers and serving them young. High alcohol content and the preservative qualities of hops inhibited the growth of non-yeast

microorganisms. These characteristics, coupled with healthy yeast slurries, would yield fairly high quality beer. This became the practice in Britain.

However, the future direction of brewing, and in particular the industrial brewing of the nineteenth and twentieth centuries, emerged in the German state of Bavaria. Ales were quite common in Bavaria, especially effervescent wheat beers (*weizen*), but over time, Bavarians increasingly fancied beers stored in cold mountain caves. This practice developed to compensate for the hot summer months when brewing was less successful. Most brewers would make a yearly supply during the cooler months from fall to spring and hold their surplus in storage. Beer that spent months in these cold caves acquired a brilliance and smoothness highly prized by the Bavarians. It has been agued by a famous beer critic that, "this storage (*Lagerung* in German) empirically selected bottom-fermenting yeasts."[7] Once the difference between summer beers and stored beers became apparent to brewers and consumers, government regulation wasn't far behind:

> In 1553, summer brewing was outlawed altogether in Bavaria. By then the authorities—always worried about the supply of healthy summer beer—had obviously learned that cold fermentation yielded a purer beer with better keeping qualities than possessed by those unwittingly brewed and probably bacterially infected top-fermented beers of summer. The official brewing season was, therefore, restricted to between St. Michael's Day (September 29) and St. George's Day (April 23). From spring to fall, brewers had to seek alternate employment. It is obvious that this kind of brew schedule, decreed from above, favored the production of lagers. In many breweries, you simply could not make ales in the cold Bavarian winters.[8]

This regulation led to the creation of Bavaria's most famous festival, Oktoberfest, which celebrated the opening of the brewing season. The special lagers served at Oktoberfest were brewed in March and stored over the summer. They were usually referred to as *Märzen* in honor of the beer's month of birth.[9] The new tradition of lager brewing was restricted to Bavaria in pre-industrial times, but as more extensive trade connections emerged in Europe and science and technology enabled control over and understanding of the brewing process, lager brewing

became popular outside of Bavaria and eventually came to dominate the world market.

III

The secret of Bavaria's beers seeped out in the nineteenth century, and this process accelerated as German trade became more integrated under the *Zollverein*. Lager brewing appeared in Berlin (1830), Hannover (1832), Dortmund (1843), Pfungstadt (1846), and Holzminden (1848).[10] Additionally, brewers in Europe and the United States began to make the increasingly popular style. But successful lager brewing required much more careful control over the brewing and storage process than had been possible in pre-industrial brewing. The nineteenth century ushered in industrialization and with it the theoretical knowledge and technological inventions that gave brewers the tools to transform their art from small craft businesses to large-scale industrial enterprises. Although traditions always remained strong in the beer business, industrialization affected all aspects of brewing from the farmer's field to the imbiber's glass.

Of course, lagering required storage space, and as the popularity of Bavarian beer spread, breweries needed more and more extensive cold cellars. "Some breweries had multi-stored cellars reaching more than sixty meters (two hundred feet) underground, its galleries sometimes totaling one and a half kilometers (one mile)."[11] Brewers packed these cellars with natural ice in order to achieve the cold temperatures necessary for lager beer. Ice would be harvested from the mountains, lakes, and rivers in the winter and stored for use year-round. This allowed for cool fermentations even in summer, and because of the utilization of natural ice "...the Bavarian government was ...able in 1850 to remove the old law forbidding summer brewing."[12] The opening of summer brewing put even greater demands on the ice industry. Until 1870, most of Germany's natural ice went to the brewing industry.[13] Unfortunately, the supply of natural ice was dependent on the weather. Varying supplies caused varying prices from year to year. The unstable supply of natural ice and its cumbersome and bulky nature limited the production of lager.

Brewers realized that if they could produce artificial ice, they would no longer be dependent on nature or the ice trade. Two brewers and friends, Gabriel Sedlmayr of the Spaten brewery in Munich and Anton Dreher of the Dreher brewery in Vienna, became interested in the work of Carl Linde, who was on the faculty of the Munich Polytechnic School. Linde wrote an article on artificial refrigeration that dealt with the issue in theoretical terms. Linde couched his work in the new field of thermodynamics that had emerged by the 1870s.[14] He described the

ideal process of refrigeration as the inverse of the perfectly efficient steam engine cycle as described by Carnot. A reverse Carnot-cycle would yield the perfect refrigeration system. Linde argued that a vapor-compression machine would come closest to the ideal.[15] Sedlmayr encouraged Linde to put his ideas into practice at the Spaten brewery with all expenses paid.[16] The first machines manufactured by Linde and his Augsburg Machine Company produced artificial ice under coal and steam power. This ice was used in the brewery much the same as natural ice had been. Soon after, Sedlmayr's friend Anton Dreher had Linde install an ice machine at his Trieste brewery in 1877. Interest in Linde's machines quickly spread. The Dietrich Brewery of Düsseldorf ordered one in 1877, Carlsberg received one in 1878, and Heineken installed the first in Holland in 1881.[17] "By the end of 1890 the Augsburg Machine Co. had sold more than seven hundred machine systems, of which four fifths went to breweries."[18] By the end of the nineteenth century, Linde's systems were refined to cool rooms and vessels directly cutting out the bulky and wasteful use of unhygienic block ice. These later machines used ammonia as a refrigerant, which cooled a brine reservoir. The near-freezing brine could then be circulated through pipes in heat exchangers and fermenters to achieve a desired temperature. This control over temperature allowed brewers to shorten cooling times after the boil, when wort was most susceptible to infection, and to maintain ideal fermentation and lagering temperatures. Also, refrigeration negated the fears of warm summer brewing. Spaten, one of the first modern breweries began brewing lagers year-round in 1888.[19]

While temperature was important for lager brewing, good and healthy lager yeast was essential. However, other than temperature control, brewers were helpless in selecting their yeast. This began to change as scientists and then brewing professionals began to understand the nature of yeast. Louis Pasteur did the first important work describing fermentation and yeast's role in 1862.[20] Beyond academic work, Pasteur advised several breweries regarding yeast management and sanitation procedures. Building on Pasteur's work, Emil Christian Hansen, who directed the laboratory at Carlsberg Brewery in Copenhagen, developed techniques for separating yeast cells by dilutions and culturing them:

> Hansen could...take a commercial brewing yeast (which was most likely to be a mixture of strains), isolate a number of single yeast cells into separate tubes of sterile wort and from each cell produce a pure culture strain. The technique also provided an opportunity to free the yeast from attendant bacteria and wild yeasts because

> only uncontaminated cultures were accepted as stocks, and propagation was conducted in sterile wort in sterile containers.The strains could be examined in small-scale fermentations and selected for pilot-scale fermentations...When for various reasons, the yeast no longer gave satisfactory results in the brewery, it could be replaced by propagating stocks either of the same clone from the laboratory, or of another selected clone...[21]

Hansen's work at Carlsberg was widely published, and in honor of Carlsberg's role in the development of pure lager yeast cultures, lager yeast was originally classified as *saccharomyces carlsbergensis*. The Carlsberg yeast that Hansen worked with came from the Spaten brewery of Munich. Jacob Christian Jacobsen, Carlsberg's founder, trained at Spaten and obtained his inaugural yeast from Sedlmayr.[22] Now that Hansen had isolated Spaten's lager yeast strain, other breweries were anxious to obtain pure lager cultures. Hansen and A. Kühle, the Carlsberg manager, soon developed a way to produce pure yeast on a massive scale:

> Hansen and Kühle devised a yeast propagator based on semicontinuous methods. The [yeast propagation vessel] received sterile wort, labaortory yeast culture and air which had been filtered sterile. Rousing was achieved by a hand-cranked impellor. The yeast and beer produce were withdrawn periodically for pitching the brewing fermentation vessels, but a portion of the yeast was retained for seeding fresh wort run into the propagator.[23]

Hansen's techniques quickly spread. "Early in 1886 Heineken became the second brewery to produce cultured yeast and was soon selling surplus yeast to brewers in Austria, Belgium, France and Germany and to bakers at home."[24] With pure lager yeast and temperature control, breweries in any country in any climate at any time of year were able to make the now famous Bavarian style.

Control over temperature and yeast selection was part of what Mikael Hård described as the "scientification of brewing" in the nineteenth century. This process affected all aspects of brewing and packaging beer. In short, scientification combined with the emergence of modern economies created industrial brewing. The brewery that most

supported and benefited from scientification was Spaten. Not only did Spaten fund Linde's work on refrigeration and provide yeast for Hansen's work at Carlsberg, but Spaten also led the way in industrializing German brewing.

In the 1830s, Gabriel Sedlmayr of Spaten and his close friend Anton Dreher traveled to England to study its advanced brewing industry. They observed the British brewer's harnessing of steam power. Steam power had become available to London breweries in 1784 when "Boulton & Watt Co. had introduced their famous transmission system which enabled the steam engine to perform rotative work."[25] Sedlmayr installed steam power at Spaten in 1844.[26] The use of steam mechanization was critical in brewing's growth to the industrial scale. Mechanical rakes instead of manual labor could stir large mashes.

Sedlmayr and Dreher also noted British malting techniques and the use of the thermometer to check mash temperatures and the sacchrometer to measure wort extract. The British introduced indirect kilning for malt, and Sedlmayr's father had followed suit in 1818:

> After 1818, the taste of beer improved greatly as indirect hot-air kilning of malted grain gradually replaced the traditional direct-smoke kilning. Instead of sending hot, dirty smoke over the moist bed of malted grain, in an indirect system, the fuel heated a stream of clean air that was blown through the grain. Thus the grain no longer picked up smoky residues from coal or wood, flavors that used to be passed on to the beer. The new kilns also allowed for more precise temperature control of the drying grain and thus gave the brewer for the first time dependable pale malt as well as malt with predictable mashing qualities.[27]

Mashes and resulting worts became more consistent from these malting improvements. Also, the introduction of the thermometer in the brew house permitted exact control over mash temperature, which is critical for quality wort. British brewers began utilizing them in the brew house in the eighteenth century.[28] The sacchrometer, which measured the sugar content of wort, proved to be another useful tool. Like the British, Sedlmayr and Dreher adopted the thermometer and sacchrometer, later the hydrometer, in their brew houses. These devices gave them control over the brewing process undreamed of by their ancestors.

Nineteenth century brewers also had new tools for packaging beer. Filtration science was worked out in the 1850s, and commercial

filters became available in 1878.[29] Although filtration stripped some body and flavor from beer, it removed yeast and protein haze and promoted stability. Beer could also be pasteurized to ensure against infection. Louis Pasteur explained the process of pasteurization whereby a liquid is heated to 145°F for thirty minutes to kill any microorganisms present.[30] Pasteurization can increase the likelihood of oxidation, but it became standard in the industry after the introduction of bottles. Bottles marked a new era for beer. Cheap glassware appeared in the 1840s and with it a move towards lighter colored beers. Bottles accelerated this process and made beer more portable. Gustav Stresemann, a minister of foreign affairs for Germany and a descendent of a family of bottlers, offered an anecdote of bottled lager's popularity:

> Since the introduction of the Bavarian type, beer is consumed much more simply and conveniently. The worker puts one or more bottles into his pocket and drinks whenever he feels like it. The trade of the building workers is a very difficult and strenuous one, especially in summer when unprotected they are exposed to scorching heat. At the same time, the pay is mostly good and thus a lot of beer is drunk on the sites. The daily average may amount to six or ten bottles per head.[31]

Stresemann wrote in Berlin. The popularity of Bavarian lager in Berlin testified to the increasing interconnectedness of Germany in particular and Europe on the whole. This interconnectedness depended on the ever-increasing rail and shipping trade links. The breweries of Austria and Bavaria "were situated far away from coal resources and the economic centers of the continent and could grow only as the rail road expanded; Munich was connected to Augsberg in 1840, to Berlin in 1851, and to Vienna in 1860."[32] The rails, improved canals, and international shipping and immigration carried the lager revolution around the globe.

Much of the expertise of this revolution came from brewers educated in the new polytechnic schools cropping up in the nineteenth century. Full degrees in brewing science became available at Weihenstephan (1852), Augsburg (1869), Berlin (1883), and Prague (1869).[33] Trained brewers coupled with modern technology and transportation allowed lager-brewing techniques to spread.

IV

The Pilsner Urquell brewery offered an excellent case study in nineteenth century brewing. In 1842, the burgher-brewers of Plzen joined their capital to form a civic brewery dedicated to lager brewing. They hired a Bavarian brewer, Josef Groll, who was intimately familiar with lager techniques. The brewery utilized steam power and had extensive storage cellars that "extended for about 6 miles."[34] The brewery incorporated the latest technologies for malting which produced lighter colored malts and yielded the first golden colored beer of the age. The release of this new golden beer coincided with the introduction of cheap glassware, which made it all the more appealing. Pilsner Urquell became one of the fastest growing styles of the modern era, and the brewery continued to incorporate modern technologies:

> The brewery first used gas for lighting in 1865, and was wired for electricity in 1891. Exports increased with the opening in 1862 of the West Bohemian Railway; by 1865, three-fourths of the brewery's beer was being exported, and it was #3 in Czechoslovakia in production. By 1913, the brewery was producing more than 1 million hL of Pilsner Urquell per year and was the largest brewery in Europe.[35]

By 1887, Pilsner Urquell was available in its classic green glass bottles, which further expanded its reach. A lighter pilsner style would eventually highjack twentieth century brewing in Germany, Japan, Australia, and the United States.

V

Brewing looked much different at the dawn of World War I than it had after the French Revolution. It went from a local concern to a large-scale international commodity: from complex and cloudy ales to clear and clean lagers: from an artisan's craft to a business dependent on science and engineering. Mechanization and scientification characterized this century's development. Austria-Hungary provides an excellent example: "At the close of 1894 there were in all 1,802 breweries at work in Austria-Hungary. Of these, seventy-three per cent worked by machinery and twenty-seven per cent by hand; the production per brewery ranged from six hundred and forty hectoliters to seven hundred thousand hectoliters."[36] Clearly, European brewing had changed from its home and monastic roots.

At the beginning of the nineteenth century, the process of making beer was difficult to monitor and manipulate, and it was not completely understood. But by World War I, the role of yeast had been

discovered; the effects of temperature on mashing were understood; the brewing process could be closely monitored with thermometers and hydrometers; mechanized equipment permitted large-scale production; refrigeration allowed for year-round brewing and storage; and distribution networks had been established. Beer had become big business and it was facilitated by the rapid discoveries and developments of nineteenth century science and trade. No other century saw as much change in the production and consumption of alcoholic beverages.

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[1] Jackson, *Michael Jackson's Beer Companion*, 20.
[2] Jackson, *Michael Jackson's Beer Companion*, 237.
[3] Briggs, Hough, Stevens, and Young, *Malting and Brewing Science*, 320.
[4] Hughes, E. A Saving of Twenty Percent, 10.
[5] Briggs, Hough, Stevens, and Young, *Malting and Brewing Science*, 320.
[6] Jackson, *Michael Jackson's Beer Companion*, 24.
[7] Jackson, *Michael Jackson's Beer Companion*, 25.
[8] German Beer Institute, "Three Millennia of German Brewing."
[9] Fix, *Vienna, Märzen, Oktoberfest. Classic Beer Style Series*, 12.
[10] "German Brewing Statistics." http://www.xs4all.nl/~patto1ro/gerstats.htm
[11] Hård, *Machines are Frozen Spirit*, 37.
[12] Ibid, 198.
[13] Ibid, 41.
[14] Ibid, 31-33.
[15] Ibid, 84.
[16] Ibid, 129.
[17] Hård, *Machines are Frozen Spirit*, 137 and Wilson and Gourvish. *The Dynamics of the International Brewing Industry Since 1800*, 23, 61.
[18] Hård, *Machines are Frozen Spirit*, 151.
[19] Ibid, 201.
[20] German Beer Institute, "Three Millennia of German Brewing."
[21] Briggs, Hough, Stevens, and Young, *Malting and Brewing Science*, 624-625.
[22] Jackson, "The Birth of Lager."
[23] Briggs, Hough, Stevens, and Young, *Malting and Brewing Science*, 625.
[24] Wilson and Gourvish. *The Dynamics of the International Brewing Industry Since 1800*, 25.
[25] Hård, *Machines are Frozen Spirit*, 187.
[26] Jackson, "The Birth of Lager."
[27] German Beer Institute, "Three Millennia of German Brewing."
[28] Combrune, Michael. *The Theory and Practice of Brewing*, 30-39.
[29] German Beer Institute, "Three Millennia of German Brewing," and Briggs, Hough, Stevens, and Young, *Malting and Brewing Science*, 704-705.
[30] German Beer Institute, "Three Millennia of German Brewing."
[31] Quoted in Wilson and Gourvish. *The Dynamics of the International Brewing Industry Since 1800*, 78.
[32] Hård, *Machines are Frozen Spirit*, 27.
[33] Ensminger, "The History and Brewing Methods of Pilsner Urquell."
[34] Ibid.
[35] Ibid.
[36] "The Beer Industry of Austria-Hungary."