Introduction to Brewing Science

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1.1 Science and the Brewer

Master brewers know a lot about the process and the product that they make. In most cases, they have spent a considerable number of years at their craft, experimenting with different malts and grains, different yeasts, and different processes until they have arrived at what they consider to be the perfect beer. Any courses or training that the master brewer takes is extremely rigorous, often involving multiple months or years of intensive study and potentially even an apprenticeship under an experienced master brewer. Those years of training to master the art of brewing beer require not only mastery of the processes and recipes, but also an understanding of how the science behind the process results in a particular flavor or product profile.

Many brewers would agree that knowing the science of brewing is important to the process of brewing beer. Not only does the science govern how hop oils protect beer from minor spoilage or how barley must be sprouted before it can be used to make beer, but the general principles used to practice science guide the brewer everyday. What principle helps a brewer make everyday decisions?

1.1.1 The Scientific Method

The *scientific method* is a process of thinking about problems. The method is outlined in Fig. 1.1. Brewers, or anyone for that matter, that use this process methodically arrive at the answer to a problem or develop a law or theory based on observations. This is the same way of thinking about the world around us that scientists use everyday. An example helps guide us to understanding the scientific method.

A brewer starts with an observation. For example, suppose they notice that a recently brewed batch of beer tastes a little like buttered popcorn. The brewer would then develop an educated guess, called a hypothesis, which would attempt to

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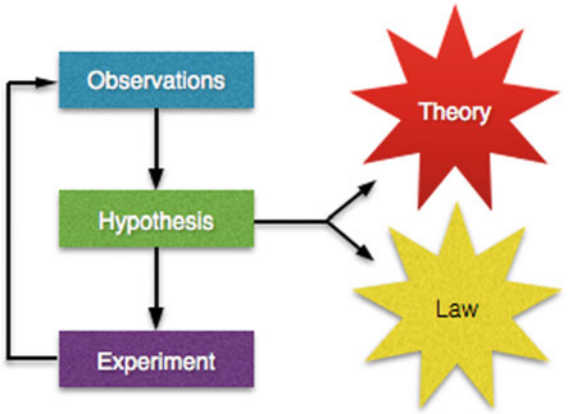

Fig. 1.1 The scientific method. A researcher makes observations, develops a hypothesis, and then tests the hypothesis with carefully designed experiments. This is a cyclical process that eventually results in a proven hypothesis that can either be called a theory or a law

explain the origin or cause of the off-flavor. For example, the brewer may hypothesize that the temperature of the water used in the process was too hot. Then, the brewer would perform an experiment to try to eliminate that flavor, in this case by reducing the temperature in the next batch of beer. After making more observations (tasting the beer, running laboratory analysis of flavor components, etc.), the brewer would then compare those results to the original hypothesis. If the observations did not fit the original hypothesis, the brewer would modify the hypothesis and return to the brewery to perform another experiment. Then, they would modify or recreate the hypothesis and test it out in the brewery. This cyclical process would continue until the hypothesis did not need modification after repeated experiments. The brewer would have found the answer to the observation and know what to do if that situation ever arose again. When the hypothesis is proved in such a manner, it can be called a law or a theory.

A law is a tested and proven hypothesis that explains the initial problem. Laws do not explain why the problem occurs, but simply what happens if another thing is done. In our previous example, the brewer may eventually discover that if the serving tap for the beer was cleaned immediately before use, the off-flavor would disappear and arrive at a law: Cleaning the beer tap removes the buttered popcorn flavor in the beer.

A theory, on the other hand, is a tested and proven hypothesis that explains why something happens. Theories are the most definitive statements that can be made. They are not just statements that identify the outcome of a particular step in the brewery. They predict the outcome by providing a detailed explanation of why that outcome occurs at any level of observation. To a brewer, and any scientist, a theory is the best statement that one can have about a process. In our example, the brewer may develop a theory that explains that bacteria in the tap line cause the off-flavor.

We will use this method as we explore issues surrounding brewing science. We will learn the existing theories about the science and use the scientific method to suggest additional directions that the brewer could use to advance their understanding of the process. Let us start by examining beer and brewing from its origins to the present day.

CHECKPOINT 1.1
In your own words, what is the difference between a law and a theory? Why would a brewer likely be satisfied with a law instead of a theory?

1.2 What Is Beer?

The word "beer" has many possible origins. Most likely this word derives from the Middle English word bere or from the Old English word bēor. The Old High German word bior may also be the precursor, as could the Middle Dutch word bēr. As we can see, the word "beer" has roots from Europe at least as early as the Middle Ages (fifth to fifteenth century). The words from that time that gave us "beer" referred to a fermented drink made from malted cereals and flavored with a myriad of different ingredients. In some cases, roots or other starchy plant materials instead of cereal grains were used to make the drink.

It is clear that beer is vastly different from wine. Beer is brewed, and wine is not. Brewing is the process of converting starches into fermentable sugars. In other words, the starch in grains or other materials is converted into sugars, and then, those sugars are fermented into an alcoholic beverage. Because fermentable sugars already exist in fruit, a beverage made by adding yeast to fruits is not brewed, but still results in an alcoholic beverage we know as wine. While both wine and beer are alcoholic drinks, making beer requires a few more steps.

The people in the early years of brewing did not use the same recipe to make beer. One group of people used recipes that vastly differed from other groups. Some used malted barley; others used roots, wheat, rice, and other grains to create the beverage. Flavoring agents added to the drink were equally as varied in those early days and in many cases absent from the finished product. Moreover, the alcohol content in beer was varied. Some early beers (and some beers that are still found today) had very little alcohol content, while others were quite potent. It all depended upon the process, the availability of ingredients, and the tastes of the peoples that made the drink.

The first recorded recipe The first beers were most likely made in Mesopotamia, the cradle of civilization, well before the eighteenth century BC. We know this because references to beer parlors were noted in the Code of Hammurabi. This code

of laws was written around 1772 BC by the sixth Babylonian king, Hammurabi. The code explained the laws for the operation of their civilization; the phrase we know as "an eye for an eye" comes from these laws. Beer was noted in many places within the laws as well, hinting that beer predated this time enough to have pervaded society by 1772 BC.

Specifically written in the code were severe penalties for beer parlor owners who overcharged for their product. They were to be drowned as punishment. This is harsh punishment to be sure, but most likely necessary to stop brewers from gouging their customers. The laws even noted that high priestesses were to be executed by fire if they were caught in establishments that served beer. While priestesses often drank and used beer in religious ceremony, they were not allowed to do so in a bar. This indicates that a separation between the religious uses of beer and the common consumption of beer was desired in their society.

Other evidence of beer is also found in this region of the world. Ninkasi, a deity worshipped by the Sumerians, was known as the goddess of beer. Archaeologists uncovered a tablet written in cuneiform dating from about 1800 BC that outlines just how important Ninkasi was to her worshippers. The Hymn to Ninkasi, either chanted or sung to a tune that was not written down, details how to make beer. Most likely the hymn was created as a way for the average citizen to remember the recipe, because only highly skilled people could write during those times. It is clear that the beer made by the recipe was used not only for religious rituals, but also served as a staple for the average citizen. The second verse of the hymn explains this use:

> May Ninkasi live together with you! Let her pour for you beer [and] wine,
>
> While I feel wonderful, I feel wonderful, drinking beer, in a blissful mood.

The recipe described in the hymn refers to the preparation of a loaf of bread made from malted barley. The bread was to then be soaked in water and allowed to ferment. The resulting mixture, with the sort of a soft oatmeal-soup-like consistency, was then poured into vessels to be consumed. This differs greatly from today's brewing process, but still results in a drinkable beer if you do not mind drinking soggy bread-beer.

Early beer in other regions of the world Clay tablets dating from 2500 BC confirm that the Sumerians were producing beer in cities across their domain. A specific tablet was found that appears to be a receipt for an order of beer from the city of Ebla. Evidence exists that beer was likely a staple long before even these writings were made. In the same region of the world, tombs and figurines from ancient Egypt illustrated beer making and drinking (Fig. 1.2). These reliefs and figurines date to about the same time as the Sumerians were enjoying the fruits of their labors. Interestingly, the Sumerians and Egyptians made their beer almost the same as it was described in the Hymn to Ninkasi.

Fig. 1.2 Egyptian wooden model of beer making in ancient Egypt, located at the Rosicrucian Egyptian Museum in San Jose, California. Photograph by E. Michael Smith

The Chinese were also in the wonders of beer. Evidence exists from some archaeological sites that this drink was produced as early as 7000 BC from a mixture of rice, honey, and fruits. The evidence takes the form of residues found on pottery excavated from ancient sites. The rice used in this process was most likely germinated before brewing or chewed by the brewer to promote the release of starches and their conversion into fermentable sugars. While no text has yet been found that describes the process or provides a recipe that was used, it is clear that the ancient peoples of China enjoyed beer.

As time progressed, a number of different recipes for making beer were developed. In fact, records from early Greek historians indicate that there were over a dozen different types of drinks that we might call beer. And as the drink moved north out of Africa and Mesopotamia, that variability continued to grow. The different recipes used to make beer resulted in a similar variability in the number of words that refer to the beverage. For example, the Sumerians called it "ka." The Egyptians called it "bouza." Even within a culture there were multiple names for the beverage, most likely because of many different recipes or reflecting different uses of the beer. In fact, the Egyptians referred to seventeen different types of beer, including one known as "joy bringer" and another known as "heavenly." The ancient Babylonians called the beverage "sikra."

These early beers differ greatly from the beers we find in the stores today. We currently recognize the beverage as a product made from malted grains (typically barley) and hops and fermented to provide an alcoholic drink with varying degrees

of bitter flavor. The ancient beers, from what evidence can be found, were likely very malty, bready, and in some cases sweet or dry depending upon the addition of fruits and their type. It is very evident that there was little, if any, bitterness to them. The development of beer from the early fermented bread–water mixture to that of today is a long and storied history that we will explore later in this chapter.

CHECKPOINT 1.2
A brewer makes an alcoholic drink from yams. Is this a beer or a wine? Why? Why was beer not made with the same ingredients in different places of the world?

1.3 Some Common Conventions

In our studies of beer, we have to make sure that we can communicate with other brewers, malt and hop suppliers, yeast producers, customers, and tax enforcement officials correctly and accurately. To do so, a series of conventions have been established that help us in our conversations. These conventions ensure uniformity in reporting the values associated with volume, temperature, and weight measurements.

Unfortunately, this uniformity did not always exist. In the early years of brewing, descriptions of the amount of grain, the amount of water, and the amount of added fruits or herbs were akin to a trade secret. The brewer had a serious problem. How do you tell someone how to make beer but avoid using words such as kilogram, pound, or gallon? So recipes, if they existed, were developed using whatever measuring device was available. For example, if a certain amount of malt was to be added to the mashing vessel, the quantity might be described as equivalent to the weight of a person, or the same as would be used to make a dozen loafs of bread. It is easy to see that without a standard to compare, recipes were difficult to follow and very rarely was the same flavor of beer replicated.

The issue in reporting specific values lies within three main categories. An accurate recipe must be able to provide the brewer with ways to measure the volume, the temperature, and the mass of the ingredients. While the initial measurements might be done using reference to known things, once a standard was developed, the recipes were able to be accurately reproduced.

1.3.1 Volume

The volume of a liquid is the space that it occupies. That space in the USA is often referenced in terms of the number of fluid ounces, cups, gallons, quarts, etc. In the scientific world, volumes are referenced in terms of the dimensions of a cube that could hold the liquid. Reporting the volume in scientific terms means knowing the

dimensions of the cube and describing it using the distances on each side. For example, a cube that is 2.0 in. by 2.0 in. by 2.0 in. is said to be 8.0 $in.^3$ or 8.0 $in.^3$.

$$2.0\,\text{in.} \times 2.0\,\text{in.} \times 2.0\,\text{in.} = 8.0\,\text{in.}^3$$

In the scientific world, a set of standards is used rather universally. Those standards are referred to as the Système international d'unités (in English, the International System of Units, or SI system). Distances in SI units are recorded using base units of meters. A meter is slightly more than the US yard, so the volume described by a cubic meter is a very large measurement. For example, in the USA, we still order concrete using the units of cubic yards (a volume of concrete that is 3 ft by 3 ft by 3 ft). To reduce this down to something more manageable, scientists often talk about volumes in terms of liters. A liter is the volume represented by a cube that is one tenth of a meter on each side (0.1 m by 0.1 m by 0.1 m) and is close to the same size as the US quart.

The use of SI units outside of the USA is very common. Brewers use liters to describe the volume of beer that they produce, or more accurately, brewers describe the volume of beer that they produce in units of hectoliters, where 1 hL is equivalent to 100 L. But in the USA, volumes are still reported using gallons and many of the older English measurements such as quarts, pints, and tuns. These were originally determined based on the different sizes of casks and other containers that were used to hold beer. Some of these units may seem foreign, but knowing them can be very helpful.

We can still measure the volume using a ruler and multiplying to get the number of cubic inches. All that is necessary at that point, then, is to convert the number of cubic inches into gallons or barrels or whatever other unit we wish to know. Table 1.1 lists some common volumes of beer and their relationship to the number of equivalent cubic inches and US gallons. The number of cubic inches is supplied in the table to aid in conversion from one unit to another and to show just how large some of the measurements of volume can be.

It is important to note that the volume measurements outlined in Table 1.1 are specific to beer or ale. Believe it or not, if we talked about a different liquid or even a solid material like flour, our volume measurements would be completely different. What is very apparent is that there are a lot of different volume measurements for beer. And from the note to the table, volume measurements for beer were redefined a few times as time passed. Moreover, we can see that the current names for many of these units have been used for quite some time to relate quantities of beer.

There is more than one volume measurement known as a barrel. The two most common for beer are indicated in Table 1.1, but there are a lot of other definitions for the barrel (and the volume actually depends upon what you are measuring). The myriad of volume measurements is due to the long history of beer; different countries used different sized barrels to measure their liquids based on their own customs and how things were taxed. Standardization of some units, in fact, did not occur until recently.

Table 1.1 Common conversions with beer volumes

Unit	Number of Cubic Inches	Number of US gallons	Equivalence
1.0 L	61.02	0.264	
1.0 hL	6102	26.4	100 L
1.0 gallon (US)	231.0	1	4 quarts
1.0 quart	57.75	0.250	2 pints, 64 oz (US)
1.0 pin*	1248	5.40	
1.0 firkin*	2496	10.8	2 pins
1.0 kilderkin*	4992	21.6	2 firkins
1.0 barrel (UK)*	9987	43.2	2 kilderkins
1.0 barrel (US)	7161	31.0	0.5 hogshead
1.0 puncheon*	19971	86.4	2 barrels (UK)
1.0 tun*	59913	259.2	3 puncheons or 2 butts
1.0 hogshead*	14978	64.8	6 firkins
1.0 butt*	29956	129.6	2 hogshead
1.0 keg (US)	3581	15.5	0.5 barrel (US)
1.0 quartel (US)	1790	7.75	1 pony keg
1.0 sixtel (US)	1194	5.17	1/6 barrel (US)

Note The values marked with an asterisk reflect, where possible, the use of the most current usage of the imperial system. For example, the ale firkin until 1688 was equivalent to 2256 $in.^3$; from 1688 to 1803, it was 2397 $in.^3$; and from 1803 to 1824, it was 2538 $in.^3$. In 1824, it was defined in imperial gallons equivalent to 2497 $in.^3$

In the US brewing industry, the focus on beer volume measurement is on the use of the barrel (USA) and smaller sizes. A small microbrewery in central Colorado may describe the amount of beer that they produce in each batch as 7 bbls. In the UK, this would be roughly equivalent to the brewery that manufactures 8.2 hL. Smaller measurements in the USA are useful when the beer is sold to the consumer. These smaller volumes include the keg (1/2 of a barrel known also as a "full size keg"), the pony keg (1/4 of a barrel also known as a quarter), and the sixtel (1/6 of a barrel). The pony keg is often referred to as a slim quarter if the container itself is designed to be tall like a soda pop keg.

Many US homebrewers that keg their beer rather than bottle it prefer to use reconditioned or new soda pop containers known as Cornelius kegs after the company that manufactured these containers for the soda industry originally. "Corny" kegs come in many sizes and range from 2 to 10 US gallons (with the 5 gallon version being the most common). These kegs are rarely used in the brewing industry due to differences in the way beer is added and withdrawn from the containers. Cleaning and other issues with the soda kegs make them suitable for soda pop, but not very suitable for the brewer.

While we often do not consider it as a volume measurement, the bushel (bu) is just that. This unit is used quite heavily in the USA and still has use elsewhere in the world. Unfortunately, even today, the bushel is a different measurement based upon

what you are measuring and in which country you live. In the USA, a bushel of barley is 48 lb, a bushel of malt is 34 lb, and a bushel of corn is 56 lb. In Canada, the bushel of oats (34 lb) is a little heavier than in the USA (32 lb.) In the past, a bushel even was considered a different weight depending upon the state where you measured it. Iowa barley was 48 lb to the bushel; yet, in Illinois, the bushel was 44 lb.

CHECKPOINT 1.3
How many pins are there in a kilderkin?
A start-up brewery decides to make their beer in 5.3 barrel (US) batches. How many gallons will they make per batch? …how many hectoliters is this?

1.3.2 Temperature

The temperature of the ingredients during the brewing process is very important. Temperature is a measure of the amount of heat, or thermal energy, contained by a substance. Things that are hot are said to have a large amount of this energy, and things that are cold have less. When something has no thermal energy at all, it has the coldest temperature possible. This is known as absolute zero. At the other end of the scale, however, there is essentially no upper limit. We will explore heat in much greater detail in Chap. 8.

The brewer prior to the invention of the thermometer definitely needed to know how much thermal energy was present during the brewing process. Recipes dating from the seventeenth century (prior to the use of the thermometer in brewing) often refer to an ingenious way to obtain a somewhat reproducible temperature for mashing. In that method, water was heated to boiling and then allowed to cool slowly. When the brewer could see his face in the liquid through the steam, it was deemed to be at the right temperature. This often resulted in a temperature very near to 150–160 °F, almost the perfect temperature needed for mashing malt.

In the early days of the development of science as a discipline, fascination with temperature was common among practitioners. Each was interested in devising an instrument to measure temperatures in the most accurate and practical method possible. In fact, there are at least 52 different thermometers that were invented. While most of these are no longer used today, a couple of them are used very heavily across the world.

Scientists, as we noted before, tend to prefer units and measurements that are outlined in the SI unit definitions. For temperature, this includes the use of the units in Celsius (°C), named after Anders Celsius (1701–1744), and Kelvin (K), named after William Thompson, Baron Kelvin (1824–1907). The Celsius scale places the temperature at which water freezes at 0 °C and the temperature at which water boils at 100 °C. The Kelvin scale simply adds 273 to these numbers so that the coldest temperature possible, absolute zero, is at 0 K, freezing water is at 273 K, and boiling water is at 373 K. Note that the Kelvin scale does not include the degrees

symbol (°) and that reporting values in this unit one does not say the word "degrees." For example, if we report the value of 273 K, we say out loud "two hundred seventy-three kelvin."

The brewer, especially in the USA, might use the Fahrenheit scale named after its inventor, Daniel Gabriel Fahrenheit (1686–1736). The definition of this scale is such that water freezes at 32 °F and water boils at 212 °F. Luckily, a very simple conversion between Celsius and Fahrenheit allows brewers to communicate with each other no matter which scale they prefer:

$$^{\circ}\mathrm{F} = (1.8 \times {}^{\circ}\mathrm{C}) + 32$$
$$\mathrm{K} = {}^{\circ}\mathrm{C} + 273$$

For the brewer, temperatures are often measured from just below the freezing point to the boiling point of water. The freezing point is simply the temperature at which a liquid becomes a solid. The boiling point, on the other hand, is the temperature where the vapor pressure of the liquid equals the pressure of the atmosphere.

As the temperature of any liquid increases, the amount of vapor above that liquid also increases. For example, when we heat a pot of water on the stove, the amount of steam above the liquid increases as the water gets hotter. When the pressure of that steam is equal to the pressure of the environment, the water is said to be boiling. Note that the boiling point is not the temperature where we see bubbles forming in the liquid. That temperature is close to, but not the same as the boiling point of the liquid. In fact, the bubbles we do see are actually steam (not bubbles of air) where locally, and the water is hot enough to boil, but the entire pot of water has not reached the same boiling temperature yet.

As we increase our altitude where we perform our boiling water experiment, the temperature of the boiling water drops. At sea level, boiling water occurs when the temperature is 212 °F (100 °C). In Denver, Colorado, a mile higher into the atmosphere than at sea level, the boiling point of water occurs near 202 °F (94 °C). This occurs because the atmosphere is thinner in Denver; the pressure of the atmosphere in Denver is less than the pressure at sea level. Therefore, we do not have to heat the water as hot to get the pressure of the steam to equal the pressure of the atmosphere. It may save some energy to heat our water to boiling at a higher elevation, but the decreased temperature also results in a lower temperature of the boiling process in brewing beer. This decreased temperature means that we may have to boil the water longer in order to have certain chemical changes occur in the beer that we desire.

This is immediately apparent if we look at the back of a box of cake mix. There is often a special set of directions that help account for the decreased boiling points of water at higher altitudes. Usually, a small amount of additional water is added to account for the increased evaporation at the higher altitude. Table 1.2 provides the boiling point of water at a series of selected cities across the world.

Table 1.2 Boiling point of water versus elevation

Boiling point of water	Elevation	Example city
212 °F (100 °C)	0 ft, sea level	Miami, FL
210 °F (98.9 °C)	1000 ft	Kansas City, MO
207 °F (97 °C)	2500 ft	Tucson, AZ
202 °F (94 °C)	5280 ft	Denver, CO
198 °F (92 °C)	7250 ft	Mexico City, Mexico
195 °F (90 °C)	9250 ft	Quito, Ecuador
191 °F (88 °C)	11,000 ft	Cusco, Peru
187 °F (86 °C)	13,500 ft	Potosi, Bolivia

Luckily, the freezing point of water is independent of the pressure of the atmosphere (at pressures, we would experience in the brewery). Therefore, the temperature of the freezing point of water in Miami, Florida, will be equivalent to the temperature for freezing water in Mexico City.

Other changes occur for water as the temperature changes, as we will explore in a later chapter. Most notably, however, is the fact that as water gets hotter it swells in volume. This means that hot water occupies more space than cold water, a fact that we will have to take into consideration as we are uncovering the science behind brewing.

CHECKPOINT 1.4
What is the temperature, in °C, of water that is reported to be 150 °F?
If a brewer makes beer in Cusco, Peru, and must boil the wort for 60 min, what effect would the altitude have on his resulting beer?

1.3.3 Weight

We often refer to objects by how much they weigh. For example, we might say "Add 2 lb of hops to that kettle." The pound, a unit that measures the weight of an object, however, has a very specific scientific definition. Weight depends upon the force of gravity at the location where the object is measured. For example, a barrel of beer weighs more on the Earth than it does on the Moon, because gravity is six times stronger here on Earth. Carried to the extreme, an object on Earth can have different weights based upon the minute differences in gravity where the object is placed on the scale. Because of this difference, scientists prefer a better term, the mass, to define the quantity of a substance. The mass of a substance refers to the specific amount of material that makes up that substance. Mass is independent of the gravity, and objects with a given mass on Earth have exactly the same mass on the Moon.

While the definition of weight and mass is different, non-scientists often use the two words interchangeably. Just remember that a question such as "How much does that bag of malt weigh?" has a different answer than "What is the mass of the bag of

Table 1.3 Common weights and mass units

Unit wanted	Abbreviation	Number of pounds	Simple conversions
1.0 stone	st	16	16 lb
1.0 kg	kg	2.204	1000 g
1.0 g	g	0.002204	15.4 grains
1.0 lb	lb	1.0	16 oz
1.0 oz	oz	0.0625	16 drams
1.0 dram	dr or ʒ	0.0039	27.3 grains
1.0 scruple	sc or ℈	0.002857	20 grains
1.0 grain	gr	0.0001429	

Note The dram, scruple, and grain were apothecaries' units with many different definitions. While it is rare to encounter the dram and scruple, the grain finds use in the brewery because water hardness in the USA is sometimes reported in grains per gallon of water

malt?". Brewers know the difference between the words, but often follow the common lingo that is used where they live and sometimes interchange the words.

Mass, according to the SI system, is measured in kilograms, where a kilogram is approximately 2.2 lb on Earth. Smaller masses can use other terms, such as the gram. Just as in the units for volume and temperature, there are a myriad of different terms and units used based on the area of the world where the unit was developed. Interestingly, the unit of weight known as the "grain" was originally devised based on the weight of a single grain of barley, one of the more important grains used in beer production. Table 1.3 lists many of these units.

Looking at Table 1.3, we notice that the ton is not included. This is because the ton as a measurement of dry weight has many different definitions. In the USA, the short ton indicates 2000 lbs and the long ton is 2240 lbs. In many other countries, the tonne (note the different spelling) is 1000 kg or 2204 lbs. Due to the potential for confusion, this unit is not used much in the brewing industry. Instead, the use of the pound and ounce in the USA and kilogram and gram in most other countries tends to predominate.

CHECKPOINT 1.5
How many kilograms are 325 lbs of malt?
How many grains are in a pound? How many stone does a 210 lb person weigh?

1.4 Yes Virginia, Beer Contains Alcohol

Part of the early allure to beer as a beverage was most likely the fact that it contained alcohol. While early beers, such as those discussed in Sect. 1.1, probably contained a very small percentage of alcohol, it was obviously recognized as an important part of

the drink. That slight intoxication might have been recognized as divine euphoria. This could be the reason beer was involved in religious ceremonies in those early civilizations. To be sure, beer's intoxicating effects would have been thought of as a welcome release from the daily toils of the common citizen. Those effects were noted by many of the historians of the time, a hint that many new recipes for beer might have developed in search of ways to increase the euphoric feeling.

In addition to getting a little tipsy, the early brewers slowly began to realize that beer did not spoil as quickly as other beverages (such as milk, juice, or even water). Milk, for example, spoiled in warm climates very quickly after it was obtained and had to be consumed soon or it would go sour. Beer, on the other hand, did not appear to show a deterioration in its flavor as quickly and so it could be kept for a little while after it was made. In some cases, it likely tasted better when it was a little old.

The early brewers did not understand what gave drinkers the feeling of euphoria or allowed the beer to be kept for a while before consumption. Today, we know that the small amount of ethyl alcohol (also known as ethanol, grain alcohol, or simply alcohol) produced in the beer during the brewing process is the reason for these effects. Some beers possess quantities of alcohol that are <1 % of the total volume, and others can be 10, 20, 30 % or more alcohol by volume. While the preservative properties of alcohol are clearly recognized as beneficial to beer and were known long ago to be helpful during transportation of the beer to market, today we know that overconsumption of alcohol can have a serious detrimental effect on our health. Labeling on beer often reminds us of the hazards of alcohol (see Fig. 1.3).

Alcohol can impair one's abilities and capabilities. Thus, many of the states in the USA have limits on the amount of alcohol that can be in one's body if that person plans to be in public, drives a car, or operates any machinery. In the pre-1970s, laws that limited your consumption were rather relaxed. We have seen the old TV shows of the drunk driver receiving a ride home by the police after being stopped. That is definitely not the case today. Studies illustrating the increase in motor vehicle accidents and fatalities due to overindulgence and society's distaste for those that "could not hold their liquor" resulted in our current system of severe penalties for those that drink and drive. And those laws are not there just to be admired. Today, enforcement of drunken-driving laws has become a very high priority across the USA.

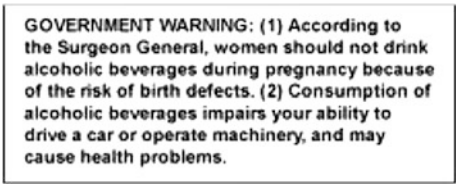

Fig. 1.3 The US federal government requires that all bottles containing alcohol for sale be labeled to indicate the hazards of alcohol consumption

Research has shown that impaired performance as a driver occurs with as little as 0.04 BAC (percent blood alcohol content). Most states in the USA (and throughout the rest of the world) have mandatory driving while intoxicated (DWI) laws that severely punish those with 0.08 BAC or higher. Penalties often include automatic loss of your driver's license, jail time, and hefty fines. In addition, violators often must attend rehabilitation or driver's education training. Of course, this assumes that the drunken driver did not get in an accident; penalties for an accident caused by an intoxicated driver can be extremely severe. Some states even have penalties associated with the lower level BAC (0.04 BAC) known as driving while impaired. And penalties can be nearly as harsh as the DWI. In short, it is just not worth the risk of spending the next couple of months in jail. If you have even been sipping an alcoholic beverage, do not even think about driving.

Table 1.4 indicates the typical BAC based on how many 12-oz beers are consumed per hour. The table is not 100 % accurate as body mass and the strength of the beer factor heavily into the actual BAC that a person acquires. What is very evident from the data is that it does not take much to be intoxicated by the rules of law. And it even takes less to be impaired. For example, one beer an hour might keep some people below the 0.08 BAC, but severely impair the abilities in others.

We have all heard phrases at the parties: "one more won't hurt" or "let us have one more for the road." Peer pressure and ignorance have led to many things that people take as truth about drinking. Unfortunately, most of the sayings we have heard about drinking are in fact misconceptions and untruths. For instance, many people believe that drinking coffee will reduce their level of intoxication and their BAC levels. This is simply not true. Research has shown that drinking coffee, water, or other beverages does very little to the BAC level. The caffeine in coffee may make a person feel like they are less intoxicated, but they are not. Others believe that vigorous exercise will reduce a BAC level, and still, others think that eating certain foods before drinking will stop them from being intoxicated. These beliefs, as well, are not true. While eating certain foods may reduce the rate at which alcohol is absorbed by the body, the effect is minimal and the alcohol will still eventually be absorbed into your bloodstream. In every case, a BAC level reduces only by waiting. Every hour that passes, on average, can reduce your BAC

Table 1.4 Estimated BAC based on gender and body weight

Standard drinks	Body weight				
	100 lbs	140 lbs	160 lbs	200 lbs	220 lbs
1	0.05/0.04	0.03/0.03	0.03/0.02	0.02/0.02	0.02/0.02
2	0.09/0.08	0.07/0.06	0.06/0.05	0.05/0.04	0.04/0.03
3	0.14/0.11	0.11/0.09	0.09/0.07	0.07/0.06	0.06/0.05
4	0.18/0.15	0.13/0.11	0.11/0.09	0.09/0.08	0.08/0.06
5	0.23/0.19	0.16/0.13	0.14/0.11	0.11/0.09	0.09/0.08
6	0.28//0.24	0.20/0.18	0.17/0.14	0.14/0.11	0.11/0.09

The first number in the table is the BAC level for women, and the second number is the BAC level for men

by about 0.01 %. Note that BAC levels rise very quickly when you drink, but decrease very slowly over time.

In addition to laws against drinking and driving, some US states and local governments have public intoxication laws. These laws possess penalties that are less harsh than driving while intoxicated laws, but do have penalties for violators. Drinking in public, being drunk in public, and abusing alcohol overall are just things that society does not appreciate.

Not only are there laws against public intoxication and impaired driving, but alcohol can be damaging to your health. The US National Institutes of Health defines binge drinking as four drinks for women or five drinks for men over a 2-h period. Repeated binge drinking episodes can lead to heart problems such as stroke or heart attack, severe liver damage such as hepatitis or cirrhosis, and even an increased risk of cancer. Consuming more than one to two drinks a day is definitely not worth the risk.

Most importantly, intoxication is contrary to the reason we should be drinking beer. Beer is about enjoying flavors and aromas and about enjoying and appreciating the end result of the brewer's craft. Drinking beer should not be about getting drunk. Put another way: It is hard to appreciate a fine barleywine if you are prostrate on the floor. Brewers know that the consumer wants to savor and appreciate the work they have done. So, they spend time to make their products into finely crafted beverages that produce pure satisfaction to the entire palate. We should do our part to savor the efforts of their labor and drink responsibly. In short, we should drink for the pleasure of the beverage.

CHECKPOINT 1.6

Investigate the laws where you live and determine the penalties for driving intoxicated. Use Table 1.3 to determine how many drinks you could have to reach this level of intoxication.

Use the Internet and determine what chronic binge drinking does to the kidneys.

1.5 A Short History of Beer in the World

As we noted in Sect. 1.2, the initial development of beer as a religious and spiritual tool in Mesopotamia and Egypt gave rise to a large number of different recipes and names for the alcoholic beverage. Most beer was made in the home. However, there were some attempts at mass production via government-run or commercial enterprise. Some breweries uncovered by archaeologists in ancient Syria could produce up to 100 gallons per batch. Beer, likely the reason for civilization itself, still pervaded society.

Beer in its early stages was a soupy mix of semisolids and liquid. People either drank their beer like a thin slush or sucked the liquid through a clay or reed straw. Most beer drinkers preferred the straw method as the vessels used to hold beer were

much too heavy to lift comfortably. In fact, consumption of beer was a group event; groups of people gathered around the beer jar and passed the straw as they consumed the drink. Hieroglyphs, cylinder seals, and wall images from pre-2000 BC depict many scenes of people sitting around a container of beer drinking it through straws. The use of a straw to drink beer is still done today in regions of the world where the beer is made as an unfiltered mass of solids and liquids in large vessels. Some evidence suggests that the straw might have been used to filter the solids from the beer, but this is likely not the reason for the use of the straw.

Just as in the Hymn to Ninkasi, beer at that time was prepared by essentially making bread from barley, mixing it with water, heating the soup to cook and distribute the ingredients evenly, and then cooling it. Wild yeasts and bacteria in the air or living in the pottery or wooden spoons used to stir the mixture would grow quickly in the cool mixture, and fermentation would result. After few days, the fermentation would have slowed dramatically and the beer would have been consumed. The mixture was most likely served as it was at this point or only partially clarified by decanting or crudely filtering the liquid away from some of the solids that settled to the bottom of the vessel.

The brewing process changed as time passed. One notable change was the way in which the ingredients were mixed and "cooked" before the fermentation started. Malted grains, spices, and other additives were poured in a vessel and heated slowly to boiling. The slow increase in the temperature converted the starches into sugars, and boiling helped to thin the mixture and clarify it. The early brewer probably also learned that stepwise heating should be part of the process. At these early stages, however, none of the grains were removed until after the boil was complete. After it was cooled, the liquid was poured off into large vessels and the mixture allowed to ferment. From those fermentation vessels, the beer was transferred into mugs or cups for each consumer to drink individually. With the smaller mug and clearer beer, the consumer could consume the beverage without the use of a straw.

By the time of the Roman Empire, beer and wine had already permeated the peoples living around the Mediterranean Sea. Its consumption was part of what citizens did during their daily lives. And as the empire grew, the Romans took their preferred recipes with them. Prior to the invention of the wooden casks, beer was made, stored, and transported in clay pots or amphora (Fig. 1.4). These containers often weighed more than their contents and were difficult to transport and use. By 21 AD, the Romans had obtained wooden casks from the Celts and put them to good use holding, transporting, and for use in serving beer into smaller mugs. The much lighter and easier to transport casks meant that beer did not have to be made in the same town it was produced. While some transportation was possible, these early beers did not survive the rigorous handling that accompanies being moved very well, so most beer was still consumed close to where the brewery was located.

There is no evidence that the Celts, the makers of the wooden barrel, provided the recipes to make beer to the Romans. But similarities in the brewing processes of the two peoples reflected at least more than a casual interaction. For example, *celea* and *cerusia* were Celtic words used by the Romans for beer made directly from grain rather than the ancient Sumerian method of brewing from bread. Posidonius,

Fig. 1.4 Amphora as they might be stacked for transport in a ship. Image courtesy of Ad Meskens (https://creativecommons.org/licenses/by-sa/3.0/deed.en)

in 100 BC, wrote that beer was the drink of the common Celt and wine was the drink of the aristocrats. Beer and wine, part of the staples of life, moved with people as they settled the continent.

As Posidonius noted, not everyone preferred beer as the drink of choice. In fact, some did not even find the beverage palatable. For example, Xenophon (430–354 BC), a Greek historian, noted in his writings that beer was consumed in many regions of Europe, but to him, it was an "acquired taste." Tacitus (56–117 AD), a Roman historian, also found the drink distasteful and preferred wine to beer. Whatever the tastes of those living along the coast of the Mediterranean Sea, beer was greatly enjoyed by many across Europe.

Beer was not the only alcoholic beverage that was consumed. Mead, a drink made from fermented honey and sometimes spiced with herbs, was preferred by the lower classes of northern European society. While honey itself was more expensive than grains such as barley, diluting a batch of honey prior to fermentation could result in significant reduction in the cost of the resulting drink. Members of the upper classes preferred the more expensive, more flavorful, and more alcoholic beer. Braggot, mead that was flavored by adding beer or brewed with grains in the same manner as beer, was also popular.

Wine, the drink we typically associate with Roman culture, was not consumed much by the average citizen. Why was this so? Wine was relatively expensive; grapes cost more than grain, and they were less plentiful as you moved to less temperate climates. In addition to the much longer fermentation times required for making wine, the higher alcohol content in wine meant that it was not something to consume during the workday (especially if your productivity would suffer). Across Roman society, the average citizen still preferred beer to wine.

The use of beer as a staple meant that the average citizen consumed the beverage throughout the day. A glass in the morning would accompany the start of the day and quench the thirst of those who could afford it (or made it at home) during the workday. At night, it filled your glass during your evening meal. By the start of the Middle Ages, nearly everyone in Europe consumed significant quantities of the beverage daily. Overuse of the beverage was not typical because the alcohol content was very low for these beers. Afterall, this was a drink consumed as part of the daily activities. It was not free (purchasing or growing the ingredients cost money), and stretching the amount of grain used to make the beer was the norm. This meant that the beer was alcoholic, but only slightly so.

Recipes and the overall process improved as time passed. Instead of making a beer that was often much less than 4 % alcohol, these improvements increased the alcohol content significantly. As the alcohol content increased, overuse of the beverage in some places appeared to be a problem. Some brewers would mix their grains with beer instead of water in order to make the drink stronger. This "double beer" had the effect they sought and became extremely popular. In England, King Edgar (959–975) saw the overindulgence as a threat to the way of life in his kingdom. Thinking that the intoxicated people he saw were the result of too many breweries, he instituted a rule outlawing more than one brewery per town. This law did little to stop the production of more alcoholic beers, let alone the number of citizens that overindulged.

Beer was so ingrained in culture and society that even wars, invasions, restrictions, laws, and culture changes did not reduce the production and consumption of beer as a beverage and staple in the diet of the common citizen. People made beer at home, and often, this was relegated to the duties of the housewife or, if you were wealthy, to the kitchen staff. Large breweries serving groups of people, such as communes and monasteries, started to take hold in the early seventh and eighth century (see Fig. 1.5). Those breweries were typically included in the plans when a new monastery was built. And the plans kept a keen eye on making sure the space in the brewery was enough to supply the monks and their visitors with an endless supply of beer.

In northern France in 822 AD, hops were recorded as one of the flavoring agents being used in beer. Pliny the Elder, almost 800 years earlier, had written about the hop plant. And even though mention was made of the cultivation of hops by 736 AD, beer was typically made without hops. In addition to imparting a very desirable flavor to the finished product, beer flavored with hops tended to last longer. Therefore, it did not have to be consumed as quickly as unhopped beer. However, hops were difficult to obtain everywhere in Europe, and the amount of hops needed for a batch of beer was hard to determine because of the variability of the amount of bittering agents in the wild plant. This meant that as people traveled, the beer they consumed had vastly different flavors resulting from the availability of what ingredients were found near the breweries. We can imagine that those regional flavors might not be palatable to every traveler.

Governments, realizing that beer was an integral part of the society in which they reigned, set out to standardize the flavors of beer across their kingdoms. Doing so would ensure that beer in each of the cities and towns was of equal quality. One of

Fig. 1.5 This drawing from a book was completed about 1426. The book listed the members of a fellowship or commune in Nuremburg. The text states "The 46th brother, who died here, was named Herttel Pyrprew." Pyrprew was the word for brewer. (Image in Public Domain: CC-PD-US)

the laws that were instituted in Bavaria required beer to be flavored with gruit (pronounced groot).

Today, we do not really know what gruit was. Some of the confusion is based on the fact that gruit was a spice mix that likely had a variable recipe. No one appears to have recorded the recipe for gruit, or at least the recipe has not yet been discovered. The actual mixture of herbs and spices was likely only passed from person to person by word of mouth. Our best guess today is that gruit included dried crushed leaves from the bog myrtle plant, wild rosemary, and other common herbs. Bog myrtle is a small bush that grows in wetlands and is relatively common across northern Europe. The leaves have a bitter flavor that, while an acquired taste, would be recognizable and probably acceptable as a flavor in beer.

Governments owned gruit. In some cases, a gruitrecht, or right to produce gruit, was granted to certain citizens under their rule. Clergy, towns, and even prominent citizens could be granted a gruitrecht. This was done as a favor to the recipient, or to repay a debt that the government owed. Anyone interested in making beer, as most families were, had to visit the gruithaus (gruit house) owned by the holder of the gruitrecht. There, they would purchase enough of the spice mixture to make a batch of beer. If a family had the financial ability to do so, they could purchase a

daily supply of beer from a monastery or a municipal brewery that had already acquired the gruit. Monasteries and communes even supplied free beer, often the lowest quality beer, to travelers or the poor.

The money that was charged for the gruit was essentially a tax that was collected by the holder of the gruitrecht. Governments used these funds to support the kingdom. While brewing was a domestic practice, it was clear that towns and monasteries were operating more and more breweries in an effort to assist families with supplying their daily intake of the nourishing beverage. For example, the Weihenstephan Abbey obtained its gruitrecht in 1040. It continues to brew beer to this day.

Beer consumption by the average citizen grew as the years progressed. By the Middle Ages, beer was an integral part of life. Everyone from infant to the convalescent senior drank beer. It was consumed at every meal and essentially any time that someone was thirsty. Moreover, those that could afford it or had the supplies to make it at home preferred beer to water. Beer was even prescribed as nutritional supplement for nursing mothers. Beer was food and drink.

Prior to the modern age in Europe, cities were not the cleanest places to live and work. In fact, they were incredibly dirty. People dumped their garbage and raw sewage into the street outside their house. Rivers, streams, and lakes also served as garbage dumps. Children played in the garbage, and people walked through filth. With no control over waste, citizens of those cities had no choice but to drink the same water that they polluted. At the very least, the appearance and flavor of drinking water were not pleasant. At worst, drinking that polluted water resulted in constant outbreaks of diseases such as cholera. In fact, the unsanitary nature of the cities meant that disease was commonplace. And once a disease started in a city, it spread very quickly across the population and even to neighboring towns. Drinking beer instead of water, which was boiled as part of the brewing process, provided a much more pleasant experience and offered some minor protection from waterborne illnesses.

As an example, let us examine what London looked like for the average citizen to see how beer was so important. About 1200 AD, there were roughly 350 ale houses (taverns) for the approximately 80,000 London residents. Brewing supply stores that sold malted barley and other ingredients were even more common. Records from the time indicate that there was approximately one supply store for every 60 residents. Everyone was making and drinking beer. In fact, the citizens of London had many different choices when it came to beer, from making it at home to buying it in an ale house. It was not uncommon for many city dwellers to send their children to the ale house to buy the family's beer for the day.

Unfortunately, the makeup and quality of beer across Europe varied greatly. Depending upon where you lived, you could be drinking beers flavored with hops, gruit, or a whole host of other spices or herbs (some were even toxic). You could have beer made from malted barley, wheat, oats, or almost any other type of starchy vegetable. Some were high in alcohol; some very low. If you were traveling, it was likely that the beers you would encounter each day were not even close to those "like mom made." Some likely did not even come close to being enjoyable or

familiar to what the average traveler was used to consuming. The argument for maintaining quality eventually became important enough that the Duke of Bavaria, William IV, in 1516 issued a law known as the Reinheitsgebot (the Bavarian Purity Law). This law was constructed not only to assure some uniformity in beer production, but also to ensure that enough grain was available to make bread for people to consume. The Reinheitsgebot dictated that beer had to be made from barley, hops, and water. (Yeast was not known in the sixteenth century and thus was not added to the list of acceptable ingredients.) This law was officially still on the books until 1987. Barley malt was thus restricted to the production of beer, a task for which barley is very well suited. Grains, such as rye and wheat, which were much better for use in bread making, were not to be used to make beer.

The industrial revolution swept across Europe in the mid- to late 1800s, resulting in a dramatic impact on the production of beer. Engines that could operate machines, the invention of the thermometer and hydrometer to monitor beer production, the development of coal-fired ovens used to kiln malt, and small but very useful improvements to packaging beer for sale in bottles served to increase the output of municipal and commercial breweries. In fact, that increase in production signaled the beginning of a shift from brewing beer in the home to brewing beer commercially. The economies of increased scale meant that beer became cheaper and easier to buy than it was to make in the home.

CHECKPOINT 1.7
Why was beer so important to societies in early Mesopotamia?
What was gruit and what was the purpose of gruit?

1.6 History of Beer in the USA

Travel on ships across the ocean was a perilous adventure. Early transportation and exploration by ship typically meant sailing close to shore. Captains did this for many reasons, including being close enough to land in case the provisions ran low. As ships began exploring farther from land and trips on those ships began to take longer and longer, food and drink became more and more important as a stable supply on board.

Because refrigeration was not available, food was stored in wooden barrels or crates for the long ocean voyages. The typical ship brought along large amounts of food that did not need refrigeration, such as pickled fish, salted pork, or dried beef. Often, the meat still spoiled or became infested with maggots. Bread in the form of hard tack or flatbread was also included. The hard breads were chosen as they tended not to spoil as easily. However, spoilage was still a problem, and weevils were a constant problem. It was said that most sailors were advised to eat quickly

and not look at the food while they ate in order to avoid the unpleasant nature of the food and the occasional weevil.

Vegetables and fruits were not included in the typical sailor's diet because they did not last long before spoiling. This posed a serious problem on long voyages. For example, scurvy, a disease resulting from vitamin C deficiency, crippled those that did not eat properly over long periods of time. The English Navy eventually learned that citrus fruits had to be included regularly in the diet to combat the incidence of scurvy. Limes were often chosen for those navy ships, and English sailors became known as "limeys" because of it.

Drink on board a long voyage included grog and beer. Freshwater was included on board, but it quickly turned green from algae growth and became undrinkable. Being ones not to waste anything, the water was made palatable and relatively safe by diluting three parts of water with one part of rum and adding other spices or flavorings. The result was known as grog. Grog was common onboard ships, typically one pint in the morning and one in the evening. Beer, on the other hand, was very plentiful onboard a ship. The typical ship-ration included a gallon of beer per day for each sailor.

Needless to say, stores of food and drink would eventually run out unless the ship could be reprovisioned. This was the case for the sailors on the Mayflower. As the story goes, John Carver, the leader of a Pilgrim migration, booked two ships to carry the colonists to the New World. They had negotiated to start a settlement in the Virginia Colony near the mouth of the Hudson River (at that time, Virginia stretched as far north as the Hudson). The Mayflower and the Speedwell left London on August 5, 1620, with everyone aboard, but the Speedwell started leaking shortly after leaving port. After returning to port, the ship was repaired and the voyage attempted again. Unfortunately, the Speedwell still leaked and the voyage was further delayed. Eventually, sensing the urgency of beginning their new life as colonists, the Pilgrims crowded onto the Mayflower and left port without the Speedwell on September 6. Unfortunately, the Mayflower was now heavily overloaded with 102 passengers and about 30 crew for the voyage across the Atlantic. Due to rough weather along the way, the trip took much longer than expected (66 days). The crew sighted the shores of Cape Cod on November 9 as their provisions started to look rather bare.

Attempts to round Cape Cod and head south to the Hudson River were met without success due to storms. The captain of the Mayflower, Ship's Master Christopher Jones, became concerned about the supplies on board, especially the supplies of beer and grog. Most likely it was he who convinced John Carver to identify a suitable site for their settlement as quickly as possible. As one of the settler's wrote in their diary:

> We could not now take time for further search of consideration, our victuals being much spent, especially our beere.

A suitable site for the colony was found in present-day Massachusetts, but by the time the colonists were off-loaded, it was too late in the season for the Mayflower to return to England. So, while the settlers of the Plymouth Colony spent the brutal

winter of 1620–1621 on dry land, the crew of the Mayflower stayed on the ship to guard their beer supply for the trek back to England planned for the following spring. There are many accounts of Pilgrims begging for supplies from the ship's stores that were only, albeit begrudgingly, supplied to those settlers who were ill.

All across the east coast of the New World settlements were started. While some settlements in the south imported their beer from Europe, the majority of the colonies set about building a brewery as one of the first buildings in their new villages. In fact, the earliest help wanted advertisement in the New World was in 1609 for a brewer. The supplies brought over to start the brewery in the new settlements often contained both barley seed for growing a new crop and bags of malted and raw barley for use in making beer immediately. To be sure, the stockpile would not last long. New barley would have to be grown and malted quickly.

In many settlements along the coast, the European barley strains would not grow well. Supplements and even replacements for the barley were needed. Wheat, rye, oats, and other grains were chosen for the purpose. Those immigrants that befriended native tribes learned to use corn as a replacement for barley. In fact, the natives in the New World had been making their own version of beer using corn and other ingredients for centuries. Their knowledge coupled with the immigrant's skill in making beer resulted in a beverage that was said to be better than an English ale. This could have been optimism, but it was clear that the production and consumption of beer were so important that the colonists would try anything.

The first formal brewery in the New World was established in 1612 in New Amsterdam (later to become New York City), roughly 8 years before the Pilgrims began their voyage. Had the Mayflower found its way to the Hudson, the Pilgrims and crew of the ship would have been close enough to access this brewery immediately. As it was, the Pilgrims followed suit with many of the other settlements and built their own brewery.

Evidence of the importance of brewing in the New World is clear. For example, in 1640, a law was passed in the Massachusetts Colony stating that no one should be allowed to brew beer unless he is a good brewer. Other laws were enacted to ensure the quality of beer. In 1655, in the New York Colony, a law required brewers to have sufficient skill and knowledge in the art and "mystery" of brewing if they planned to sell their beer. Obviously, at least one person was not a fan of the beer produced in the brewery at the time.

As the settlements grew, brewing followed. The task was still accomplished in the home for those that had the ingredients and time, or could afford to make the beer the way they liked it. In settlements without a communal brewhouse, families grew or bartered for the ingredients to make beer. Trade and traveling from town to town was also common and that led to the development of taverns across the colonies. Taverns often had a communal room to serve meals and beer and bedrooms or bunkrooms for those that stayed the night. The first recorded tavern was licensed to Samuel Cole in 1634 in present-day Boston. These places served as restaurants, hotels, and gathering places where the locals would obtain the day's news (Fig. 1.6). When the colonies started to stretch their legs and proclaim

Fig. 1.6 Scenes such as this were common in the colonial tavern. Taverns were more than just places to drink beer. Patrons visited with each other, learned the news of the day, conducted business, and enjoyed a relaxing time. "Sea captains Carousing in Surinam" by John Greenwood (Image in Public Domain: CC-PD-US)

independence, many heated discussions were held in taverns. In fact, Thomas Jefferson is said to have written the Declaration of Independence over a 3-day period at his usual table in the Indian Queen Head Tavern in Philadelphia.

Taverns also served a major role in the American Revolution. When a state would "call up" a militia, the commander of the militia would usually buy a barrel or two of beer at a local tavern and give away the beer to anyone that showed up. Able-bodied men from all around would appear for their free beer or two (or three) and join the militia. George Washington, a skilled brewer at home, quickly learned the power of the tavern. As a young lieutenant in the Continental Army, he found out that supplying beer to the polling places dramatically increased one's chances of being elected to office. Later, in his role as General, he insisted that his troops received a quart of beer each day. During that fateful winter at Valley Forge, he decreed that the troops received their daily ration of drink before the officers.

As America entered the nineteenth century, small breweries became commonplace. Brewing was still done in the home, but the time-consuming nature of the process meant that there was a place for the brewery. These breweries produced their beer primarily for local use, storing the beer in casks until it was consumed. By 1810, there were 140 commercial breweries in the USA. Production was not very large for these breweries, and most of the business was local, but those breweries that were successful did quite well. Vassar College, for example, was founded from the profits earned by brewer Matthew Vassar in 1860.

While some growth in the industry happened in the early 1800s, large growth in the industry was not really observed until the decades after the end of the Civil War. The first federal tax on beer production was imposed in 1862 to help offset the costs of the US Civil War. After the war had ended, the incidences of heavy drinking,

however, increased. The war had been very traumatic on everyone in the country, and for many, solace was found in overindulgence of alcohol. Advocates for less alcoholic alternatives to "hard" liquor became more and more vocal.

In addition, as immigrants from Germany began coming to the USA, their taste for lagers over ales helped fuel the increase in beer production and the development of more and more breweries that specialized in this style of beer. With the invention of artificial refrigeration, the mass production of beer and transportation to different parts of the country became commonplace. Annual production of beer in the USA rose from 3.7 million barrels in 1865 to 39.5 million barrels by 1900. The dramatic increase in production meant that beer was available year-round in nearly every part of the country. This resulted in a similar increase in the per capita consumption to nearly 16 gallons per person per year.

The worldwide interest in temperance, or restraint from the consumption of alcohol, became a movement in the USA in the 1800s. As early as the 1820s and 1830s, organizations were formed that promoted abstinence from alcohol as a way of life. These organizations were fueled by the increasing abuse of distilled beverages and were linked to social behaviors that were deemed inappropriate or illegal. While it was suggested that beer was better than liquor because it was less intoxicating, every alcoholic drink quickly became included in the temperance movement. And the movement took on abstinence as forcefully as it could. In 1851, Maine was the first state to outlaw the sale of alcoholic beverages. By 1855, twelve states had adopted similar "Maine Laws" making it illegal to sell beer. Unfortunately for the movement, a riot in Maine overperceived access to beer in 1856 resulted in repealing the law in that state. The temperance movement stalled in the second half of the 1800s in the USA due to many different factors. Recognition of a need to tackle more important issues such as emancipation and women's suffrage pushed the ideals of national abstinence to the back burner.

However, growing anti-German sentiment in the USA during and after World War I empowered the temperance movement in the USA. Because families of German decent operated many of the larger breweries in the country, the link to abstinence was fueled. The Anti-Saloon League (founded by Howard Hyde Russell) used its political power to sway the federal legislature and enact a mandate against alcohol. In 1917, the United States Congress passed the 18th Amendment to the US Constitution. Thirty-six of the 48 states had ratified the amendment by the end of 1919. The law implementing the amendment, the Volstead Act, went into effect on January 17, 1920. It outlawed the "manufacture, sale, and transportation of alcoholic beverages in the USA and its possessions." Overnight, the future of alcoholic beverages in the USA changed.

Many of the small breweries closed shop and sold off their equipment to anyone that was interested. Some just closed their doors and waited, hoping that Prohibition would not last. Others retooled themselves and produced non-alcoholic beer, soda, root beer, and even ice cream. When Prohibition was repealed in 1933, and states again allowed the sale of beer (the last to allow beer to be sold was Kansas in 1937, although some counties in the USA still outlaw the sale of beer), beer production began in earnest. Initially, only beer containing 3.2 % alcohol or less by volume

was approved for sale. This worked well for the breweries in that less malt was required to make such a beer. In addition, the initial shortage of malt as the breweries came back online meant that other adjuncts would need to be used. Thus, rice and corn use in the manufacture of beer in the USA entered the scene en force.

The breweries that weathered the years from 1919 to 1933 produced vast quantities of lager style beer for the thirsty American public. Immediately, the number of breweries increased as there was a seemingly endless market for beer. Unfortunately, the initial rush to produce beer in quantity was immediately followed by World War II. Rationing of malt and other staples during the 1940s meant that the adjuncts initially used to help the breweries get by until malt production increased were to become an integral part of the standard recipe. The continued production of the American Lager meant that the average US citizen learned to love and accept this as the only possible flavor of beer. Afterall, many beer drinkers in the 1940s and beyond had only this style available their entire life. After World War II, the production of the American Lager continued with vigor. And until the 1980s, there was very little else in the way of domestic beer styles to choose from.

CHECKPOINT 1.8
Why did ships carry barrels of beer when they left port?
What was the purpose of a tavern in Colonial America?
What events occurred that resulted in national prohibition in the USA?

1.7 The Current Market for Beer

By the 1970s, there were less than 100 breweries remaining in the USA. The variety of beer styles that were available in the local supermarket or liquor store was limited primarily to the American Lager style with very few imported beers that did not sell well. Public perception of beer was that "beer is beer." Very little variety existed, and if you did not care for the flavor of an American Lager, there was not much you could do. The American Lager was only supplemented in the market by the American Light Lager that catered to those interested in limiting their caloric intake.

Table 1.5 lists the top 10 breweries in the country in 1980. The market had changed dramatically from the pre-Prohibition era. Thirty years earlier, the top ten companies produced nearly equal volumes of American Lager, but by 1980, mergers and acquisitions were the game of the brewery. If a company wanted more customers, it would just buy one of the other companies. Large companies were more successful than the small ones through large marketing campaigns, economy of scale, and consistency of their product. Between the 1980s and the present day, the top three companies, Anheuser-Busch, MillerCoors, and Pabst, remained on top by acquisition of the competition in the marketplace.

Table 1.5 Top 10 breweries in 1980

Brewery	Brand names include	Rank in 1980	Fate
Anheuser-Busch Inc.	Budweiser, Busch	1	
Miller Brewing Company	Miller	2	Merged with Molson Coors in 2007
Pabst Brewing Company	Pabst Blue Ribbon	3	
Joseph Schlitz Brewing Co.	Schlitz	4	Bought by Heileman in 1981 then Stroh in 1982
Adolph Coors Company	Coors, Coors Light	5	Became Coors in 1989; merged with Molson in 2005; merged with Miller in 2007
G. Heileman Brewing Co.	Heileman's Old Style	6	Acquired by Stroh's in 1996
Stroh Brewery Company	Stroh's	7	Acquired Schlitz in 1982; acquired Heileman in 1996; acquired by Miller in 2000
Olympia Brewing Co.	Olympia, Hamms	8	Acquired by Pabst in 1983
Falstaff Brewing Company	Falstaff	9	Acquired by Pabst in 1990; discontinued label in 2005
C. Schmidt & Sons	Schmidt's	10	Acquired by Heileman in 1987

President Jimmy Carter, in 1979, was instrumental in the development of the current beer market. (His brother, Billy Carter, is well-known for the Falls City Brewing Company's Billy Beer brand.) The president helped enact a federal law that allowed beer production in the home. Homebrewing, or the production of beer in the home for personal use, was still illegal (both formally and informally) in some states until 2014. Currently, the majority of the states allow the annual production of 100 gallons of beer per adult in a household, up to a maximum of 200 gallons, for personal use. The specific rules that homebrewers must follow are highly dependent upon the state in which they reside. These specifics may include obtaining a permit, not transporting the beer outside of the home, making less than the federally approved 100 gallons, or adhering to other restrictions. Federal law and most state laws require that production beyond the 100 gallon limit involves filing documentation and taxes as a beer producer. And for those that do not follow the rules, there are severe penalties including fines and jail time.

But the freedom to produce beer in the home again meant Americans could make whatever style they wanted to try. The average person's tastes for styles other than the American Lager grew and continue to do so as more and more people explore the different styles of beer. This exploration of styles opened the brewing industry for the craft-brewing and brewpub industries. By 1988, there were over 200 breweries in the USA (Fig. 1.7). As the American consumer began to appreciate different beer styles, the number of breweries grew even faster. That number continues to grow today, with over 2000 breweries producing nearly every beer

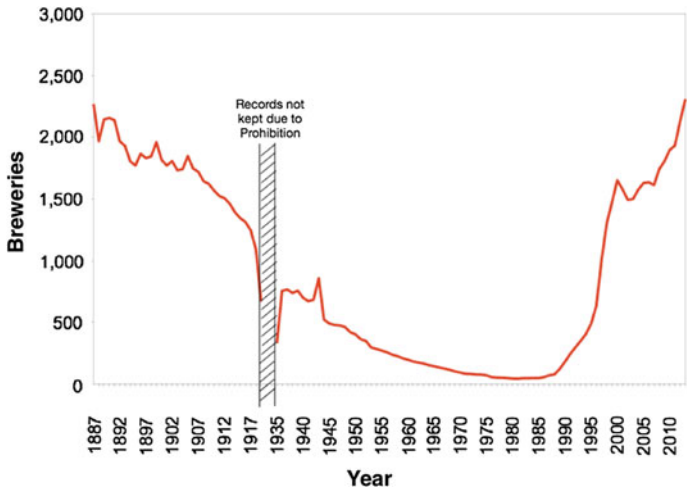

Fig. 1.7 Breweries in the USA by year. Data are from the Beer Institute (https://www.beerinstitute.org)

style possible—and pushing the envelope on many of those styles. Note in Table 1.6 that the top 10 breweries in 2011 include three craft-brewers. Also note that many of the major breweries that specialize in the American Lager have expanded their style offerings as well. In some cases, this has occurred by the purchase of smaller craft-breweries and, in other cases, by the development of styles on their own.

Table 1.6 Top 10 Breweries in 2011

Brewery	State	Brand names include	Rank in 2011
Anheuser-Busch Inc.	MO	Budweiser, Bass, Beck's, Busch, Goose Island, Landshark, Michelob, Rolling Rock, Shock Top and Wild Blue	1
MillerCoors	IL	Coors, A.C. Golden, Batch 19, Blue Moon, Colorado Native, Herman Joseph, Keystone, Killian's and Leinenkugel's	2
Pabst Brewing Co.	IL	Pabst Blue Ribbon, and Schlitz	3
D. G. Yuengling and Son Inc.	PA	Yuengling	4
Boston Beer Co.	MA	Sam Adams	5
North American Breweries	NY	Dundee, Genesee, Labatt, Magic Hat and Pyramid	6
Sierra Nevada Brewing Co.	CA	Sierra Nevada	7
New Belgium Brewing Co.	CO	New Belgium	8
Craft Brew Alliance, Inc.	OR	Kona, Red Hook, Widmer Brothers, Omission	9
The Gambrinus Company	TX	BridgePort, Shiner and Trumer	10

Mergers and acquisitions continue to emphasize the changing face of the brewing market. The merger of SABMiller and AB InBev in 2015 further mixes up the field of the top 10 beer producers in the world. So, what does the ever-changing face of the brewing industry mean for the consumer? In the end, not much. Most, if not all, of the brands that consumers are used to buying will still be on the shelves. The cost of those brands, the quality of the product, and everything else one can think about as a consumer likely will not change either. The biggest change will be in how this large merger may require divestiture of brands in the USA and China due to anticompetition rules. This may mean that some smaller companies may return to the top 10 lists as individual producers. Only time will tell.

Nonetheless, beer production in today's market contributes significantly to the economy. Table 1.7 illustrates the initial growth in beer production after the Civil War and the impact of Prohibition on the industry. Per capita consumption (how many gallons of beer are consumed per person in the USA) of commercial beer rose dramatically after the economic downturn of the late 1970s, but has leveled off in recent years. In fact, consumption has slightly declined each year since the high of 25.9 gallons per person in 1983. Despite the reduction in per capita consumption, alcoholic beverages amount to about 12 % of a US family's annual food and beverage budget. Even that number is down from the average over the period since the end of World War II. One reason for this decline is likely due to the consumption of homebrewed beer.

Tax revenue from beer consumption is a major factor in state and federal budgets. In fact, the Federal government's first tax on beer production has been in place since it was instituted. The tax in 1862, initially set at $1.00 per barrel of beer to help the USA pay for its debts during the Civil War, has increased over the years to the current maximum of $18.00 per barrel (for large producers and for more than 60,000 barrels for small producers; small producers only pay $7.00 per barrel for the first 60,000 barrels). According to the Beer Institute 2015 report (https://www.beerinstitute.org), the 2014 US federal tax on beer production generated over $5.4 billion and over $5.2 billion in state taxes. When taken into consideration with the more than $37 billion in business and personal taxes for beer production, this represents a very large influx of money destined for the operation of federal and state governments. Recent legislation in the US congress has been proposed to modify this tax to encourage small brewery growth.

Table 1.7 Beer production in the US

Year	Production over previous 10-year period (in million gallons)	Per capita consumption (in gallons)	Federal tax on beer, imports, and domestic (in millions of US dollars)
1880	118	3.8	–
1910	1844	20.0	–
1930	114	0.9	–
1960	2931	16.3	800.9
1980	5840	25.8	1547.6
2010	6049	19.6	3651.0

Currently, beer production injects more than $250 billion (2014 data) into the US economy. It results in numerous jobs directly involved in the brewing process, but also indirectly impacts many other industries. Advertising companies benefit from logo design, TV ads, and other marketing products. Secondary sellers of T-shirts, glasses, coasters, and other paraphernalia benefit. Farmers supply barley, wheat, hops, and other ingredients for manufacturing beer. Trucks, trains, and other shipping move the raw materials and finished products. The cattle industry benefits from the purchase and use of spent grains after mashing. And let us not forget the immediate sale of the end product in bars, restaurants, and other retailers. Each of these industries benefits from brewing.

CHECKPOINT 1.9
What events occurred that resulted in the ability of US citizens to homebrew? What are the reasons for the large increase in the number of breweries in the US post 1980?

Chapter Summary

Section 1.1

The scientific method is used to evaluate a problem and arrive at a solution that can result in a law or a theory.

Section 1.2

Beer as a beverage is first recorded in Mesopotamia and Egypt about 4000 BCE, although it is probably used much earlier.
The Hymn to Ninkasi outlines the first known recipe used to make beer.

Section 1.3

The volume of a liquid is the space that the liquid occupies. Conversions from one volume to another involve unit-conversion mathematics.
The boiling point of water decreases as the atmospheric pressure increases.
The mass of a substance is a measure of the quantity of that substance. The weight of a substance is a measure of the force of gravity on the substance. While not interchangeable, the two words (mass and weight) are often used interchangeably.

Section 1.4

Blood alcohol content increases dramatically as alcohol is consumed, but decreases very slowly only with time.

Penalties for operating motor vehicles, or being in public, when one is intoxicated, can be very severe.

Section 1.5

Beer spreads quickly through Europe via the Romans and other peoples.
The Reinheitsgebot and other laws were created to govern the production of beer.

Section 1.6

Breweries and brewing were introduced to the USA as peoples from Europe migrated to the New World (although beer already existed in the New World).
Commercial breweries became numerous and spread across the USA between the Civil War and World War I.
Temperance societies led the push to enact national prohibition. This severely impacted the brewing industry.
The American Lager style became the major style of beer produced in the USA after Prohibition.

Section 1.7

Relaxing the laws for beer production in the 1970s resulted in people trying new beer styles. This encouraged the growth of the craft brewery in the USA.
Currently, beer is a multi-billion dollar industry supporting hundreds of other industries.

Questions to Consider

1. A brewer tests a hypothesis and comes to the conclusion that "cooling wort quickly reduces the off-flavors in the finished beer." Is this a law or a theory? Explain.
2. Another brewer comes to the conclusion after much experimentation that "calcium in the strike water binds to tannins and reduces the tealike flavors in beer." Is this a law or a theory? Explain.
3. How many quarts are in a barrel (US)? …in a puncheon? …in a liter?
4. A cooking pot holds 14 quarts; how many gallons of beer will fit in the pot?
5. How many tuns are in the cooking pot described in question #4?
6. How many firkins are there in the volume described by the pot in question #4?
7. What is the temperature of water in °C if the water is found to be 32 °F?
8. Determine the boiling point of water in the city in which you live. You may need to use Table 1.2 to estimate the value.
9. How many scruples does a 1.0 oz sample of hops weigh?
10. If a recipe calls for 0.25 stone of malt, how many pounds is this? …what is that mass in ounces? …in kilograms?

11. A brewer in Denver, Colorado, wishes to heat their water to 150 °F. What is that temperature in °C? Does the altitude have an effect on this process?
12. If a mash tun contains 250 lb of mash and the materials are 7.5 in. deep, how deep would the bed be if the mash tun contained 400 lb of material?
13. If a person drinks one 12 oz beer and their BAC increases to 0.05, what would be their BAC if they consumed a 22 oz beer in the same amount of time?
14. Does the per cent of alcohol in a beer have an effect on the BAC for the consumer of that beer? What is the "standard" alcohol found in a beer? What BAC would you expect for a 140 lb person that drinks a 12-oz glass of beer containing 8 % alcohol?
15. Describe the impact on the Pilgrims if the Speedwell had been able to make the voyage across the Atlantic Ocean.
16. A cooking vessel is 12 in. in circumference. How many inches deep will 1 gallon of wort be in that vessel? (Use the Internet to determine the volume of a cylinder.)
17. Why did the US consumer of the 1950s prefer the American Lager style?
18. What is the oldest continuously operating brewery in the USA? What style of beer are they known to produce?
19. If the 102 passengers and 30 crew aboard the Mayflower consumed 1 gallon of beer per day, how many barrels (USA) of beer did the crew have to bring to survive a 66-day voyage?
20. Use the Internet to find the text of the Hymn to Ninkasi and then construct a recipe using modern ingredients and methods to make the beer.
21. Use the Internet to find the text of the Reinheitsgebot. What were the penalties for violation of the law? How would being punished that way be a severe penalty?
22. Visit the Web site for the state where you live. What are the penalties for driving with a BAC greater than 0.08?
23. In your own words, describe why colonists to the New World were so concerned about setting up a brewery quickly. Be sure to factor into your description whether the colony was interested in trading with Europe or not.
24. It was stated in the chapter that the native peoples of the New World were making many different styles of beer prior to the arrival of the Europeans. For example, use the Internet to look up "chicha" and discover how it is made. Based on that information, speculate how these peoples developed similar styles of beer.
25. Visit the Web site for a brewery that is closest to your home. What styles of beer do they produce? What volume of beer do they make each year?
26. What is the reason for the decline in the number of breweries from the 1880s to the start of Prohibition and from 1945 to 1980?
27. Two brewers decide to make a batch of beer while they are on trips in different parts of the world. One, in Denver, Colorado, heats some water to 100 °F. The other, in Cuzco, Peru, repeats the exact process. Which brewer will notice more steam coming from their water?

Laboratory Exercises

Familiarization with laboratory measurements

This "experiment" is designed to familiarize you with the standard types of laboratory equipment used in the analysis of beer and its components. This is very useful if you are not familiar with the SI system of units and serves as very good review if you are.

Equipment Needed

Laboratory scale to 2 decimal places
100-mL graduated cylinder
Pint-sized Mason jar
Thermometer
Approx. 200 g of malt, corn, or other grains

Experiment

Obtain a graduated cylinder, beaker, and thermometer. Also obtain a ziplock bag of malt from your instructor.
Mass—First, estimate the mass of a single grain of malt. Use the balance to weigh 10 kernels of malt and record the mass in grams to two decimal places. From this mass, determine the average mass of a single kernel of malt. Then, obtain the mass, in grams, of the entire bag of malt (be sure to not include the mass of the bag). Estimate the number of kernels of malt in the bag and then calculate the number of kernels using the average mass of a single kernel and the mass of the entire bag.
Volume—Fill the beaker approx. ¼ full with water. Estimate the volume of the water in milliliters. Then, tare the graduated cylinder and pour the water from the Mason jar into the graduated cylinder to determine the volume of the water.
Density—Note the mass of the graduated cylinder containing the water. Subtract the mass of the empty graduated cylinder to determine the mass of the water. Then, divide the mass of the water by the volume of the water to determine the density of water in grams/mL. Repeat the measurement of density for the malt by filling the graduated cylinder with 20 mL of water and adding a known mass of malt to the graduated cylinder. Swirl until all of the malt is below the surface of the water and determine the new volume of the material in the cylinder. Use the mass of the malt and the difference in the volume in the cylinder to determine the density of the malt. Does your value agree with your prediction for the density of the malt?
Temperature—Fill the Mason jar approximately ¼ full with crushed ice and a very small amount of water until you have a slushy-like mixture. Place the thermometer in the ice and record the temperature. Does this agree with your estimate of what the temperature should be?

Exploring the Internet

This "experiment" involves using the Internet to further explore some of the history of beer and brewing.

Experiment

Choose one of the topics from the list below and write a one-page summary of the information you find about this topic using the Internet, the library, or any other source available to you. Present your findings to the rest of the class.

Topics (others may be presented by your instructor):

Pulque	Kvass
Chicha	Carrie Nation
Taverns in the colonies	Temperance fountains
Taxes on Beer in the 1800s	States that ratified the 18th Amendment
US counties that remain "dry"	The problems with Prohibition
Anton Dreher	George Washington's Beer Recipe
Small Beer	Alcohol Belt in Europe
Breweries in the New World before 1700	
How archaeologists know that a vessel contained beer	
Tavern signage	When lagering was "invented"
Beer bottles before 1940	The glass tax in the 1700s
The avoirdupois system	The apothecary system
Why temperance failed to be a national US movement in the 1800s	
Adolph Coors	Women's Christian Temperance Union
Louis Pasteur	The invention of the crown cap
Billy Beer	Breweries in Philadelphia in 1885