The science of alcohol

About this free course

This free course provides a sample of level 1 study in Science

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This free badged course, *The science of alcohol*, lasts 24 hours, with 8 weeks. You can work through the course at your own pace, so if you have more time one week there is no problem with pushing on to complete a further week. The eight weeks are linked to ensure a logical flow through the course. They are:

1. What is alcohol?
2. An introduction to brewing
3. Taste and smell
4. Brewing on an industrial scale
5. The short-term effects of alcohol
6. Distillation and spirits
7. The long-term effects of alcohol consumption
8. Product protection and maintaining product provenance.

This course will develop your confidence and skills for online study, whether this is to explore natural science topics or part of your preparation for other study.

You'll start by thinking about how alcoholic beverages are produced, how different products are manufactured and analysed. The effects on the body will be explored, both in terms of consuming alcohol and how they smell and taste. The history of alcohol manufacture will be explored and you will have the chance to make your own drinks, through an optional home-brew experiment. All these aspects will be explained, so don't worry if they seem unfamiliar at the moment. There are vivid videos examples to help with this and you'll get plenty of opportunities to demonstrate your new understanding and practise your study skills.

Part of this practice will be the weekly interactive quizzes, of which Weeks 4 and 8 will provide you with an opportunity to earn a badge to demonstrate your new skills. You can read more on how to study the course and about badges in the next sections.

After completing this course, you will be able to:

- describe the process of fermentation and how it is used to create different varieties of alcoholic beverage
- compare brewing on the microscale and commercial scale, and describe how a spirit such as gin is produced on a large scale
- describe how alcohol affects the human body, both in terms of long and short term effects
- describe how chemicals within a drink give it its taste and aroma, and how the body recognises it

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- discuss how modern-day scientists use cutting edge technology to protect against counterfeiting and contamination.

Moving around the course

In the ‘Summary’ at the end of each week, you will find a link to the next week. If at any time you want to return to the start of the course, click on ‘Full course description’. From here you can navigate to any part of the course.

It’s also good practice, if you access a link from within a course page (including links to the quizzes), to open it in a new window or tab. That way you can easily return to where you’ve come from without having to use the back button on your browser.

The Open University would really appreciate a few minutes of your time to tell us about yourself and your expectations for the course before you begin, in our optional start-of-course survey. Participation will be completely confidential and we will not pass on your details to others.

What is a badged course?

While studying *The science of alcohol* you have the option to work towards gaining a digital badge.

Badged courses are a key part of The Open University’s mission *to promote the educational wellbeing of the community*. The courses also provide another way of helping you to progress from informal to formal learning.

Completing a course will require about 24 hours of study time. However, you can study the course at any time and at a pace to suit you.

Badged courses are available on The Open University’s OpenLearn website and do not cost anything to study. They differ from Open University courses because you do not receive support from a tutor, but you do get useful feedback from the interactive quizzes.

What is a badge?

Digital badges are a new way of demonstrating online that you have gained a skill. Colleges and universities are working with employers and other organisations to develop open badges that help learners gain recognition for their skills, and support employers to identify the right candidate for a job.

Badges demonstrate your work and achievement on the course. You can share your achievement with friends, family and employers, and on social media. Badges are a great motivation, helping you to reach the end of the course. Gaining a badge often boosts confidence in the skills and abilities that underpin successful study. So, completing this course could encourage you to think about taking other courses.

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How to get a badge

Getting a badge is straightforward! Here's what you have to do:

- read each week of the course
- score 50% or more in the two badge quizzes in Week 4 and Week 8.

For all the quizzes, you can have three attempts at most of the questions (for true or false type questions you usually only get one attempt). If you get the answer right first time you will get more marks than for a correct answer the second or third time. Therefore, please be aware that for the two badge quizzes it is possible to get all the questions right but not score 50% and be eligible for the badge on that attempt. If one of your answers is incorrect you will often receive helpful feedback and suggestions about how to work out the correct answer.

For the badge quizzes, if you're not successful in getting 50% the first time, after 24 hours you can attempt the whole quiz, and come back as many times as you like.

We hope that as many people as possible will gain an Open University badge – so you should see getting a badge as an opportunity to reflect on what you have learned rather than as a test.

If you need more guidance on getting a badge and what you can do with it, take a look at the OpenLearn FAQs. When you gain your badge you will receive an email to notify you and you will be able to view and manage all your badges in My OpenLearn within 24 hours of completing the criteria to gain a badge.

Course contributors

Alongside Dr Louise MacBrayne, a chemist from The Open University, two other academics will feature throughout this course. Dr Daniel Allwood from Sheffield Hallam University is an organic chemist and keen homebrewer. Daniel will lead on presenting the key chemistry throughout this course. Dr Paul Kosmetatos is a Lecturer in Economic history at the University of Edinburgh. He has an interest in the history of alcohol production and how it has shaped our history. Paul will present context for the science in this course, highlighting how the industry of alcohol affected us all.

This course is produced with the kind support of:

Hook Norton Brewery: a world-renowned brewery situated in Oxfordshire that has been run by the same family since 1849.

Cotsworld Distillery: a craft distillery situated in the North Cotswolds producing English whisky, small batch gin and other liquers.

CAMRA: founded in 1971 and with over 188,000 members, the Campaign for Real Ale (CAMRA) is a non-proft consumer body who tirelessly promote traditional beers and ales.

Videos filmed at the brewery and distillery also feature prominently through the course.

The course was also developed with the help of Dr Nick Turner, Senior Lecturer in Bioanalytical Chemistry in The School of Pharmacy at De Montfort University. He is also a visiting Fellow at The Open University.

Get started with Week 1.

Week 1: What is alcohol?

Introduction

Welcome to this free course, *The science of alcohol*. Have you ever wondered why there are so many varieties of gin? Or how beer is produced? Do you want to know what a hangover really is? This course will answer these and other questions regarding the science which is responsible for the creation of alcoholic drinks and the effects alcohol has on the human body.

Before you start, watch the following short video in which Louise MacBrayne, the course author, gives a flavour of what is covered in the course.

Video content is not available in this format.

In this first week you will read about topics that will set the scene for this course.

You will first be introduced to the simple chemistry of the ethanol molecule and its physical properties. Next you will learn about yeast, the fungal microorganism that is used to convert carbohydrates, such as sugars and starches, into carbon dioxide and ethanol through the fermentation reaction. You will look at a homebrew kit and you can take part in an optional home experiment that will run alongside this course. Furthermore, you will learn about the distant history of alcohol production and how it has shaped our culture.

No prior knowledge of chemistry or science in general is assumed in this course and you will be guided through the basic scientific principles which underlie the topic materials. If you feel inspired to explore science further following this course, you might enjoy another free course on OpenLearn, *Discovering chemistry*.

By the end of this week, you will be able to:

- describe the ethanol molecule and distinguish it from other alcohols
- explain why ethanol is easily absorbed into the body
- describe some of the basic chemical reactions that ethanol can undergo
- discuss the fermentation reaction and the conditions that affect it
- depict how early human civilisations used alcohol and its effect on their culture.

So, to start, what exactly is alcohol?

The Open University would really appreciate a few minutes of your time to tell us about yourself and your expectations for the course before you begin, in our optional start-of-course survey. Participation will be completely confidential and we will not pass on your details to others.

1 Introducing the science of alcohol

The brewing and distillation industries bring together the sciences of biology, chemistry and engineering in a unique way that has developed over thousands of years. We are now surrounded by a choice of many different types of beer and spirits to consume. But why, for instance, are there so many different varieties of gin? What happens to your body when you drink alcohol, and just why are hangovers so bad?

Nick Boley, a National Director of CAMRA (the Campaign for Real Ale), will now introduce the concept of the science of alcohol and the themes of this course further.

Video content is not available in this format.

1.1 What is alcohol?

To start with it is important for you to know exactly what alcohol is. This will make it easier as you read through the course and will facilitate a clearer understanding of the science, as the term ‘alcohol’ has both a generic and a specific meaning.

- What do you understand by the term ‘alcohol’?
- You may have considered any of the following images as defining, or being associated with, alcohol (Figure 1).

Figure 1 Images which you may commonly associate with the word ‘alcohol’

In general the word alcohol is associated with an alcoholic drink, but we need to be more specific than this. In scientific terms an alcohol is a compound (a group of atoms that make a molecule) that contains ahydroxyl group (–OH) bound to a carbon atom (C). Figure 2 has some examples of these alcohols to show you some of the structures of these chemicals.

When describing a chemical structure, the terms ‘bond’, ‘bound’ and ‘binding’ are used to discuss how atoms and molecules interact with each other. You don’t need to know the details at the moment; just be aware of the terminology.

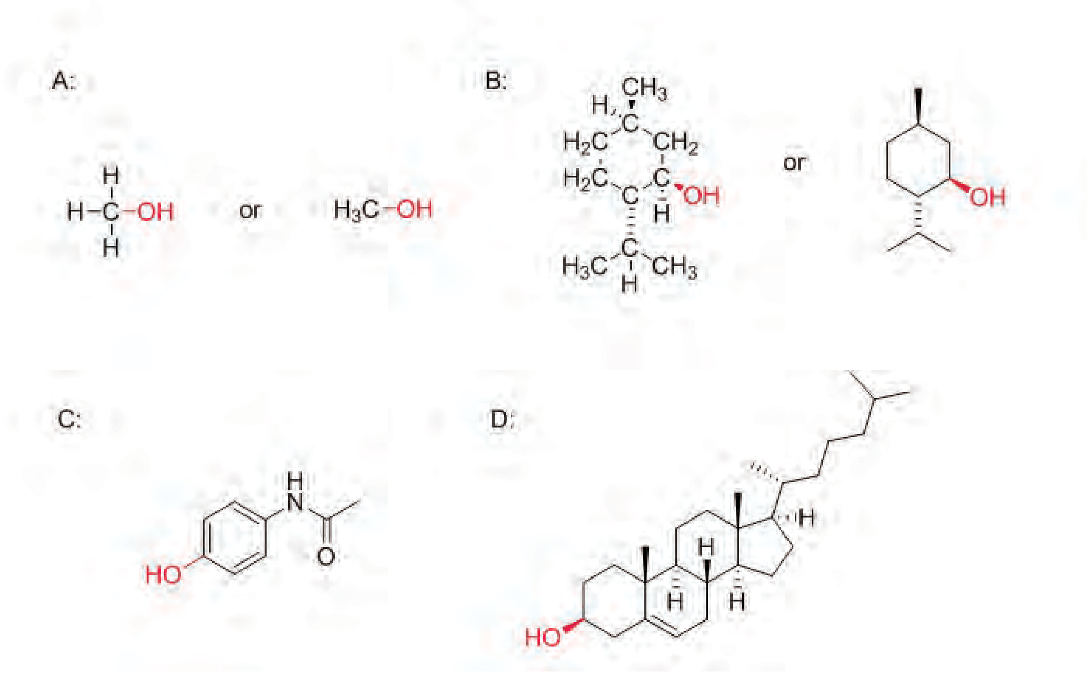


Figure 2 Several 'alcohol' compounds with the hydroxyl group shown in red. Note that the OH group in red can be written as either OH (as in compounds A and B) or HO (as in compounds C and D). The hydroxyl group is always joined via the oxygen atom (O) to the rest of the molecule so will be written as OH or HO depending on its position in the molecule.

Figure 2 depicts the following alcohol compounds:

A: Methanol. This is the simplest alcohol containing a single carbon atom, three hydrogen atoms and the hydroxyl group (an oxygen and a hydrogen atom). On the left the full structure is shown. The carbon atom and the three hydrogens together form a 'methyl' group which can otherwise be written as CH_3 or H_3C so that the group is joined to the rest of the compound via the C atom.

B: Menthol. This natural compound is found in mints. This compound interacts with the human body as a mild anaesthetic and has a cooling sensation. It has a number of different atoms bound together. The left-hand figure shows the full structure but it is easier for chemists to simplify it as shown on the right, where the 6-sided ring structure is a much simpler way to represent the arrangement of carbon and hydrogen atoms.

C: Paracetamol. This common drug is used to treat pain and fever. It is classed as one of the world's essential medicines but, like many drugs, it is dangerous in large amounts. Note that N denotes an atom of nitrogen.

D: Cholesterol. This is a natural compound found in animal cells and is an essential molecule for life, forming the basis for some hormones and other important chemicals. High levels of cholesterol in the blood can lead to cardiovascular disease.

So all the compounds shown in Figure 2 are technically alcohols.

- What do the names of these four compounds have in common?
- They all end in –ol. In fact, if the name of any compound ends with –ol then it will have a hydroxyl (–OH) group in it and be an alcohol.

The ‘alcohol’ that is referred to in drinks is one of this family of similar chemicals containing an –OH group, and the particular one that is present in alcoholic drinks has the chemical name ethanol.

2 What is ethanol?

The proper chemical name for the alcohol in alcoholic drinks is ethanol. The chemical formula of ethanol is usually written as C_2H_5OH. There's an important point to note here about how this formula is written.

- Can you see a possible problem if the formula were to be written as 2C5HOH?
- Use of the number 2 at the start of the formula implies that there are 2 atoms of every element which follows in this formula, which is not the case. This confusion is further increased by the use of the number 5 in front of the first H. This could imply that there are 5 O atoms as well in this formula.

The correct nomenclature for writing a chemical formula is to use numerical subscripts immediately following the atom, to show the correct number of atoms of that element in the formula.

So the formula C_2H_5OH makes it very clear that there are 2 carbon atoms, 5 hydrogen atoms, 1 oxygen atom (if there is no numerical subscript you can assume the value is 1) and 1 further H atom. In fact you can simplify this formula further by collecting numbers of like atoms (in this case the hydrogens) as you will see shortly.

The structural formula of ethanol is illustrated in Figure 3 and shows the order in which the atoms are joined together.

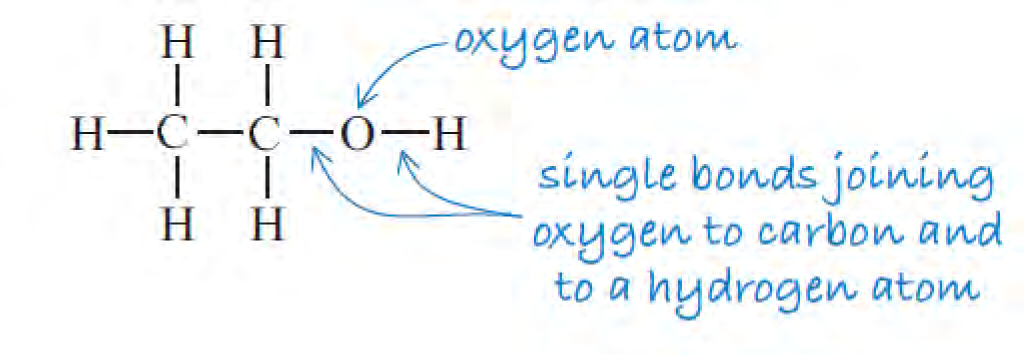


Figure 3 The structural formula of ethanol

- How many atoms of each type are there in ethanol?
- There are two carbon atoms, six hydrogen atoms and one oxygen atom.

- How many atoms in total does this molecule contain?
- There are nine atoms in total.

- Does the formula C_2H_5OH tell you the order in which the atoms are bonded?
- The formula C_2H_5OH does *not* tell you the order in which the atoms are bonded. For that you need the *structural formula* (Figure 3) which shows how the atoms are arranged in the compound.

The structural formula is important because the way in which atoms bond together determines the size and shape of a molecule and how it interacts with the body. The size and shape of a molecule will determine, for example, whether or not it can dissolve in water and whether it is small enough to move across a cell membrane. This in turn affects the way the molecule interacts with the body.

2.1 Physical properties of ethanol

The size, the shape and the physical properties of ethanol dictate where and how it can move in the body. For instance, ethanol moves quickly through the walls of the stomach and small intestine into the bloodstream; a process you will explore later on in this course.

The two most important physical properties of ethanol are:

1. **Ethanol can be completely dissolved in water.** Unlike many chemical molecules, when added to water ethanol forms a homogeneous *solution* (one that is completely mixed) enabling it to be readily carried around in the bloodstream. Because of the solubility of ethanol in water, when a person drinks an alcoholic drink, the ethanol also dissolves easily in the watery blood and body fluids, and so gets transported all around the body, affecting each organ as it goes.
2. **Ethanol boils at a lower temperature than water.** You will see the importance of this in Week 6.

Now you know the physical properties of ethanol, you will now look in more detail at how it reacts.

2.2 Chemical reactions of ethanol

When something happens to a chemical compound and a change of some sort takes place, there has been a *chemical reaction*. Ethanol undergoes a number of important chemical reactions – you will come across several of them as you work through this course. But this week you'll start by looking at two chemical reactions in particular:

- the combustion of ethanol
- how it reacts to form acetic acid, the main component in vinegar.

But first, you need to see how chemists express a chemical reaction in the form of a *chemical equation.*

In writing a chemical equation you need to state what you start with and what you end up with. Let's look at a simple example using two elements: hydrogen gas, H_2, and oxygen gas, O_2, which react with each other (explosively) to form water, H_2O, and nothing else.

The simplest way of writing this down chemically is to note the formulae of the elements that react with each other – the reactants – and use an arrow to indicate what has been formed in the reaction – the product, as shown in Figure 4.

$$\overbrace{H_2 + O_2}^{\text{reactants}} \longrightarrow \overbrace{H_2O}^{\text{product}}$$

Figure 4 The formation of water

Notice the convention of reactants on the left and products on the right. This equation is useful in that it tells you, in a shorthand form, which types of molecule you start with and finish with, and you can see that the reactant molecules interact in some way. However, if you look closely at the equation, you'll see that there is a problem in that the number of atoms in the reactants is not equal to the number of atoms in the product, and atoms cannot be destroyed (or created) in a chemical reaction.

Chemists would say that this equation is 'not balanced'. It is important to be able to produce a balanced equation for a chemical reaction, because it is only from this that the quantities of the substances involved can be calculated, and hence the energy absorbed or released by a reaction can be determined. Our ultimate goal is to calculate the energy involved in the combustion of ethanol. So we need to find a way to balance the equation. Let's start with the first element, hydrogen. Looking at Figure 4, you can see that the hydrogen atoms balance – there are two on either side of the arrow. Moving to oxygen, there are two oxygen atoms on the left, but at present only one on the right.

As an atom of oxygen cannot be lost, and only water has been produced, two molecules of water must have been made. To indicate this, a prefix '2' is placed in front of the formula for the water molecule (Figure 5).

$$H_2 + O_2 \longrightarrow \overset{\text{prefix}}{2}H_2O$$

Figure 5 Balancing the equation for the formation of water

Unfortunately, this immediately unbalances the equation again as now there are two hydrogen atoms on the left, and four (2 × 2) on the right, and this is where you must hold your nerve – you simply go through the process again! This time, using two reactant molecules of hydrogen corrects the problem (Figure 6):

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Figure 6 A balanced equation for the formation of water

And now the equation 'balances'.

Notice again the different uses of numbers in the equation. The subscript 2 in the formula indicates that two hydrogen atoms are contained in the water molecule. The prefix 2 in front of the water formula indicates that there are two H_2O molecules.

2.2.1 Burning of ethanol

When you burn – or combust – ethanol (C_2H_5OH) in air (which contains oxygen, O_2), the final products obtained are carbon dioxide gas (CO_2) and water (H_2O). Looking at this reaction is important as it produces the same products as does the metabolism of ethanol in the liver, which you will look at in Week 5 of this course.

Now try to produce a balanced equation for the combustion of ethanol:

- Start by writing out the reactants and the products.
- The reactants and products are:

- Now compare the number of carbon atoms in the reactants and products, and start to balance the equation.
- The two carbons of ethanol must make two molecules of carbon dioxide:

- Now balance the hydrogens in the equation.
- The six hydrogens of ethanol must produce three molecules of water (as every molecule of water contains two hydrogens):

- Finally, consider the oxygens. What do you have to do to balance them in the equation?
- There are now seven oxygens on the right-hand side and so three molecules of oxygen are needed on the left – you now have a fully balanced equation:

Notice that if you chose to start with oxygen then the oxygens already balance; but it is important that you still go on to balance each of the other elements until all are balanced. There are no fixed rules for which atom to balance first, and sometimes a trial and error approach is needed. It is important to remember that, since atoms cannot be created or destroyed, an equation, if it shows a feasible process, can always be made to balance. An arrow or an equals (=) sign can be used to denote a completely balanced reaction. You will see either used, although the most common convention is to use an equals sign when the equation is completely balanced, and arrows in the previous steps of 'working out'.In the following video, Louise MacBrayne demonstrates the combustion of ethanol. Despite burning 'slow' a great deal of heat is generated or, put another way, the reaction releases a lot of energy. In fact there is so much energy released that an ethanol rocket can be manufactured using an empty plastic soda bottle as illustrated in this video.

Video content is not available in this format.

Burning ethanol in air happens in one fast high-temperature reaction as seen here. In contrast the liver does the same overall process in three low-temperature stages. This will be explored in Week 5, discussing how much energy is generated and comparing the result with other foods and fuels.

2.2.2 Vinegar from wine

If you have ever had the misfortune of ordering a bottle of wine that is 'corked', the beverage will taste of vinegar – a clear sign that it is off and not worth drinking.

The reaction here is again between ethanol in solution and oxygen gas, but this time the outcome is different:

(Eqn 1)

Activity 1 The chemical formula for vinegar

Allow approximately 5 minutes for this activity

What is the correct chemical formula for vinegar (also known as acetic acid)?

- CH_3COOH
- CH_2COOH
- CH_4COOH
- C_2H_5COOH

Discussion

If the beverage tastes of vinegar, then the vinegar must be a product of the reaction shown above. You learned in the previous section that H_2O is the formula for water. Therefore the formula to represent vinegar must be CH_3COOH. This is in fact a substance known as acetic acid. Note that you can simplify this formula to CH_3CO_2H, both versions of this formula are correct.

This reaction is not one that occurs spontaneously. It requires the presence of a bacterium called *Acetobacter* which uses this reaction to gain energy for its own biological processes. *Acetobacter* must be prevented from growing in wines and turning them to vinegar, and so wine must be bottled in very clean conditions, air must be excluded by good corking, and a preservative, sulfur dioxide, is usually added. When a bottle is 'corked', the seal has been broken, allowing bacteria and air in.

However, note that the same process is encouraged in some circumstances to produce 'wine' or 'cider' vinegar. This is a good example of how the 'ill-effects' of nature can also be used to some benefit.

A further chemical reaction takes place when ethanol is fermented – a reaction which allows us to produce an alcoholic drink.

2.3 Ethanol fermentation

Fermentation is a metabolic process (one that is required to sustain life) in which living cells break down larger molecules into smaller ones. In fermentation, the living yeast uses sugars, rather than oxygen, to break down the complex energy-rich molecules into simpler ones, releasing energy in the process. You will see this illustrated in the brewing process in Week 2 via the addition of barley grains. This energy is harvested by the cells, to generate a molecule called adenosine triphosphate or ATP, which is the principal energy transfer molecule used in many biochemical processes that occur in living organisms. A series of enzymes within the yeast catalyse the sugar breakdown (thereby increasing the rate of the reactions which breakdown the sugar) . This occurs over several steps starting with sucrose, common table sugar, which has a formula of $C_{12}H_{22}O_{11}$. In the presence of a specific enzyme and water, sucrose splits, forming two molecules of glucose ($C_6H_{12}O_6$).

From this point a series of enzyme-catalysed reactions occur, turning glucose into ethanol and carbon dioxide. You will learn more about enzymes and the role they play in this process in Week 5. The overall reaction – that is, the equation for fermentation – is shown in Equation 2.

(Eqn 2)

Humans have hijacked this process to great effect, notably in brewing and baking. In brewing, as you will learn in Week 2, the ethanol is the desired product. On the other hand, the generation of carbon dioxide is essential for the baker, as this gas allows their bread (or other product) to rise (or leaven). While the rising process also results in the production of ethanol, this evaporates due to the high temperatures used in the baking process.

- What conditions may affect the fermentation reaction?
- Fermentation is a biological reaction so temperature will affect the reaction as enzymes tend to have an 'active window' between certain temperatures, with a particular temperature being optimal for effective activity. Outside this window the enzymes do not work efficiently and the reactions will not happen.

  The **presence of air (oxygen)** will have an effect on this reaction. The fermentation reaction occurs in *anaerobic* conditions (without air). The presence of oxygen can affect the rate of reaction. Different yeasts are affected in different ways – some work fine in aerobic conditions, as you will see later in this course.

  The **types of grain** used will mean different starches and therefore sugars present. As these molecules are the basis of the reaction their chemical make-up will have a significant effect on reaction performance. Starch is a complex polysaccharide, i.e. it consists of numerous smaller sugar units joined together that need to be broken down by enzymes before the yeast is able to use them as raw materials for fermentation.

All ethanol contained in alcoholic beverages is produced in this manner, i.e. fermentation carried out by yeast. Different yeasts are key to brewing, with many strains used. You will learn more about these in Week 2 of the course.

3 The long history of alcohol

Humans have drunk alcohol for at least twelve thousand years and it has been used in religious rituals in ancient cultures as diverse as Samaria, Babylon, the Chinese Imperial court and Anglo-Saxon Britain. The ancient Romans had a god of wine, Bacchus; so did the ancient Greeks, Dionysus (Figure 7).

Figure 7 The Roman god of wine Bacchus on the left, and the Greek god of wine Dionysus on the right

Christian Communion services and certain Jewish religious rituals include wine to the present day. Alcohol has more than ritual significance: wine was routinely drunk in Mediterranean countries and, further north, beer was part of the staple diet until the early twentieth century. It was probably a safer drink than the often-contaminated water of earlier times – food for the body as well as a blessing from the gods. When people raise a glass of alcohol to toast each other, they often reflect this benevolent view: the English say, ‘Good health!’ or ‘Cheers!’, the French say *À votre santé!* (‘to your health’), and in Germany they say *Prost!* (‘may it do you good’).

In this video Paul Kosmetatos introduces how alcohol affected the ancient world.

Video content is not available in this format.

Yet attitudes to alcohol vary greatly around the world. In the richer nations, it is an accepted way to unwind from the pressures of life, a common accompaniment to meals and many social occasions. Home-brewed beer and distilled spirits are drunk throughout Africa and South America.

In a few ancient cultures, the ability to drink huge quantities of alcohol was considered a sign of masculinity, for example, among followers of Dionysus. Echoes of this attitude can be found on Saturday nights among young men and, increasingly, also young women in some Western city centres.

By contrast, in Islamic and Buddhist cultures alcohol is generally prohibited. Throughout its history, drinking alcohol to excess has been associated with deviant behaviour and harm, as another term for drunkenness – *intoxication*, from the Latin *toxicum*, a poison (as in *toxic*) – signifies.

The advocacy of total abstinence from alcohol began as early as 200 AD. It is best known from the Temperance movement in predominantly Christian countries in the nineteenth century, that gave rise to the term ‘teetotaller’ (short for ‘temperance total’) – someone who deliberately abstains from alcohol. Alcohol was banned in the USA during the Prohibition era from 1920 to 1933. Mississippi was the last state to repeal its prohibition laws in 1966.

In 2000, around four billion abstainers worldwide outnumbered alcohol drinkers by about two to one, but the ratio is shifting rapidly as alcohol drinking spreads into countries with little previous use and women take up the habit in increasing numbers. Conversely in some Western cultures there is a move towards abstinence in the younger generation as lifestyle, health and fitness concerns have become more considered.

4 Homebrewing

Much like baking home goods to wow your friends, you can do the same with brewing. Home brewing is a popular hobby that is easy to get into. Specialist shops and websites stock all the necessary materials, but starter kits can be purchased from large supermarkets and online vendors.

For this course, as for others, there is no better way to support your learning than to put it into practice. This is not a requirement of the course, but it would be a fun way to visualise what you are studying – a genuine home experiment. Conveniently most homebrews take about eight weeks, which is also the length of this course. It doesn't matter what type of beer you decide on as the basic processes are the same but you should aim to start your homebrew this week. So watch this video and consider putting your study into action.

In this video Danny Allwood introduces homebrewing, its attractions and how to get started.

Video content is not available in this format.

In the next section, you'll start to think about setting up your own experiment.

4.1 Setting up your homebrew experiment

If you would like to set up your own homebrewing experiment, you should now watch the following video of Danny Allwood explaining what equipment you will require to brew your own beer. Even if you do not want to do the experiment yourself, you will still find it useful to see how it is done by Danny.

Video content is not available in this format.

You should note that Danny make references to an instrument called a hydrometer. This is a simple instrument that will allow you to calculate the final alcoholic strength (referred to as % alcohol by volume, ABV) of your home brew. If you are planning to take part in the home experiment, you should try to buy a kit which includes one of these, or buy one separately.

A hydrometer is an instrument used to measure the specific gravity or relative density of liquids, i.e. the ratio of the density of the liquid to the density of water. Hydrometers are usually made of glass and consist of a cylindrical stem and a bulb weighted with a heavy material to make it float upright. Examples of a hydrometer you can readily purchase are illustrated in Figure 8.

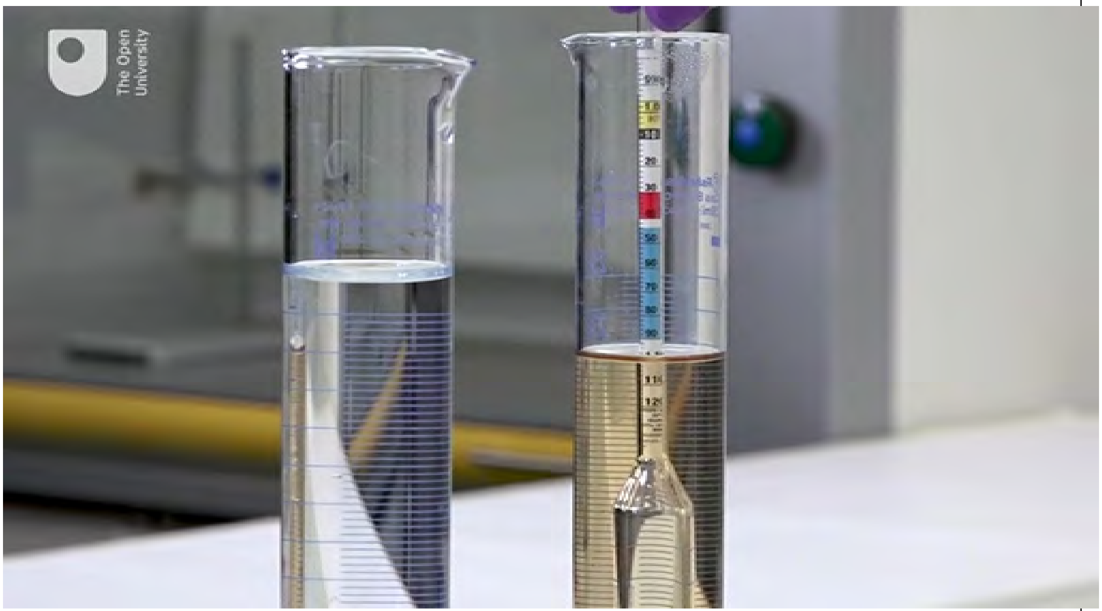
Figure 8 Examples of commercially available hydrometers

4.1.1 Using a hydrometer

In order to calculate the strength of your homebrew you will need to take two readings – one at the start of the brewing process, and one when it has completed. In Week 8 you will learn how to use these two readings to calculate the strength of your homebrewed beer.

Now watch the following video showing the use of a hydrometer to take your first homebrew reading at the start of the brewing process.

Video content is not available in this format.



A hydrometer works on the principle that water has a specific gravity of 1.000. Prior to fermentation your beer will contain sugars which make the liquid denser and so the hydrometer will float higher in the liquid than in water and will therefore give a higher specific gravity reading. For example, the starting specific gravity for an average ale or lager will be in the range 1.038–1.050. This reading is termed the original gravity, or OG.

Following the instructions in the video, you should now take a reading of your OG for your homebrew. Make a careful note of this, as you will need it in Week 8.

5 This week's quiz

Well done – you have reached the end of Week 1 and can now do the weekly quiz to test your learning.

Week 1 practice quiz

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click on the link. Return here when you have finished.

6 Summary of Week 1

Week 1 introduced you to what alcohol is from a chemical perspective and how alcohol is introduced into drink using the fermentation reaction.

You should now be able to:

- describe the ethanol molecule and distinguish it from other alcohols
- explain why ethanol is easily absorbed into the body
- describe some of the basic chemical reactions that ethanol can undergo
- discuss the fermentation reaction, and the conditions that affect it
- depict how early human civilisations used alcohol and its effect on their culture.

Next week you will learn more about how one particular type of alcoholic drink is produced – the process of brewing to manufacture beer.

You can now go to Week 2.

Week 2: An introduction to brewing

Introduction

This week you will learn how beer is made. You will first look at the basic components of a beer and see what each of them brings to the development of a beverage. You've already met yeast briefly in the first week of this course. This week you will look at the other components – water, hops, barley and malt – and see why they are important.

You will be introduced to the basic brewing process and the terminology used, and you'll explore how different types of beer are made, and the methods used to achieve these.

By the end of this week, you will be able to:

- describe the importance of the constituents of beer
- explain the mechanisms of the brewing process
- discuss the difference between different types of beer.

1 The components of beer

You may be surprised to hear that there are only four key components of beer, regardless of what type of beer is being brewed.

Before considering the process of brewing you can explore the different components of beer by watching the videos below. In the sections which follow, you will explore in detail the brewing process at Hook Norton but, before this, it is useful to know a bit more about each component individually.

The following videos will show you more about the role of the main components of beer: barley, water, yeast and hops.

Video content is not available in this format.

Barley

Video content is not available in this format.

Water

Video content is not available in this format.

Yeast

Video content is not available in this format.

Hops

1.1 Water

You may be surprised to hear that water usually makes up 90–96% of beer, the rest being mainly alcohol and compounds to flavour it. Believe it or not, this high percentage of water has a large impact on the flavour of the beer and historically has led to certain types being predominantly brewed in specific areas.

Different types of beer can be brewed depending on the hardness of the water. Hard water is best suited to stout type beers such as Guinness, whereas soft water is better for light, hoppy beers such as lager and pilsners.

- Do you think Dublin is likely to have hard or soft water?
- Dublin is well known for its production of Guinness, and the area has particularly hard water.

Many Guinness fans are convinced that Guinness produced in Dublin is superior to that brewed in other locations. They may well be correct – Dublin's particularly hard water contains large amounts of bicarbonates and calcium which raise the pH of the water. pH is a scientific scale used to define how acidic or how alkaline a particular substance is, with an acid having a pH less than 7, and an alkaline having a pH greater than 7. In fact, in order to avoid harsh flavours in the beer, Dublin brewers have to use enzymes with very specific pH requirements of around 5.1–5.5. This requires roasted malts – which have an acidic effect on the brew – to lower the pH to these values. These water conditions have resulted in the development of Guinness and other stout type ales in this part of Ireland.

Soft water on the other hand has a very low pH which is better suited to the brewing of pilsner lagers. So, for example, the Pilsen region in the Czech Republic, a location renowned for its pale, hoppy, lagers, has very soft water.

What do we actually mean by hardness of water? Water hardness refers to the mineral content of water, and more specifically the calcium and magnesium content.

A water is deemed to be 'hard' if it has high levels of magnesium and calcium ions dissolved in it.

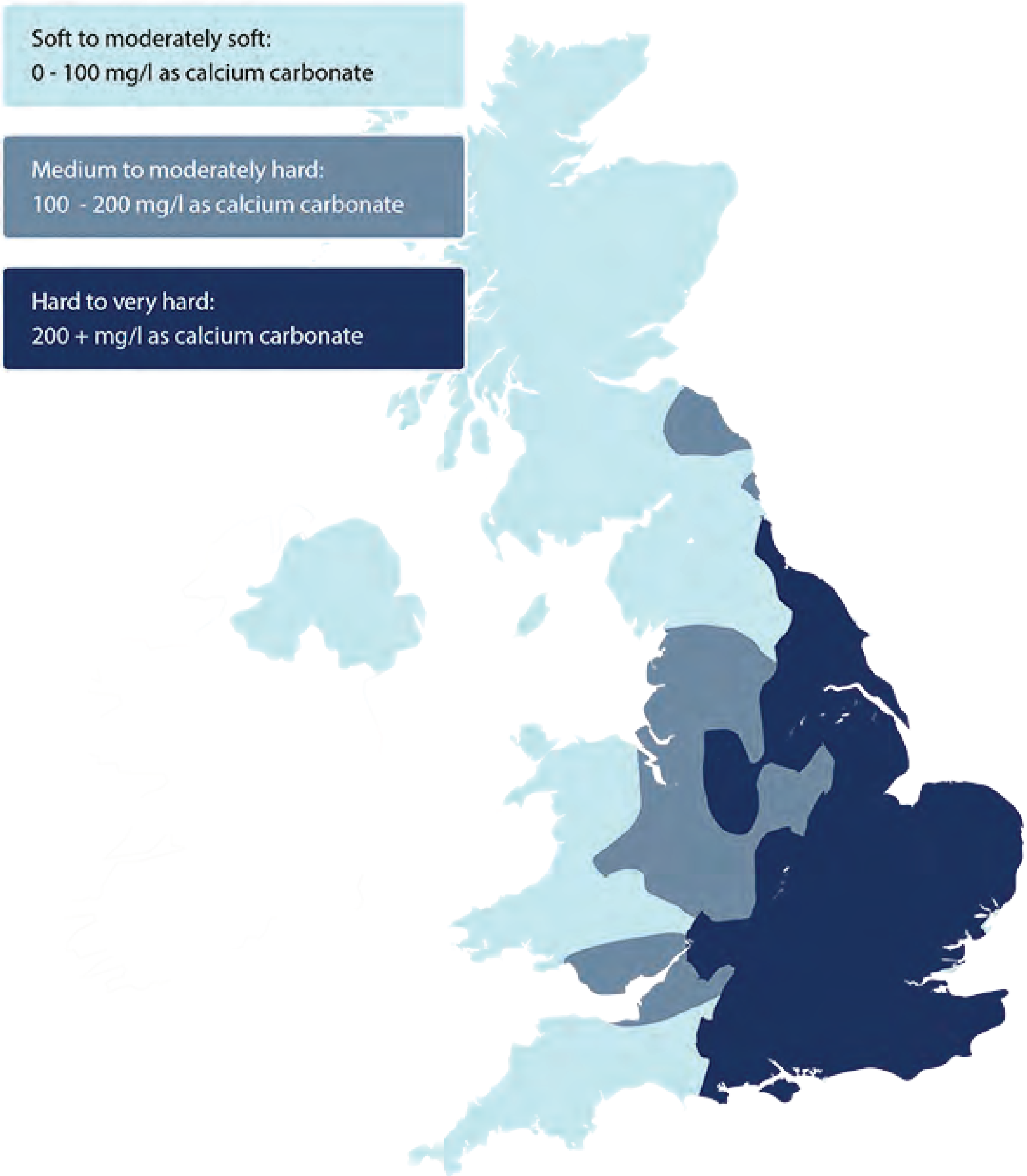


Figure 1 Hardness of water across the UK

An easy way of telling if you have hard water is to think about what happens when you use soap. It is very difficult to form a good lather with soap used in hard water areas.

In reality, water hardness is not actually a problem. A modern brewery often wants to be able to make all different types of beer, regardless of the water chemistry of their particular region. Brewers can do this by using very fine mesh filters with active carbon, basically stripping the water of anything that's not water. This means that the brewer has to add additional salts, such as calcium sulfate and calcium chloride, back into the mix in order to obtain the ideal pH during the brewing process, and this will depend on what particular beer they wish to manufacture.

1.2 Hops

The hops used in brewing are the flowers (referred to scientifically as the strobili) of the female hop plant Humulus lupulus, a member of the hemp family (Figure 2).

Figure 2 Humulus lupulus (better known as hops)

Hops are used mainly as a flavouring and stability agent in beer, to which they impart bitter, zesty or citric flavours. Although primarily used in brewing, hops are also known to have various sedative, hypnotic and antibacterial properties.

Hops contain a range of different chemical compounds that affect the flavour, the most important being the alpha and beta acids. Alpha acids such as humulone (Figure 3a) act as a mild antibacterial agent. When heated during the brewing process, it changes chemical structure into iso-humulone (Figure 3b), which imparts a bitterness into the beer.

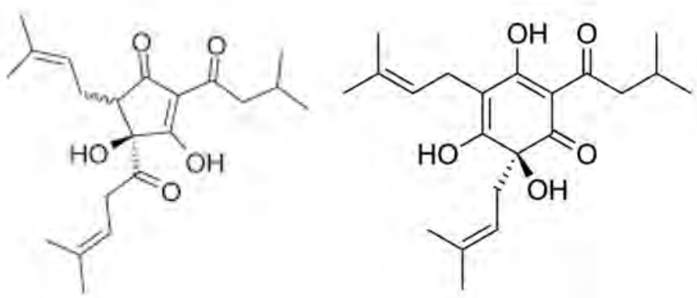


Figure 3 (a) Humulone; (b) Iso-humulone

Humulone and iso-humulone are said to be *isomers* of each other as each compound has the same number of constituent atoms, but a different three-dimensional arrangement of these atoms.

On the other hand, beta acids such as lupulone (Figure 4) are essential oils and act as aroma and flavour compounds that give the beer a distinctive taste and smell (often described as ‘hoppy’). Oils such as lupulone are volatile which means they will readily evaporate during the boil. So if a brewer wishes to produce a more 'hoppy' beer, great care must be taken about when the lupulone is added to the boil. If added too early, it simply evaporates and the flavour is lost.

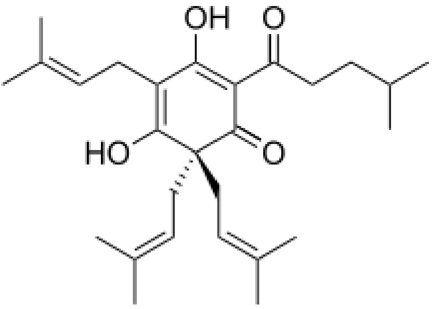


Figure 4 Lupulone

- Look carefully at the structures of both components of the hops. Do you recognise a particular functional group?
- Both humulone and lupulone contain the –OH functional groups and so are further examples of types of alcohol, although their names are derived from other functional groups within the compounds.

Because different types of hop have different combinations of alpha and beta acids, hop growers must have their produce analysed by a laboratory before the hops can be sold, so the brewer knows how they will affect the beer. In order to create a beer with an optimal combination of bitterness, flavour and aroma, the brewer must take into account the ratio between the two types of acid.

1.3 Yeast

You first met yeast in Week 1 when you were introduced to the fermentation process.

- What is the role of yeast in fermentation?
- Yeast converts sugar into alcohol and carbon dioxide during primary fermentation in brewing.

Yeast is a type of fungus, with over a thousand different species identified so far. However only one or two of these are used for brewing: *Saccharomyces cerevisiae* (Figure 5) and *Saccharomyces pastorianus*. These are also known as ale and lager yeasts in the brewing industry.

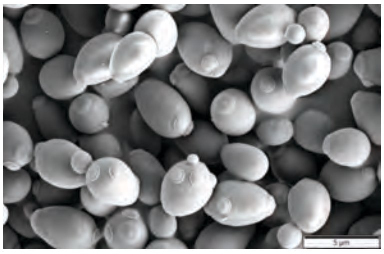


Figure 5 Microscope image of *Saccharomyces cerevisiae*

In fact, you may be familiar already with the ale yeast *Saccharomyces cerevisiae*, in particular if you are a keen baker. This species of yeast is more commonly referred to as baker's yeast and is used widely in breadmaking and baking. *Saccharomyces pastorianus* is a yeast used industrially for the production of lager and was named in honour of the French biologist Louis Pasteur (1822–1895).

These different strains of yeast ferment optimally at different temperatures, with ale yeasts preferring temperatures in the range 17–24 ! ! C, and lager yeasts preferring temperatures in the range 8–14! ! C. The higher temperature for ales results in a faster fermentation, with more flavour compounds being produced. Lagers, however, take longer to ferment and have less flavour from the yeast.

In Week 4 you will learn about a further role of yeast other than in the primary fermentation. Yeast is also actively involved in the secondary fermentation or conditioning process which further enhances, and adds to, the flavour of the finished beer.

1.4 Barley and malt

Malting is an important component of the brewing process. Malted barley is the source of the sugars (principally maltose) which are fermented into beer by the yeast. In fact, malt is simply a general term used as an abbreviation for several things associated with maltose and malted barley.

Malting is the process in which barley grain (Figure 6) is soaked and drained to initiate the germination of the plant from the seed. When the seed germinates, it activates enzymes which start converting its starch and protein reserves into sugars and amino acids that the growing plant can use. The purpose of malting a grain is to release these enzymes for use by the brewer. Once the seeds start to sprout, the grain is dried in a kiln (in a process known as kilning) to stop the enzymes until the brewer is ready to use the grain.

Figure 6 Barley grains used in malting

The brewer needs to take into account both the water chemistry and the amount of enzymes in each type of malt to optimise their beer recipes.

Specific enzymes activated in this process are primarily two types of enzyme known as amylases: α-amylase and β-amylase. These enzymes are present naturally in your saliva and break down starch ingested into simple sugars which can be digested by the body. For brewing purposes these two enzymes differ in function with respect to the sugars produced from the starch. β-amylase produces fermentable sugars (such as maltose), which are later turned into alcohol and carbon dioxide during fermentation. Conversely, α-amylase produces unfermentable sugars (such as maltodextrins), which stay in the brew, adding body and fullness and bringing a sweet, malty flavour to the beer.

β-amylase is activated at around 62–67 ! ! C, and α-amylase around 71–72! ! C. By carefully controlling the temperature of the brew, the brewer can determine the ratio between the two types of sugar, and thus the final amount of alcohol and malty flavours left in the beer.

As you have now seen, the whole brewing process is more complex than you might have first thought, with precise control needed over each of the four constituents of the final beer. You are now going to see how all of this works in practice by exploring a brewery.

2 The brewing process

Have you ever been to a brewery? If not, now’s your chance! In order to illustrate the brewing process, you will now visit (virtually, of course) the Hook Norton Brewery located in the village of Hook Norton, Oxfordshire (Figure 7).

Figure 7 Hook Norton Victorian tower house brewery

Hook Norton Brewery (referred to colloquially as ‘Hooky’) dates back to 1849 and is referred to as a ‘tower house’ brewery. This means that the stages of the brewing process flow logically from floor to floor, as illustrated in Figure 8.

Figure 8 Hook Norton tower house brewery schematic

In the following video you will learn from Mark Graham about why Hook Norton uses a tower house brewery.

Video content is not available in this format.

Now watch the actual brewing process utilised by Hook Norton.

Video content is not available in this format.

Activity 1 The order of the brewing process

Allow approximately 5 minutes for this activity

After watching the video can you list the different constituents of the brewing process in order?

Provide your answer...

Discussion

The constituents are:

- malting
- mashing
- boiling
- fermentation.

These steps are summarised in the following sections.

2.1 Malting

Malting is the process by which the barley grain is made ready for brewing. There are three stages to the malting process:

- **Stage 1: Steeping**. The barley grain is soaked in water in order to ensure a sufficient moisture level in the previously dried barley grain. This can take anything from 40 to 70 hours depending on the particular brewery and their source of barley. As you saw at the start of this week, the water used in the brewing process has a significant role to play. At Hook Norton, the water used today comes from the same aquifer as that used by brewer John Harris in 1849 in the first fermentations.
- **Stage 2: Germination**. The soaked barley is transferred into a second vessel for the process of germination in which the grain develops a root, and the enzymes needed to convert starch into sugars are activated.
- **Stage 3: Kilning**. In this process, the malt is dried within a kiln for storage. To maintain the longevity of the malt, moisture levels and temperature are controlled during kilning to ensure optimal enzyme activity in the brewing process. During this final stage of the malting process, very subtle changes within the malt can occur which impact on the final properties – appearance and flavour – of the finished beer. So for example, in the case of lager malts, these are kilned at lower temperature which results in higher enzyme activity and a paler coloured beer.

When kilning is complete, the barley grains are now known as malt. As you will have seen at the start of the Hook Norton brewing video, the malt is cracked or crushed to break apart the kernels and expose the cotyledon (part of the embryo of the seed), which contains the majority of the starches. This means that it is easier to extract the sugars needed for fermentation in the subsequent process of mashing.

2.2 Mashing

During the mashing process, the starches released during the malting phases are converted into sugars which can be extracted for use by the yeast in fermentation. The cracked malt is mixed with hot water to create a mash as illustrated at Hook Norton in Figure 9.

Figure 9 The mashing process

During the mash, naturally occurring amylase enzymes present in the malt convert the starches (long-chain carbohydrates) in the grain into smaller molecules or simple sugars such as glucose, needed by the yeast to ferment into alcohol (Figure 10).

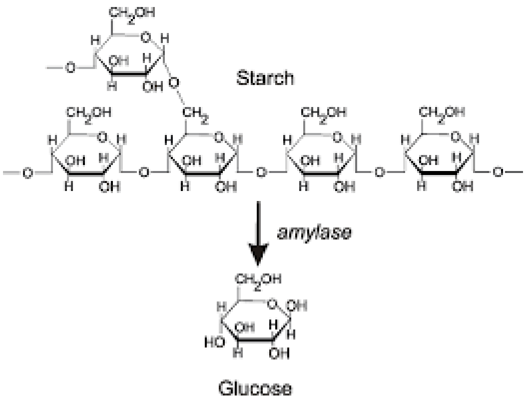


Figure 10 The breakdown of starch by an amylase enzyme into simple glucose units

Mashing results in the production of a substance rich in sugar known as the wort. The sugars produced need to be extracted so, during the process of sparging, hot liquor is sprayed onto the grain to wash the sugars along with the liquid into a copper kettle (Figure 11).

Figure 11 Sparging at Hook Norton

2.3 Boiling

Once in the copper kettle, the wort is boiled in the presence of hops (Figure 12).

Figure 12 Addition of the hops during the boiling process

- What is the significance of the hops in the brewing process?
- The hops are responsible for imparting flavour, aroma and bitterness to the finished beer.

The hops are added to the copper kettle along with the wort, and the mixture is boiled for around an hour. As you saw in Section 1, different hops have different properties which means that the addition of the hops at varying points in the boil process must be carefully managed in order to control the properties of the finished beer. Sometimes other ingredients such as herbs or sugars may be added at this stage depending on the final beer being produced.

During boiling, the enzyme activity is terminated, proteins are precipitated (deposited in a solid form from the solution), and hop acids isomerised.

- Can you define the process of isomerism?
- During isomerism one substance is converted into another substance that has the same numbers of constituent atoms but a different three-dimensional arrangement of these atoms. An example of this would be the conversion of the hop humulone into iso-humulone.

2.4 Fermentation

Following the boil, the wort is run into a vessel called the hopback (Figure 8, Step 6), where the hops settle and the wort is strained and transferred into a fermentation vessel. Next follows rapid cooling to a temperature at which yeast can be added (approximately 16–17! ! C). When the yeast is added to the wort the actual process of fermentation begins.

As a chemical equation, this would be written as:

(Eqn 1)

- Can you write out an equivalent word equation for the process of fermentation?
- Sugar/glucose → ethanol + carbon dioxide + energy.

The time needed for fermentation varies between breweries, but at Hook Norton it is around one week. Following completion of fermentation the beer is transferred into a new tank, sometimes referred to as a conditioning tank or, at Hook Norton, casks.

You will learn about the process of conditioning and storage in Week 4 and see how it further impacts on the finished beer.

3 Types of beer

Beer can be classified using various factors – colour, flavour, strength, ingredients, production method, recipe, history, or origin.

- How many different styles of beer can you list?
- You may have listed some (or all) of the following as styles of beer that can be readily purchased – pale ale, brown ale, pilsner, lager, bitter, stout, wheat beer (Weissbier), Trappist beer… But in fact, scientifically, most beers can be classified into just two types, ale and lager, and all of the other styles of beer can be grouped into one of these two types.

Although the systematic study of beer styles is a modern phenomenon, the practice of distinguishing between different varieties of beer is ancient, dating to at least 2000 BC.

Most beer styles fall into types roughly according to the time and temperature of the primary fermentation and the variety of yeast used during fermentation. As the terminology of brewing arose before the science of microbiology, 'yeast' in this context may refer not only to fungi but to some bacteria, for example *Lactobacillus* in Berliner Weisse.

Now watch the following video of Danny Allwood describing three of these different styles of beer.

Video content is not available in this format.

- What are the two main differences between the fermentation of a lager and an ale?
- Lagers are fermented using the yeast *Saccharomyces pastorianus* whereas ales are fermented using the yeast *Saccharomyces cerevisiae*.

  Lagers are fermented at lower temperatures than ales.

3.1 Top fermented beers: ales

Examples of top fermented beers include brown ale, pale ale, stout and wheat beer. The yeast used in the brewing process ferments at higher temperatures of 15–23 °C producing significant amounts of esters and other secondary flavours and aromas, often resembling those of apple, pear, pineapple, grass, hay, banana, plum or prune. This type of beer is known as a top fermented beer as the yeast used floats on top of the beer during the fermentation.

3.2 Bottom fermented beers: lagers

Lagers are the most commonly consumed beers worldwide taking their name from the German *lagern* (meaning 'to store'). Fermentation occurs at lower temperatures than for the top fermenting beers (7–12°C), with the beer then being stored at 0–4°C (the 'lagering phase'). During this time the lager clears and mellows. With modern improved fermentation control, most lager breweries use only short periods of cold storage, typically 1–3 weeks. The cooler conditions also inhibit the natural production of esters and other by-products, resulting in a crisper tasting beer. The yeast used in the fermentation of lagers is known as bottom fermenting yeast as it sinks to the bottom during the fermentation process.

Most of today's lager is based on the original Pilsner style, pioneered in 1842 in the town of Pilsen (*Plzeň*), in an area of the Austrian monarchy now located in the Czech Republic. As you learned in Section 1, this area has very soft water.

3.3 Hybrid beers

In addition to the two major beer classifications (ales and lagers), a third beer classification that's an amalgam (more or less) of the first two is hybrid beer. Hybrid beers cross over ale and lager style guidelines. A beer fermented at cold temperatures, using an ale yeast, is an example of a hybrid; likewise for a beer that's warm fermented, using lager yeast.

3.4 Stout

Stout is a type of beer which is commonly very dark in appearance (almost black).

- Can you name one very famous type of stout?
- As you saw in Section 1, Guinness is an example of a stout beer. Although many people commonly refer to stout as ‘Guinness’, the name is actually a brand name rather than a type of beer in its own right.

The colour of stout originates from the type of malt used in the fermentation – typically a dark malt is used, in particular black roasted barley which imparts a chocolate/coffee taste to the beer and gives rise to the characteristic dark colour.

Guinness is probably the best known example of a stout. Commercial advertising for the brand typically used the slogan ‘Guinness is good for you’ and, in the 1920s, post-operative patients, blood donors and pregnant women were advised to drink Guinness. Market research in the 1920s suggested that many people felt their health improved after drinking Guinness, but nowadays this is attributed to the high iron content of the stout. Pregnant women are now advised not to drink Guinness because of its alcohol content and the dangers of alcohol to the foetus.

Can you tell how a beer will taste from its appearance? Taste is dependent on both the ingredients of the beer and the process used to make it, and you will learn more about the biology which underlies both taste and smell in Week 3 of this course.

For now, James Clarke from Hook Norton will show you how to taste and appreciate the flavours of some of Hook Norton’s own beer.

Video content is not available in this format.

4 Your homebrew experiment

If you have set up your homebrew in Week 1 of the course then now would be a good time to reflect on what you did. Regardless of what particular homebrewing kit you used, your homebrew experiment will still be illustrating the fundamental principles of brewing. So for example, you will have added a particular yeast in order to initiate the fermentation, a particular hops to obtain the desired flavour and so on. It would also be worth double checking the instructions for your own homebrew kit – although 8 weeks is a standard timeframe for homebrewing, there are some kits on the market which produce the finished beer in a shorter timescale than this.

5 This week's quiz

You have now reached the end of Week 2 and can do the weekly quiz to test your learning.

Week 2 practice quiz

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click on the link. Return here when you have finished.

6 Summary of Week 2

During this week's study you have seen how the brewing process operates from an industrial perspective at Hook Norton brewery. Although all breweries will have their own exact brewing processes and recipes, the basic principles of brewing remain the same. Also this week you were introduced to the different ingredients of beer and you saw how different flavours can be introduced.

You should now be able to:

- describe the importance of the constituents of beer
- explain the mechanisms of the brewing process
- discuss the difference between different types of beer.

In the next week of study you are going to learn more about the concepts of both smell and taste from a biological perspective.

You can now go to Week 3.

Week 3: Taste and smell

Introduction

This week you will read about the senses of taste and smell, and how they are key to our enjoyment of an alcoholic drink.

In Week 2 you came across the key components and methods used in the brewing process. There you will have learned about how each component affects the beer.

Now you will look at the biological processes that occur in taste and smell, the two senses that you can link most with what you consume. You will then learn about the different flavours within beer, what makes these, and what happens when beer is spoiled; and explore some of the chemicals associated with this.

By the end of this week, you will be able to:

- provide insight into what makes a champion beer
- discuss the biological process behind taste and describe the different categories of taste
- discuss the biological process behind smell and explain what volatiles are
- explain what happens when a beer is spoiled.

1 What makes a champion beer?

In Week 2 you learned about the four main components of beer and how they instil the different characteristics into a beverage. You have also been introduced to the different types of beer that are brewed – lagers, ales and so forth. Given that beer is essentially the same product made in different ways it is surprising that so many complex properties can be found.

Activity 1 Tasting and smelling a beverage

Allow about 5 minutes

Have a think about describing the last thing you drank – it doesn't have to be an alcoholic beverage, it could be a cup of tea or glass of cordial. Write down a few descriptors that could be used to identify it by taste and smell.

Provide your answer...

Now watch this video of Nick Boley from CAMRA describing what makes a champion beer.

Video content is not available in this format.

Do any of the words you used to describe your beverage match the descriptors that Nick used in the video?

Answer

In Figure 1, you can see some words that people have used to describe drinks that they had recently.

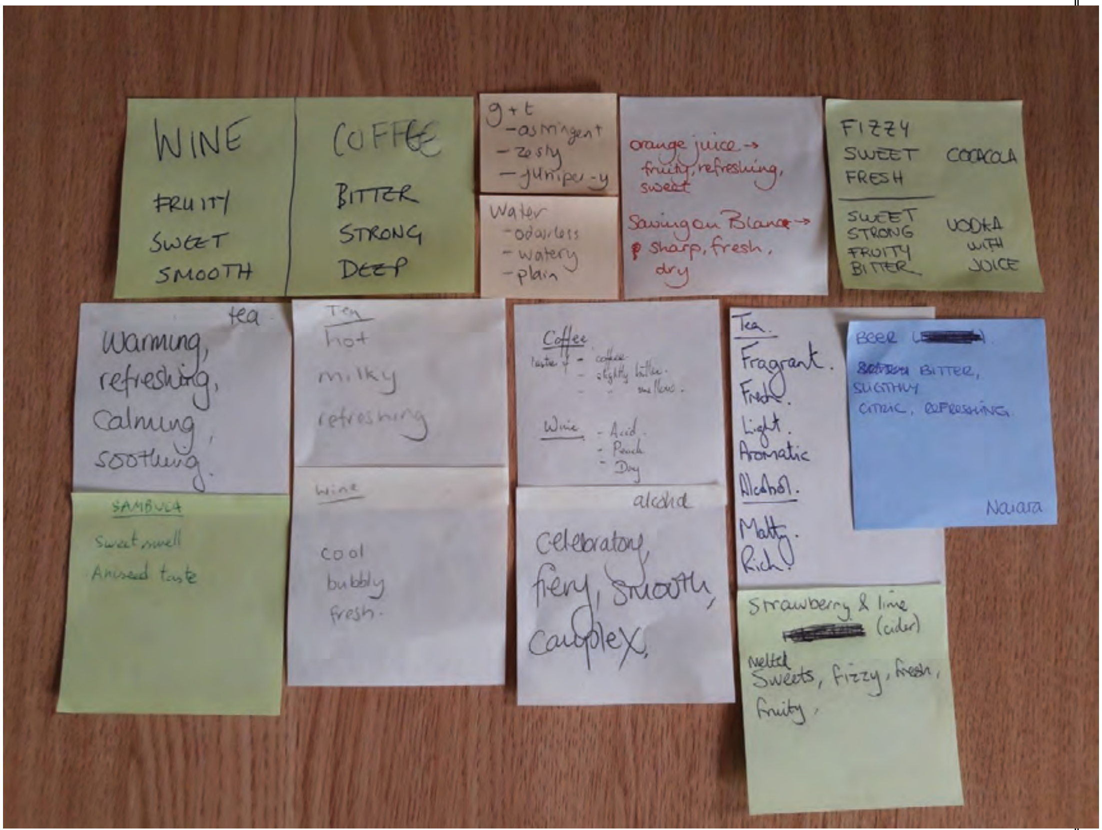


Figure 1 A variety of descriptive words for various drinks

A wide variety of words can be used. Some describe tastes such as bitter, sweet and dry but others are different (touch) sensations that we can relate to, such as whether a drink feels bubbly or smooth when it’s in the mouth.

When describing a beverage you can also describe it through what you see. For example, lager is lighter and clearer than a stout, but it is through taste and smell that you gain the most awareness of a drink as you consume it. It might surprise you to learn that these two senses are actually linked and give you a vast amount of information about what you are consuming. For this reason this week will focus on the senses of taste and smell.

2 Introduction to taste and smell

The senses of smell (olfaction) and taste (gustation) connect you directly with the *external* chemical environment in which you live and allow you to respond to chemical stimulants within that environment. These so-called ‘chemical senses’ are considered by many people to be less important than the other senses, at least in humans but, as you will see, the senses of smell and taste are central to modifying our behaviour and contributing to the overall sensory experience of our world.

In evolutionary terms, smell and taste are ancient senses. It seems likely that they developed in simple organisms as a way of detecting changes to the chemicals around them. Insects, amphibians and reptiles have particularly well-developed chemical senses. In mammals, smell and taste are used as a means of tracking prey, recognising territory, choosing a mate, enabling mother–infant recognition and avoiding predators, as well as locating food sources and determining their palatability.

Indeed, many of the odours that you are able to detect at low concentrations are those that signal potential food sources or are from material which can harm you if ingested (e.g. rotting food and waste materials). Similarly, there seems to be a close connection between your sense of taste and your nutritional requirements, as recognised in *La Physiologie du goût*, published in Paris in 1825 by the French gastronomist Jean-Anthelme Brillat-Savarin, who wrote:

> Of all our senses, taste, such as Nature has created it, remains the one which, on the whole, gives us the maximum delight: … because, when we eat, we experience an indefinable and peculiar sensation of well-being, arising out of an instinctive awareness that through what we were eating we are repairing our losses and prolonging our existence.
>
> (Brillat-Savarin, 1825)

It is not difficult to appreciate this connection between our sense of taste and the need to ‘repair our losses and prolong our existence’. If you are tired, perhaps because you have not eaten for some time or because you have been on a long walk, you may experience a craving for sweet foods. If you have undertaken more strenuous physical exercise, you may have found yourself needing to eat salty and savoury foods. A possible interpretation of these differing responses is that in the former you need to replenish energy stores whereas in the latter it is the salt, lost through sweat, and amino acids that need replacing.

The quotation above illustrates an important point of definition and it is appropriate to clarify this now. Brillat-Savarin refers to the experience of taste occurring when we eat but, in fact, the overall experience that occurs when eating is dependent on both taste and smell.

- ■ Can you estimate what percentage your sense of smell contributes towards your sensory appreciation of food and drink?
- □ Indeed, it has been estimated that smell contributes up to 90% of our sensory appreciation of food and drink.

It is easy to demonstrate this by, for example, eating a banana while pinching your nostrils. This prevents the smell of the banana from entering the nasal cavity from the back of the mouth and stimulating your sense of smell. Eaten in this way, the banana ‘tastes’ rather bland.

- Can you think of a situation when a change to your sense of smell appears to affect the ‘taste’ of food?
- The classic example is when you have a cold which would block your nasal passages with mucus. Food doesn’t taste right.

In fact, what is actually affected is the ‘flavour’ – that is, the overall perception we experience when we eat and drink, which involves the senses of both taste and smell.

You have seen that our senses of smell and taste have developed to support our survival in terms of obtaining foods that our bodies need and avoiding dangerous substances. But it also seems that smell and taste – particularly smell – also appear to possess a uniquely evocative quality that may be linked to memory and emotions in a subconscious way. Is there any particular smell that reminds you of your childhood as illustrated, for example, in Figure 2?

Figure 2 The smell of freshly cut grass may be linked to a childhood experience, for example if you grew up in a rural setting

Activity 2 The differences between smell and taste

Allow about 10 minutes

Humans have developed two complementary systems for sampling the chemical environment – smell and taste. From what you know about these two senses, identify the differences in how taste and smell operate. Look at the statement in the left-hand column and add ‘taste’ or ‘smell’ to the right-hand column.

Statement	Taste or smell?
Allows you to detect chemicals in the air – for example, perfume or the fragrance of a flower.	*Provide your answer...*
Detects substances through direct contact with the solids and liquids.	*Provide your answer...*
Is a direct indication as to whether or not solids or liquids are acceptable to eat and/or drink.	*Provide your answer...*
Does not require you to be in contact with the source of the chemical.	*Provide your answer...*

Helps you identify whether you should be attracted to, or repelled by, the source.	*Provide your answer...*
Requires you to put something into your mouth.	*Provide your answer...*
Can be detected at a distance.	*Provide your answer...*
Cannot be experienced at distance.	*Provide your answer...*

Discussion

Here are the correct answers:

Statement	**Taste or smell?**
Allows you to detect chemicals in the air – for example, perfume or the fragrance of a flower.	Smell
Detects substances through direct contact with the solids and liquids.	Taste
Is a direct indication as to whether or not solids or liquids are acceptable to eat and/or drink.	Taste
Does not require you to be in contact with the source of the chemical.	Smell
Helps you identify whether you should be attracted to, or repelled by, the source.	Smell
Requires you to put something into your mouth.	Taste
Can be detected at a distance.	Smell
Cannot be experienced at distance.	Taste

- Your ability to smell allows you to detect chemicals in the air – for example, perfume or the fragrance of a flower – and because your nose does not have to be in contact with the source of the odour, they can be detected at a distance (in some instances, hundreds of metres away). Your ability to smell seems to help you identify whether you should be attracted to, or repelled by, whatever is the source of the smell.
- Your ability to taste, however, requires you to put something into your mouth, so you need to be in direct contact with the chemicals that are 'tasted'. Taste is not something that can be experienced at a distance. In most cases, taste detects substances present in the solids and liquids you require as foods and informs you as to whether or not these are acceptable to eat.

- ■ There is also thought to be a third chemical sense, which combines both smell and taste. What is this called?
- □ A third chemical sense, combining both smell and taste, is termed 'flavour'.

You will now learn more about the science behind how smell actually works.

3 Smell (olfaction)

The human body could in theory detect thousands of different smells but not all molecules which reach your nasal passages can be detected using your sense of smell. To be smelled, a molecule must have certain characteristics. Consequently, your study of the sense of smell (or the process of 'olfaction') begins with the properties of the molecules that give rise to an odour.

Odour molecules, or 'odorants', have a number of chemical properties which allow them to be both detected and identified by the olfactory system (the system which enables you to smell a particular substance). These are:

- size
- volatility
- chemical composition.

While you will consider them in turn, it is important to recognise that the properties are all related to each other.

3.1 Relative molecular mass (RMM)

The size of the molecule is a key factor in odorants, which are normally quite small. This means they tend to have a relative molecular mass (RMM) of less than 300.

Atoms of different elements all have different masses, referred to as atomic masses. The atomic mass of a particular element can be located on the periodic table.

The periodic table is a display of all known elements arranged in order of their atomic number. The complete periodic table is illustrated in Figure 3 below.

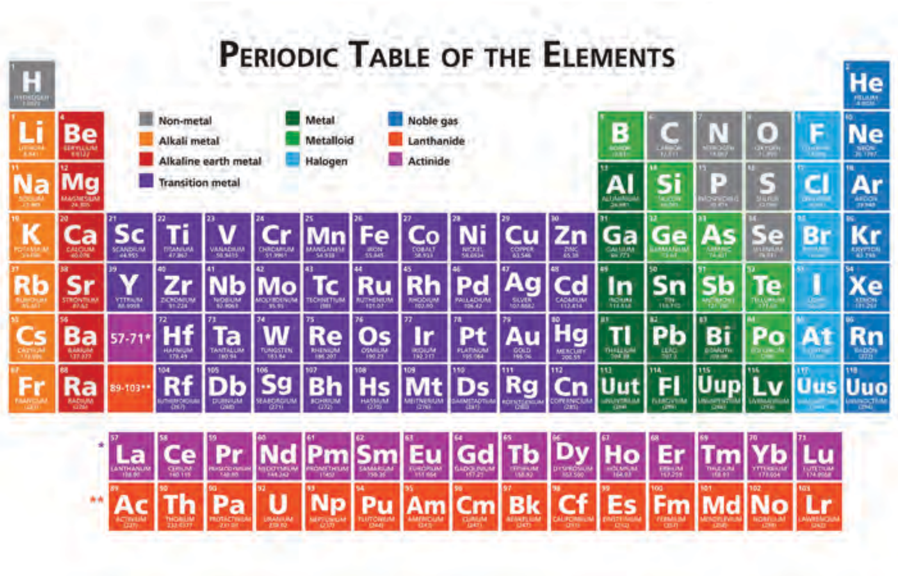


Figure 3 The periodic table, an arrangement of all known chemical elements in order of increasing atomic number

You will learn what is meant by 'atomic number' in Week 8. However, in addition to the atomic number, the atomic mass of each element can also be read from its position in the periodic table. For example, chlorine (Cl) has an atomic mass of 35.453, as illustrated in Figure 4.

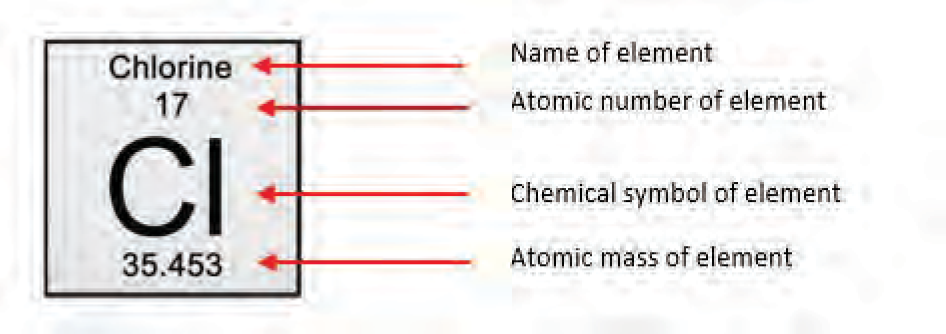


Figure 4 The properties of chlorine from the periodic table

- Water, H_2O, comprises two atoms of hydrogen (atomic mass 1.008) and one atom of oxygen (atomic mass 15.999). What is the molecular mass of water?
- The molecular mass of water = (atomic mass of hydrogen x 2) + atomic mass of oxygen.

  The molecular mass of water = (2 x 1.008) + 15.999 = 18.015.

At this stage you may be wondering about units, and rightly so, but relative mass is actually a unitless quantity. Why is this? Atoms are very small particles and so their masses are also very small. It is rather awkward to conceive of and work with such small numbers, so a convention has been adopted in which the masses of atoms are related to a standard atomic mass.

The standard chosen is a form of carbon called carbon-12, the mass of which is defined to be exactly 12. So, if you divide the mass of an atom of any element by the mass of a carbon-12 atom, then multiply the result by 12, this gives you its atomic mass relative to carbon-12. Any units of mass will cancel out, and this is why both relative atomic mass (RAM, for an element) and relative molecular mass (RMM, for a compound) are unitless quantities.

- Considering the atom chlorine as an example. Looking back at Figure 3, what is the atomic mass of chlorine?
- The atomic mass of chlorine is 35.453 amu (where amu stands for ‘atomic mass unit’)

To work out the mass of an atom of chlorine relative to carbon -12

3.2 Volatility

As well as being small molecules, odorants must be volatile molecules in order to be detected (or smelled, as is the case here). You will meet the concept of volatility again in Week 6 when you consider the laboratory process of distillation.

For something to be volatile, it means that a significant proportion of the molecules must be in the gaseous phase at room temperature. Indeed, one reason why molecules of larger mass cannot be detected is because they have insufficient volatility. It is possible to appreciate this from the boiling temperature at one atmosphere pressure of three simple odorants (Table 1):

- ethyl formate, which contains five ‘heavy’ atoms (three carbon, two oxygen)
- ethyl nonanoate, which contains 13 ‘heavy’ atoms
- ethyl palmitate, which contains 20 ‘heavy’ atoms.

Note that hydrogen is not classed as a ‘heavy’ atom.

Table 1 The boiling temperature (b.t.) at one atmosphere pressure of three odorants

Odorant	Chemical formula	RMM	Odour	b.t./°C
Ethyl formate	!Warning! Calibri not supported$C_3H_6O_2$	74	strong, fruity, rum-like	54
Ethyl nonanoate	$C_{11}H_{22}O_2$	186	cognac, nut-like	227
Ethyl palmitate	$C_{18}H_{36}O_2$	284	faint, waxy-like	340

At any given pressure, the more volatile substances are those with the lower boiling temperatures. This is because, for these substances, there are more molecules in the gaseous phase at lower temperatures – that is, they are easily vaporised.

So, at a given temperature and pressure, volatile compounds have more molecules in the gaseous phase than less volatile compounds and are therefore more easily detected. By detected, you can consider this as ‘smelled’ – the most volatile odorant, ethyl formate, has the strongest smell out of the three.

Note that for reference, the boiling temperature of water is 100 °C; water is relatively volatile (consider a day which feels very humid) but it has no odour.

■ From the boiling temperature data in Table 1, what can you say about the relative volatility of the three odorants?

□ Ethyl formate is much more volatile than the other two compounds; it boils at a temperature well below the boiling temperature of water (100 °C). Ethyl nonanoate boils at a temperature well above that of water and so is less volatile, and ethyl palmitate boils at a temperature that is even higher, so it is not very volatile at all and its smell is very faint.

3.3 Chemical composition

The chemical composition of a molecule is also really important. The seven compounds in Figure 5 all have familiar odours.

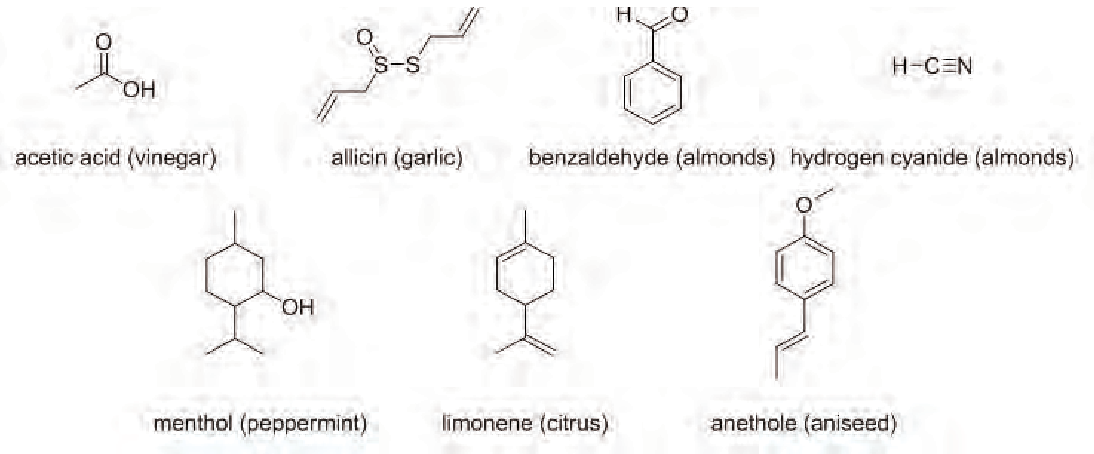


Figure 5 A group of compounds and associated odours

- Compare menthol and limonene. What can you say about their structures and the odours they elicit?
- Menthol and limonene have quite similar structures. The only major differences are the presence of double bonds (shown as =) in limonene and the C–OH in menthol and yet they have very different smells.

- Now compare benzaldehyde (C_7H_6O) and hydrogen cyanide (HCN), both of which have an almond smell. What molecular features do they have in common?
- Benzaldehyde has a higher RMM than hydrogen cyanide. Not only are the masses very different, so are the structures. Benzaldehyde contains a ring of carbon atoms and a C=O group whereas hydrogen cyanide is linear and contains a C≡N group. There appears to be no common feature, other than the C–H bond, that could be considered to cause an almond smell.

All of the compounds in Figure 5 exhibit medium–high volatility. They also have !Warning! Calibri not supportedvastly different structures. Some contain different atoms (C, S, O, N) than the others, and some have ring structures while others are linear. It is the presence of these different atoms that controls how odorants interact with specific compounds known as smell receptors located in the nasal cavity, but also the kinds of smell that the molecule elicits. It is this interaction of the odorant with the smell receptors that elicits the smell sensation. As examples, odorants which contain amino groups ($–NH_2$) generally have a fishy smell and odorants with ester functional groups (–OCOC) are usually fruity.

A direct consequence of the chemical composition of an odorant molecule, is the ability of the odorant to interact with other molecules around it (for example, water or other chemicals in the air) via a specific type of bonding known as hydrogen bonding. The odorant will exhibit slightly different properties as it associates with different molecules.

The key point to take away here is that, while the properties of an odorant seem limiting (small and volatile), the truth is actually the opposite. The complexity of the available chemistry that can make such molecules is vast, leading to thousands of potential odorant compounds, all of which are recognised by the body.

4 Taste (gustation)

> Cherries and plums fill the nose and the sweet cherry follows through the mouth where it lingers.

If you are a wine connoisseur, you will be familiar with such descriptions and the strong interrelationship between smell and taste. As you have learned, the sensation of flavour is actually a combination of both taste and smell. 'Gustation' is the term used for the action of tasting. Humans can distinguish five basic tastes:

1. sweet
2. salty
3. sour
4. bitter
5. umami ('oo-ma-me', savoury or meaty).

Detection of specific tastes occurs across many different regions of the tongue, although some are more concentrated in particular areas as you can see in Figure 6. Umami flavours are detected in the middle portion of the tongue. An overlap of sweet and salty tastes at the front of the tongue is shown.

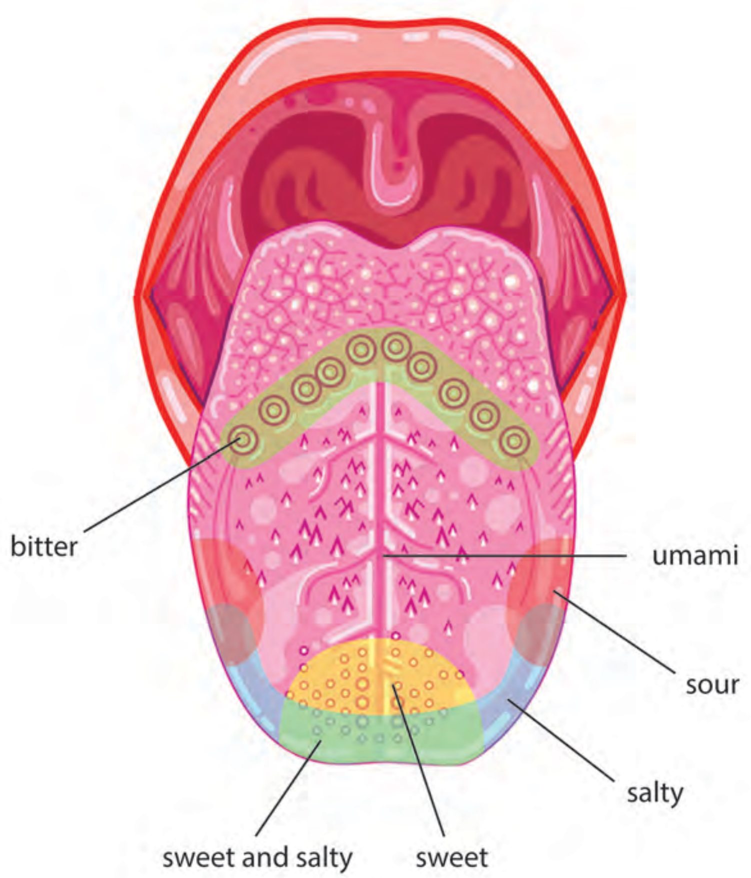


Figure 6 Detection of specific tastes occurs across many different regions of the tongue

You can test these yourself by putting some sugar (sweet) or salt (salty) granules onto a wet finger and touching the different areas of your tongue. Now try a spot of vinegar. In what areas did the tastes come out the most?

- Take a look at your tongue in a mirror. Why do you think the texture of the top of your tongue is different from the texture underneath?
- The tongue is not just for taste. It has several other functions. The top surface of the tongue is in contact with the things you eat and contains ‘papillae’ (bumps on the tongue) which detect different tastes but also textures, for example a smooth or a bubbly beer. The underneath of the tongue is important for shaping the tongue during swallowing and speech and therefore has a higher content of skeletal muscle cells and a different appearance.

Binding of specific ions to taste receptors in the taste buds produces the characteristic taste. For example, a sour taste is the detection of hydrogen ions, and a salty taste is the detection of metal ions, e.g. sodium and potassium. An ion is a charged species which results from the gain or loss of electron or electrons from a particular atom. You will learn more about ions in Week 8 and how they are formed. A sweet taste comes from the ability to detect sugars, both naturally occurring and artificial sweeteners such as sucralose and aspartame.

- Thinking back to Week 1 where you learned about corking of wine, why does a corked bottle taste sour?
- If you remember, the process of corking was due to a bacteria Acetobacter that turned ethanol into acetic acid which is the chemical in vinegar. This can be written scientifically as shown in Equation 1:

  (Eqn 1)

  In your taste test above, the hydrogen ions in your sour vinegar come from the acetic acid CH3COOH that breaks down in aqueous conditions (such as those within your mouth) to form these ions. This can be written scientifically as shown in Equation 2:

  (Eqn 2)

In addition to taste, the tongue communicates other features of the environment to the brain. If you have ever burnt your tongue on a hot drink or eaten a painfully spicy curry, you are well aware that information about temperature, pressure and pain is also sensed by the tongue. These sensations are detected by a separate set of receptors to those that detect taste; instead these are related to the sense of touch.

5 Flavours in alcoholic drinks

Alcoholic beverages come in a vast variety of flavours. Some of these are added deliberately to the drink (quite common for alcopops, fruit ciders and spirits), but in traditional drinks such as beer the flavours occur naturally, coming from the components – hops, grains, water and yeast. You first met these components of beer in Week 2. In this video, Danny Allwood describes some of the flavours associated with these components and where they come from.

Video content is not available in this format.

Within the malt, the yeasts and sugars interact producing lots of different chemicals that contribute to flavour and aroma. Brewing temperature and yeast strain strongly affect this. The main compounds are esters and phenols. In general, more esters are produced when the fermentation step is warmer. Ale yeast prefers warmer temperatures compared to lager yeast and produces compounds such as isoamyl acetate (sweet candy banana), ethyl octanoate (apple skins) and ethyl hexanoate (anise). Not all compounds smell good, though. Warm fermentations can result in ethyl acetate (acetone), which is commonly used in nail polish remover! Other flavours that are yeast dependent are 4-ethylphenol (an earthy aroma) and 4-vinyl guaiacol (cloves).

How the brewer treats the grains during the malting process leads to many of beer's prominent flavours. Toasting the grains and the drying process have a large effect and also affect the colour. For example, darker grains smell like candy floss due to the presence of maltol.

During the toasting process the amino acids and sugars react together in a caramelisation called the Maillard reaction. Literally hundreds of compounds can result from this with the most common flavours and aromas including caramel, chocolate and coffee.

Hops are some of the most recognisable flavour providers. Bitter compounds such as the humulones – known as alpha acids – are present in the hop flower. The higher their levels, the more bitter the beer will be. Varieties of hop differ in content and therefore bitterness.

The classic hop smell comes primarily from essential oils in hops. You saw in Week 2 that, for a ‘hoppy’ beer, more hops are added at the end of the brewing process. The most common oils are alpha-caryophyllene and humulatriene. These two compounds create the key pine, citrus and sage-like aromas that hoppy beers are famous for.

Consider the structure of humulone in Figure 7.

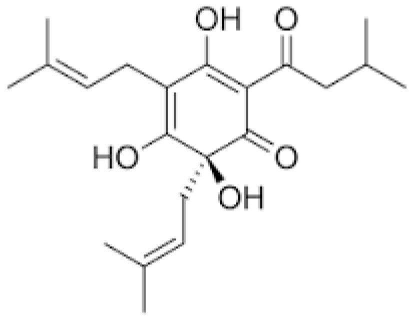


Figure 7 The alpha acid humulone, found in hops

- Is humulone likely to contribute to the taste or the smell of a beer?
- Humulone is a large molecule with an RMM of 362.46 and as such is highly likely not to be volatile at room temperature. Therefore, it is more likely to contribute to taste rather than smell. Other smaller hops can be used to contribute to the smell of a beer.

6 Spoiled beer

We can all dream of the perfect pint but just like any food that has been left out too long, or not prepared properly, beer can go off. Drinking it will not be pleasant or in some cases it will even be bad for you.

In this video Danny Allwood discusses his thoughts on spoiled beer.

Video content is not available in this format.

The brewing industry uses the term 'off flavours' to describe any undesirable flavours which arise in a finished beer.

- From the video can you recall from what stages in the brewing process off flavours are most likely to arise?
- Boiling, fermentation and storage are the main processes in which undesirable flavours can be introduced into the finished beer. However, poor sanitation at any stage in the process can lead to contamination with bacteria. When bacteria carry out the reactions needed to sustain life, compounds are produced which can lead to off flavours such as acetic acid (giving rise to the taste of vinegar, as in corked wine).

7 Your homebrew experiment

Your homebrew should now have been underway for 3 weeks. As you have just seen, contamination by bacteria is the main way that your beer can be spoiled. At this stage, a visual examination alone may not be sufficient to reveal whether your beer has been spoiled – tasting and smelling the final product is normally the only indication that your beer has been contaminated. Provided you have followed the instructions provided with your homebrew kit, contamination by bacteria is very unlikely.

8 This week's quiz

You have now reached the end of Week 3 and can do the weekly quiz to test your learning.

Week 3 practice quiz

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click the link. Return here when you have finished.

9 Summary of Week 3

Taste and smell are complex senses that give us the ability to recognise a massive range of chemical components in our food and drink. They give us enjoyment but also can warn us of poor quality.

You should now be able to:

- provide insight into what makes a champion beer
- discuss the biological process behind taste and describe the different categories of taste
- discuss the biological process behind smell and explain what volatiles are
- explain what happens when a beer is spoiled.

Next week you will look further at the large-scale brewing process and how science and engineering turned brewing from a microscale cottage venture into a large-scale commercial enterprise.

You can now go to Week 4.

Week 4: Brewing on an industrial scale

1 The history of beer and brewing

Beer is thought to be one of the oldest drinks humans have produced, dating back to at least the 5th millennium BC in Iran. It was recorded in the written history of ancient Egypt and Mesopotamia (Figure 1). Beer eventually made its way from the Middle East across the Mediterranean to Europe, where it became an integral part of life. This was especially true in northern Europe where abundant barley crops provided plenty of raw ingredients for brewers. Beer was valued both for its nutritional worth and because it was a safe alternative to drinking water, many sources of which had become contaminated with human waste.

Figure 1 Egyptian artwork, thought to depict the pouring of beer

It was during the early Middle Ages that what we think of as 'beer' was developed, and its brewing was particularly associated with monasteries. Virtually every monastery was thought to have a brewery on site. In fact, historians very often credit monks with many brewing developments and innovations, for example, the principle of lagering (storing) as used in the present day by a number of Belgian monastic breweries.

1.1 The Industrial Revolution

In the following video, Paul Kosmetatos describes how the role of brewing in early industrialisation (before the introduction of modern technology) advanced to the scales we associate with brewing today.

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In the late Middle Ages, the brewing industry in northern Europe changed from a small-scale domestic industry to a large-scale export industry. The key innovation was the introduction of hops, the constituent of beer credited with the overall improvement in the quality of the beer, which began in northern Germany in the thirteenth century.

However, it was the significant improvements in the efficiency of the steam engine in 1765 that led to the industrialisation of beer production becoming a reality.

Further innovations in the brewing process came about during the Industrial Revolution with the introduction of the thermometer in 1760 and the hydrometer in 1770, allowing brewers to increase efficiency and also further their understanding of the brewing process itself. With the thermometer, brewers were able to analyse for the first time how different temperatures affected sugar yield and fermentability. But it was the discovery of the hydrometer that really transformed how beer was brewed, and you will see for yourself in Week 8 how this simple instrument can yield valuable information about the strength of brewed beer.

Before hydrometers were routinely used, beers were brewed from a single malt: brown beers from brown malt, amber beers from amber malt, and pale beers from pale malt. Using the hydrometer, brewers could calculate the yield from different malts. These early brewers observed that pale malt, though more expensive, yielded far more fermentable material than cheaper malts and this discovery is thought to have contributed significantly to the overall efficiency of the industrial brewing process. Brewers were now able to revert to using mostly pale malt for all beers supplemented with a small quantity of highly coloured malt to achieve the correct colour for darker beers.

The invention of the microscope allowed Louis Pasteur (1822–1895) to discover the yeast that was responsible for turning the sugary wort into the alcoholic beer. Furthermore, the discovery of the microbial origins of fermentation allowed brewers to adopt sanitation techniques, allowing beers to be exported over further distances.

It is safe to say that the Industrial Revolution changed the brewing industry more than any previous time period, and today the brewing industry is a global business, consisting of several dominant multinational companies and many thousands of smaller producers ranging from brewpubs to regional breweries.

2 The scale of brewing

In Week 2 you learned about the brewing process utilised by Hook Norton brewery. This is known as commercial brewing as significant quantities of product are produced for sale. In this part of the course you will learn about some of the factors that influence brewing on this scale, and how this has led to the development of brewing on much smaller scales.

2.1 Important considerations for commercial brewing

Brewing can be considered in the same way as any other commercial manufacturing process – essentially you are scaling up a small-scale production (comparable to your own home brew) to an industrial process used by many of the leading breweries today.

Activity 1 Scaling up brewing

Allow about 10 minutes

Use the drop-down menus to select the missing words in this paragraph.

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In the following video James from Hook Norton talks about the challenges involved in scaling up from their microbrewery to the main brewery.

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- Based on the video, what specific challenges are involved in brewing on a commercial scale?

-
  - Trial and error is still needed to progress from brewing on the laboratory scale to commercial manufacturing.
  - Beer is technically considered a ‘food substance’ and hence is subject to food safety guidelines.
  - Flavour, taste, odour and appearance all have to be consistent in commercial brews and so frequent human sampling is required.
  - All ingredients used for commercial brewing must have traceable origins.

2.2 Microbreweries

A microbrewery, by definition, produces beer on a much smaller scale than a large commercial brewery. Microbreweries began to emerge in the 1970s, but have increased significantly in recent years. You may have heard microbreweries referred to as craft breweries, which produce so-called craft beers on a small scale, for example the range of American craft beers. Microbreweries are often independently owned and so have the flexibility to brew whatever consumers are demanding – they are not constrained by the scale of the large commercial breweries. Microbreweries often have their own pub, known as a brewpub, in which their own beer is sold exclusively.

In the following video, Danny Allwood and Paul Kosmetatos discuss the merits of microbrewing and the impact this has on the brewing industry as a whole.

Video content is not available in this format.

- After listening to this discussion, what do you think is the main factor driving the development of both the brewing and distillation industries?
- Consumer demand is the main factor. In the case of brewing, the demand by consumers (and organisations such as CAMRA) for better quality and more diverse beer has led to the development of microbreweries which have the flexibility to produce a wider range of different beers.

3 Removal of alcohol from beer

You may be surprised to hear that beer which is advertised as 'alcohol-free' is not completely what it seems. In fact, beer can be advertised as alcohol-free if it is found to contain less than 0.5% alcohol by volume (ABV). Amazingly, that's roughly the same percentage of alcohol found in freshly squeezed orange juice, or a very ripe banana. Technically, it still contains alcohol but not enough to get you drunk.

- How many bottles of alcohol-free beer are equivalent to one standard bottle of beer?
- You would need to drink approximately nine bottles of alcohol-free beer to drink the equivalent of one bottle of standard lager (4.5% ABV).

The majority of alcohol-free beers are lagers, although some varieties of pale ale do have low-alcohol equivalents.

3.1 The history of alcohol-free beers

You may be surprised to hear that the origins of non-alcohol beer date back to medieval Europe. These brews ('small beer') were made for everyday consumption by the working classes as a safer substitute for often polluted water, with just enough alcohol present to kill bacteria. Beer was viewed as a more nutritious alternative to water and was often part of a worker's daily pay.

The true origins, however, of the brewing of alcohol-free beer can be dated back to 1919 in the USA. During this time of the Temperance movement, alcoholic drinks that contained more than 0.5% ABV were banned from production, importation, transportation and sale.

In the face of this ban, breweries were forced to produce a different type of beer that was very pale, not so flavourful and just 0.5% ABV. So, in other words, what we would refer to today as either non-alcoholic or alcohol-free beer.

3.2 The brewing process for alcohol-free beers

A low-alcohol or alcohol-free beer actually starts its life in the same way as a standard beer, using the same processes you have already met in Week 2 and in this week's study material.

Non-alcoholic beers go through pretty much the full 'normal' brewing process: making a mash, boiling the wort, adding hops and fermenting. While regular beers are then packaged for sale, non-alcoholic beers then need to have their alcohol removed or lowered. There are three main ways that this can be achieved: through reverse osmosis, distillation (through boiling) and vacuum distilling.

3.2.1 Reverse osmosis

You are probably familiar with this process already, although you may not have heard this particular term. Reverse osmosis is, not surprisingly, the reverse of the normal process of osmosis, which occurs within the human body to allow water to move into and out of your cells and keep you alive.

During osmosis, molecules of a solvent (such as water) pass through a semi-permeable membrane from a less concentrated solution into a more concentrated one so as to equalise the concentrations on both sides of the membrane.

A semi-permeable membrane is one which allows the passage through it of water and some other very small molecules but prevents the passage of larger molecules. If you consider a concentrated salt solution to have a high concentration of salt and a lower concentration of water, then you can also think of osmosis as being the movement of water from the area of its high concentration to an area of its lower concentration across a semi-permeable membrane. This is illustrated in Figure 2.

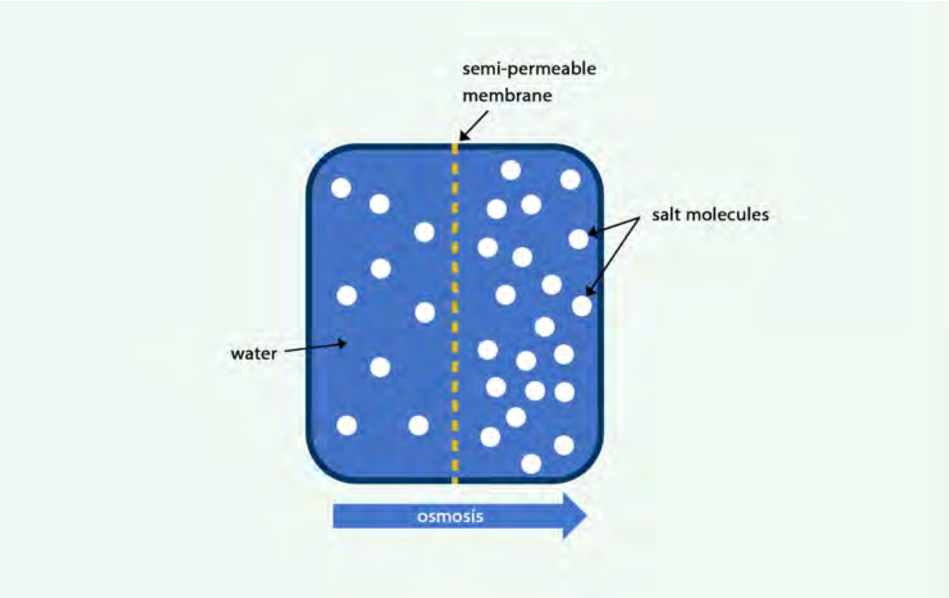

Figure 2 The process of osmosis in which water moves from a high concentration of water (a low concentration of salt) to a low concentration of water (a high concentration of salt)

- After certain dental procedures, the risk of bacterial infection is high. Based on your knowledge of the process of osmosis, why do you think dentists encourage you to rinse your mouth with a salt water solution?
- The salt water solution contains a high concentration of salt and a low concentration of water relative to any bacteria which might be growing around the affected area. So water will be drawn out of the bacteria into the salt water solution (so from a high concentration of water in the bacteria to a lower concentration in the salt solution) to equalise the concentration. The removal of the water from the bacteria causes them to dehydrate and prevents them from multiplying, so the chances of infection is reduced.

The process of reverse osmosis is used in water purification technology, where a semi-permeable membrane filter is used to remove ions, molecules and larger particles from drinking water. Kits containing semi-permeable membranes are commercially available to install in your home to remove a wide range of contaminants from your drinking water including pesticides, bacteria, microplastics, microfibres, heavy metals, fluoride and other pollutants. Reverse osmosis is also used to desalinate sea water (by removing salt molecules from the water) and is widely used in places such as the Canary Islands to provide the rain-deficient islands with potable (drinkable) water from the surrounding Atlantic Ocean.

Activity 2 Reverse osmosis

Allow approximately 10 minutes

Based on your understanding of the process of osmosis, write a statement to represent the movement of water in reverse osmosis.

Provide your answer...

Discussion

In osmosis, water moves from a high concentration of water to a low concentration of water. In reverse osmosis, water moves from a low concentration of water to a high concentration of water.

In order to work against the natural process of osmosis, pressure must be applied to force the water to flow against its natural path. One option, therefore, for the removal of alcohol from beer is to apply pressure of between 20 and 40 bar to the beer, pushing it across a semi-permeable membrane. Due to the pressure the small molecules, such as water and alcohol, are pushed through the membrane whereas the larger molecules, such as flavours, colour and protein, are unable to pass. Thus the alcohol is removed from the beer. Fresh water is then added to the beer after this filtration to restore the volume, and the flavour of the beer can be enhanced by adjusting carbon dioxide levels or by using hop extract or other flavour enhancers.

3.2.2 Boiling and distillation

As you can see, use of reverse osmosis requires specialist equipment, so might not be feasible for the small-scale brewery. One very simple technique which could be used to remove the alcohol from the beer is to use the principle of distillation that you will meet in more detail in Week 6.

Distillation allows alcohol to be separated from water (and hence the other components of the beer) by using the fact that ethanol has a lower boiling point than water. Knowing the difference between the two, brewers can heat the fermented beer to the boiling point of ethanol – but below the boiling point of water – until the desired amount of alcohol is removed.

The problem with heating beer in this manner, however, is that it affects flavour. Volatile compounds contributing to the flavour of the beer (for example the hop alpha acids) will also be lost along with the ethanol. In order to mitigate this, some brewers practice a third method for alcohol removal: vacuum distilling.

3.2.3 Vacuum distillation

Here, the process of distillation is carried out under reduced pressure – known as a ‘vacuum’. The vacuum lowers the boiling point of the ethanol, meaning that other volatile flavour chemicals (such as alpha acids in the hops) are less affected, and the flavour remains closer to the original. Under the vacuum, the boiling point of the ethanol reduces from 78 °C to approximately 34 °C. This, therefore, allows the ethanol to be removed *before* the temperature of the distillation apparatus reaches the boiling point of the volatile flavour components.

4 Conditioning and storage of beer

The very final stage in the brewing process is to consider how the beer is going to be stored prior to sale. After the initial or primary fermentation, beer is conditioned, matured or aged in one of several ways which can take from two to four weeks, several months, or several years, depending on the brewer's intention for the beer.

The conditioning process is itself a function of the yeast. Following the primary fermentation, the majority of the wort sugars have been converted to alcohol, and a lot of the yeast goes dormant because there is no more food for it; but there is still yeast activity. The conditioning process allows time for a secondary fermentation. Here the yeast starts to use the by-products of the primary fermentation as a food source. Examples of such by-products include ketones that have buttery and honey-like flavours. These compounds are considered flaws when present in large amounts in beer and can cause stability problems during storage, leading to off flavours. Acetaldehyde is an example of a primary fermentation by-product that has a pronounced green apple smell and taste. It is an intermediate compound in the production of ethanol and is harmful. The yeast reduces compounds such as these during the secondary fermentation process, making the beer safer.

Towards the end of secondary fermentation, the suspended yeast settles out and the beer starts to clear. This process can be helped by chilling the beer, very similar to what happens in the lagering process. In the case of ales, this process is referred to as 'cold conditioning' and is a popular practice at most microbreweries for the production of craft beers. Cold conditioning for one week is usually sufficient.

4.1 Cask conditioning

Cask ale or cask-conditioned beer is unfiltered. The beer is conditioned (including secondary fermentation) and served from a cask (a container traditionally used to store beer). It is then pumped up from a cellar via a hand pump. Sometimes a cask breather is used to keep the beer fresh by allowing carbon dioxide to replace oxygen as the beer is drawn off the cask. The term 'real ale' as used by the Campaign for Real Ale (CAMRA) refers to beer 'served without the use of extraneous carbon dioxide'.

James Clarke from Hook Norton now describes how beer should be presented to consumers. Given the number of proactive steps taken in the brewing process to ensure a high-quality product, it is important for breweries such as Hook Norton to increase customer awareness of how their finished beer should be stored and presented to consumers to ensure this is reflective of the actual beer quality.

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5 The future of brewing: where next?

Modern-day breweries are constantly seeking to increase the efficiency of their processes. For maximum brewing efficiency modern-day lagers are often made much stronger than the desired ABV and are diluted before bottling. However, this strategy does not come without its own set of drawbacks. Yeast used in the brewing of beer cannot survive higher levels of alcohol and die, compromising the flavour of the beer. Therefore, a new generation of yeast that can survive higher alcohol concentrations is being evolved in bioreactors with increasing ethanol content – the survivors are isolated and cultivated.

New yeasts are also being investigated for the production of the lower-alcohol or alcohol-free beers, and many industry insiders see this as the most probable way forward for the future of brewing. Brewers have clearly identified a gap between beer and soft drinks – with low- and no-alcohol brands that promise to be healthier than conventional soft drink and soda alternatives (Figure 3).

Figure 3 Could low-alcohol beer become the new soft drink of choice?

There is a growing demand for low-alcohol beers that retain certain health benefits, thought to come from the high silicon content of some grains, that may be beneficial for bone health. Furthermore, beer contains polyphenol antioxidants which can keep cells healthy, albeit at lower quantities than wine. Ironically, the ability to absorb the polyphenols from the gut depends in part on the presence of alcohol.

You'll now return to Hook Norton Brewery one last time. In the following video, James Clarke gives an insight into where Hook Norton think the future of brewing is heading.

Video content is not available in this format.

Activity 3 Influences of a modern-day brewery

Allow approximately 10 minutes

Use the drop-down menus to select the missing words in this paragraph.

Interactive content is not available in this format.

6 Checking your homebrew experiment

If you set up your own homebrew experiment at the start of this course, your brewing should now have been progressing for four weeks, so should be roughly half-way there.

In the following video Danny Allwood demonstrates the use of a hydrometer to take another specific gravity reading from your homebrew.

Video content is not available in this format.

This is exactly what you did at the start of your brewing in Week 1, but you may wish to take another specific gravity reading now to compare with the final readings you will take in Week 8 when you calculate the strength of your finished beer.

7 This week's quiz

It's now time to complete the Week 4 badged quiz. It's similar to the previous quizzes but this time instead of there being 5 questions there are 15, covering Weeks 1 to 4.

Week 4 compulsory badge quiz

Remember this quiz counts towards your badge. If you're not successful the first time, you can attempt the quiz again in 24 hours.

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click on the link. Return here when you have finished.

8 Summary of Week 4

Congratulations! You've now completed the first half of this course. In this week you have learned about the differences between brewing on a small scale, and brewing on a commercial scale for manufacturing, and the different influences which affect both scales. You have also been given an insight into where the future of brewing may be heading, including the techniques used industrially to remove alcohol from beer.

You should now be able to:

- describe how industrial processes and the Industrial Revolution affected brewing
- explain what techniques are used to store beer
- discuss the methods used post-production, to alter beer such as in the removal of alcohol, and for longer term storage
- describe where the future of brewing may be heading.

Next, you will be introduced to the effects that alcohol can have on the human body, starting with the short term effects of alcohol consumption. You will also address the matter of whether a hangover can indeed be cured!

You are now half way through the course. The Open University would really appreciate your feedback and suggestions for future improvement in our optional end-of-course survey, which you will also have an opportunity to complete at the end of Week 8. Participation will be completely confidential and we will not pass on your details to others.

You can now go to Week 5.

Week 5: The short-term effects of alcohol

Introduction

This week you will read about how the body processes and is affected by alcohol on an acute, or short-term, basis. Week 7 will consider the long-term effects of excessive alcohol consumption.

You will first look at how the body reacts to the presence of alcohol and what immediate effects the consumption of alcohol has on the body's systems. You will see why drinkers get hangovers and look at the best 'cure' or even whether a cure exists at all!

By the end of this week, you will be able to:

- describe the process by which the ethanol molecule (alcohol) is broken down by the body
- explain how the body reacts to the presence of alcohol and why it dulls the senses
- discuss the reasons for a hangover and what is the 'best' way to get rid of one.

1 Metabolism of ethanol in the human body

To have an effect on the body's biological systems after consumption, ethanol molecules need to be absorbed into the bloodstream. Initially, this involves the absorption of ethanol from the gut.

In the following sections you will explore this further.

1.1 Absorption of ethanol from the gut into the bloodstream

The structure of the digestive tract is illustrated in Figure 1. When foods or drinks are swallowed, they pass from the mouth through the oesophagus into the stomach. Here they are mixed with acid and digestive enzymes and broken down into small fragments before passing into the small intestine through the pyloric sphincter.

The stomach is not very efficient at absorbing the molecules released from digested food and drink; instead these are mainly absorbed by the small intestine. Ethanol is therefore absorbed relatively slowly while it is in the stomach, and most (about 80%) is absorbed in the small intestine (Figure 1). Absorption of ethanol from the small intestine into the blood takes place by passive diffusion across the intestinal cell membranes.

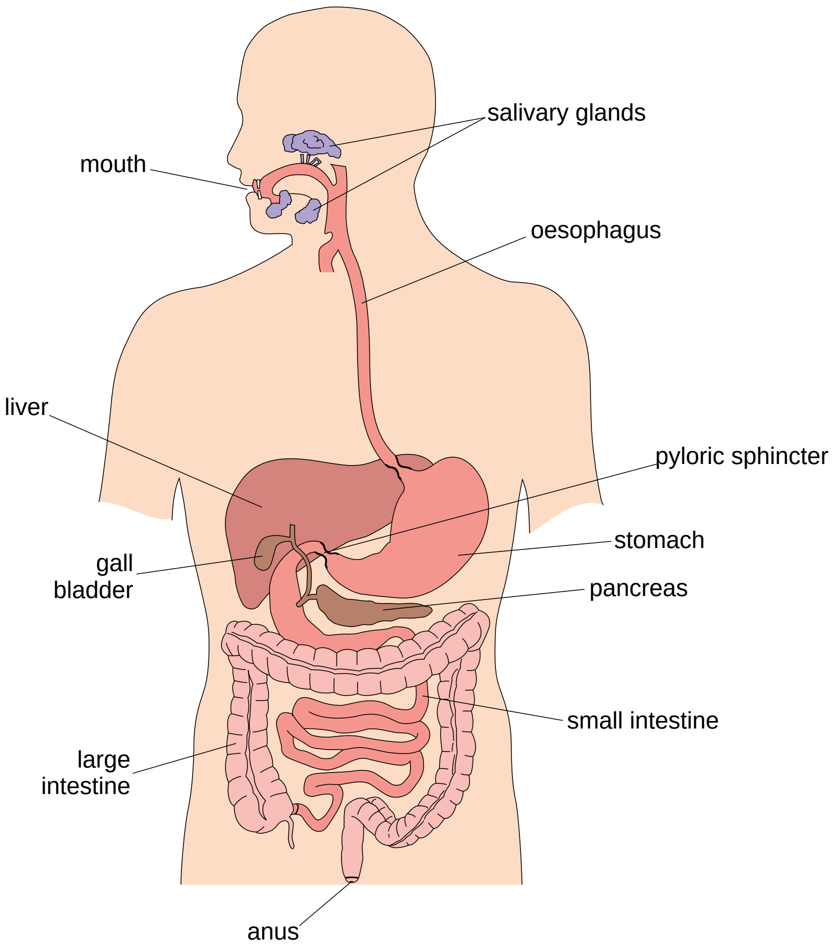


Figure 1 A schematic diagram of the digestive tract and associated organs that make up the digestive system

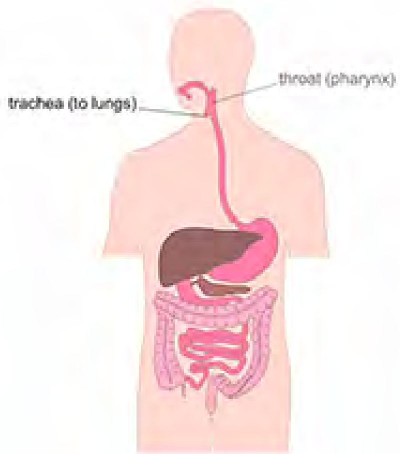
If the stomach is empty, the pyloric sphincter, which sits between the stomach and the small intestine, will be open. Consequently, if someone drinks alcohol on an empty stomach the ethanol passes straight through the open pyloric sphincter into the small intestine and hence is absorbed more rapidly.

- Would you expect the concentration of ethanol in the blood to rise more rapidly or more slowly if there is also food in the stomach?
- You would expect the concentration of ethanol in the blood to rise more slowly when there is food in the stomach. This is because the pyloric sphincter would be closed, so the ethanol mixed with the food would only be gradually released into the small intestine. The ethanol trapped in the stomach is absorbed only very slowly.

1.2 The journey of ethanol through the body

In this video you can see the journey of ethanol through the body, beginning in the mouth, passing down the oesophagus to enter the stomach and then into the small intestine where most of its absorption takes place. The video also illustrates the diffusion of ethanol molecules from the small intestine into adjacent blood capillaries which drain into the portal vein. This vein leads directly from the gut to the liver where some of the alcohol is converted into other molecules (you will learn more about this process shortly).

Video content is not available in this format.



As blood passes through the capillaries in the lungs, some of the ethanol molecules diffuse from the blood into the lungs. From the bloodstream, ethanol is able to diffuse into cells in all of the organs in the body. The rate at which ethanol leaves the blood and enters the organs is dependent upon how rich the blood supply is to the particular organ. Organs with a particularly rich blood supply include the brain and the lungs, so ethanol will tend to affect these organs sooner than others.

As it can diffuse freely, ethanol quickly becomes distributed throughout the water-based components of the body, that is, the blood and the cells of most tissues such as muscles and the brain. However, very little ethanol diffuses into the fatty tissue because ethanol is much more soluble in water than it is in fat.

Box 1 The breathalyser

A person suspected of drinking and driving is asked to blow into a detector device and the concentration of ethanol in this sample of exhaled air is measured and gives an estimate of the corresponding blood–alcohol concentration (BAC), that is how much alcohol is in the bloodstream. One way in which these devices operate is by using a chemical that undergoes a colour change in the presence of ethanol. Potassium dichromate undergoes a reaction with alcohol and, in so doing, it changes from orange to green, a colour change that can be measured quantitatively. You will see this reaction in Week 8 when you study some of the techniques scientists use to measure ethanol.

1.3 Ethanol metabolism

The liver is the key organ responsible for removing ethanol from the bloodstream. In fact, around 90% of the ethanol we ingest is converted into other chemicals as part of the metabolic chemical reactions that go on in the liver. Only about 10% is excreted unchanged in body fluids (mainly in breath and urine).

The liver receives three-quarters of its blood supply from the portal vein, which carries blood directly from the gut, and only one quarter from the general circulation (the oxygen-rich blood pumped out from the heart via the hepatic artery). This means that all of the blood from the portal vein, complete with any absorbed nutrients or other substances (ethanol, toxins, drugs etc), passes through the liver before reaching the general circulation. This means the liver gets first pass at processing foreign substances but it also means the liver is highly exposed to high concentrations of ethanol.

If you cast your mind back to Week 1, you saw the experiment showing the surprising amount of energy within the ethanol molecule. A very small amount was able to fire a homemade 'rocket' a considerable distance.

The body needs to be able to safely break down ethanol without such a violent release of energy. The human body does this in the liver through enzymatic breakdown of ethanol rather than combustion, in three stages:

1. Ethanol is converted to acetaldehyde. We can abbreviate this first conversion using the chemical formula:

   C_2H_5OH (ethanol) becomes CH_3CHO (acetaldehyde)
2. The acetaldehyde is then converted to acetic acid:

   CH_3CHO (acetaldehyde) becomes CH_3COOH (acetic acid)
3. The third step breaks the acetic acid down into carbon dioxide and water:

   CH_3COOH (acetic acid) becomes CO_2 (carbon dioxide) and H_2O (water).

If we look at this as one entire reaction, the overall breakdown of ethanol into carbon dioxide and water can be shown by the following unbalanced equation.

(Eqn 1)

- Can you balance this equation?
- A balanced version of this equation is:

- What is familiar about this equation?
- It is exactly the same as the reaction that occurs when ethanol is burnt in air. Unlike the combustion of ethanol in air which is a single fast reaction, the metabolism in the liver goes through the two intermediate stages of forming acetaldehyde and acetic acid.

This 'slow' breakdown is controlled by a series of enzymes. At this point, it would be useful to explain what an enzyme is.

1.3.1 Enzymes – biological catalysts

An enzyme is a protein molecule that has the ability to accelerate a particular chemical reaction in a cell, allowing it to take place at body temperature. An enzyme remains unchanged at the end of the reaction: in essence, a biological catalyst. In a cell, enzymes bind to their target molecules (substrate) and act to facilitate the chemical reaction for which they are responsible. During this process, enzyme–substrate complexes are formed. The enzyme-substrate complex then releases the product(s) of the reaction, in doing so reforming the active enzyme which can the move on to the next substrate molecules. The overall reaction between an enzyme and its substrate is illustrated in Figure 2.

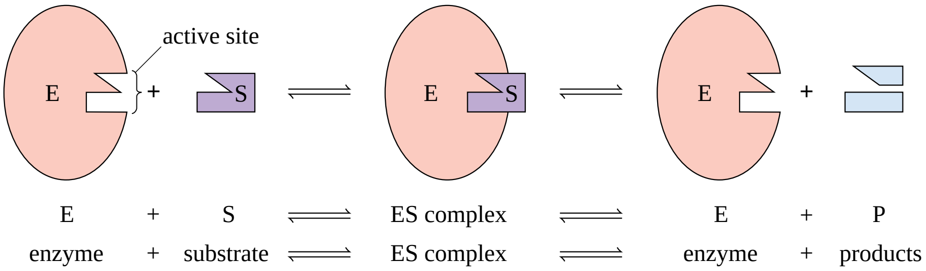


Figure 2 The reaction between an enzyme and its substrate

- Thinking back to Week 2 and the brewing process, in what steps are enzymes involved?
- Enzymes are important in the processes of malting and mashing, to convert the starch present in the barley into simple sugars which can be utilised by the yeast during the fermentation process. The yeast itself also has enzymes which are involved in the fermentation process when the sugars are used to produce alcohol.

In the cells of the liver, ethanol is first converted to acetaldehyde through a chemical reaction facilitated by a liver enzyme called alcohol dehydrogenase (ADH).

Acetaldehyde is a more toxic chemical than ethanol and, if it builds up in the bloodstream because of excess drinking, it causes people to feel very unwell, with symptoms such as vomiting, headache, rapid heartbeat and flushing (redness) of the skin of the face, neck and shoulders. However, acetaldehyde is not normally present in the body for very long because it is quickly converted by another liver enzyme called aldehyde dehydrogenase (ALDH) into acetic acid (a molecule which you may know better as the main component of vinegar), which is a non-toxic molecule in humans. Acetic acid is converted to a useful molecule called acetyl-CoA which then enters one of the body's regular biochemical cycles, for example in the process of aerobic respiration, to produce energy.

Box 2 Why is it some people can handle their drink better than others?

Individuals can have differing amounts of these enzymes in their body, but they can also have different versions of them as well. These different versions are called isoforms. Essentially, they are enzymes that are very similar to each other, but there are small differences in their structure that may affect the way in which they catalyse the reaction they are responsible for. The production of all proteins in the body – including enzymes – is controlled by genes, individual units of the inherited genetic material DNA. Everyone inherits from their parents a complete set of genes, including those that direct the production of the ADH and ALDH enzymes.

ADH exists in five different isoforms in the human population. Two of the five types of ADH metabolise ethanol to acetaldehyde more rapidly than the other three, resulting in the accumulation of higher amounts of acetaldehyde and making a drinker who possesses either of these forms feel uncomfortable more quickly – even a small amount of ethanol can make them feel very ill. These particular ‘fast acting’ isoforms of ADH are common in people of Asian origin, who therefore tend to accumulate high levels of acetaldehyde when they drink. More than 75% of Japanese people who drink report flushing (a redness of the face) compared to 5–10% of Caucasians. On the other hand, a positive effect of these unpleasant symptoms is that they help to protect people of Asian origin from developing alcohol use disorders.

In some people, irrespective of the isoform present, an insufficient amount of ADH is produced in the liver, and so such people will only be able to metabolize ethanol very slowly, causing the ethanol to remain in the system longer, thus prolonging intoxication. The level of ADH is also reduced as people get older.

The overall rate of ethanol metabolism depends on many factors, and the rate at which the blood–alcohol concentration (BAC) falls after drinking can range from less than 10 mg per 100 ml per hour to over 40 mg per 100 ml per hour for different people.

1.4 Ethanol excretion

You have already learned that 90% of ethanol is removed from the bloodstream via the liver, while the remaining 10% is lost elsewhere. Around half of ethanol is removed from the body in breath and most of the rest is excreted in urine. In order for this to happen it must first pass through the kidneys.

- Why is the loss by breath important?
- Ethanol vaporises easily. Not only can we smell alcohol on someone’s breath when they have consumed an alcoholic drink, but this vapour can also be measured. Given we know roughly how much percentage-wise can be lost through the lungs, a breathalyser can not only tell that somebody has been drinking but also suggest an amount that they have had. You will learn more about how a breathalyser works in Week 8.

The kidneys are responsible for excretion of waste substances from the blood through the production of urine. ‘Excretion’ specifically means the separation of waste products of metabolism from the blood (as distinct from ‘egestion’ which refers to the ejection of undigested waste from the digestive system).

Drinking alcoholic beverages has a familiar and characteristic effect on this process – the kidneys excrete more urine than would be predicted from the volume of liquid consumed, a phenomenon familiar to all alcohol drinkers! The performance of the kidneys and controlling the amount of water and other molecules that are excreted is regulated by a substance called antidiuretic hormone (ADH) which is sometimes also referred to as vasopressin. Ethanol inhibits the release of antidiuretic hormone, thus causing an increase in the amount of water that is lost in the urine. This in turn causes a disproportionate loss of water from the body leading to dehydration, a well-known acute effect of ethanol consumption, which in turn creates a thirst for more drinks!

1.5 Ethanol and the brain

Despite the fact that ethanol has been consumed for such a long part of human history its effects on the brain are actually quite poorly understood. The brain is a highly complex construction of cells, some of which are known as neurons. Neurons can talk to each other through specific chemicals called neurotransmitters which are used to pass signals from one neuron to another. These chemicals bind to specific proteins called receptors on neighbouring neurons.

- Think back to the properties of ethanol discussed in Week 1 – how does ethanol reach the cells of the brain so quickly after drinking an alcoholic drink?
- Ethanol is highly water-soluble. Given that the bloodstream has a high water content, this means it has a high solubility in the blood, meaning it can be transported rapidly to the cells of the brain.

Upon reaching the cells of the brain, the ethanol can potentially alter mental states, mood and behaviour by interacting with these neurotransmitter receptors. The overall effect of ethanol depends on the activity of the original neurotransmitter. For example, GABA (Gamma-Aminobutyric Acid) is a neurotransmitter that blocks impulses between nerve cells in the brain, and ethanol increases this blocking effect. Ethanol binding to GABA receptors is thought to be responsible for the sedative (sleep-inducing) effects of ethanol. However, the sleep induced by ethanol can be of poorer quality and shorter duration than normal sleep.

In contrast, a specific type of glutamate receptor, referred to as the NMDA receptor (N-methyl-D-aspartate), is known to be critical for learning and memory, and it is excitatory. Ethanol blocks glutamate from binding to NMDA receptors and this is thought to prevent the excitation that is required for learning and memory. This explains the amnesia (loss of memory) that can happen as a result of acute ethanol consumption.

To help consolidate your understanding of the acute actions of ethanol on glutamate and GABA, watch the video below.

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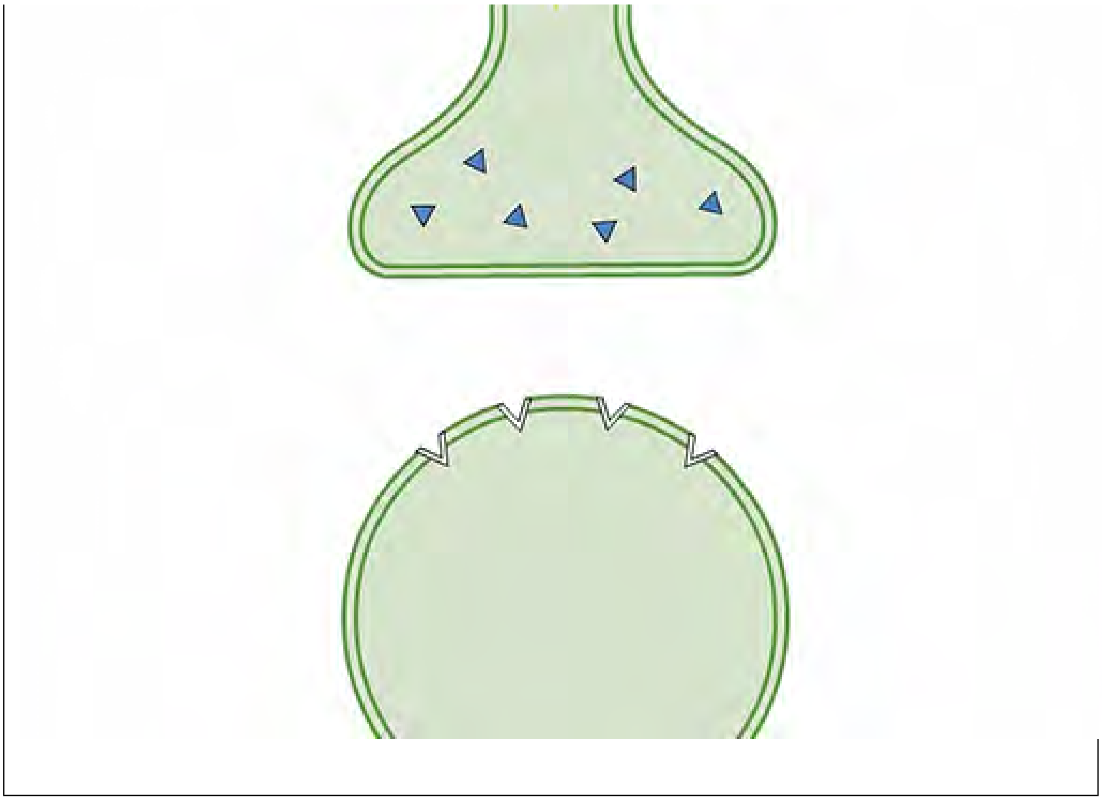


In addition to the effects of ethanol on GABA and glutamate, ethanol also affects another neurotransmitter called dopamine. Although dopamine's normal role is in the body's reward system, it is implicated in addiction. Ethanol increases the activity of neurons that release dopamine as their neurotransmitter – turning up communication by the brain's reward system. You will learn more about this in Week 7.

Overall, ethanol affects many different brain areas. The three which are of most interest to us in this week are shown in Figure 3.

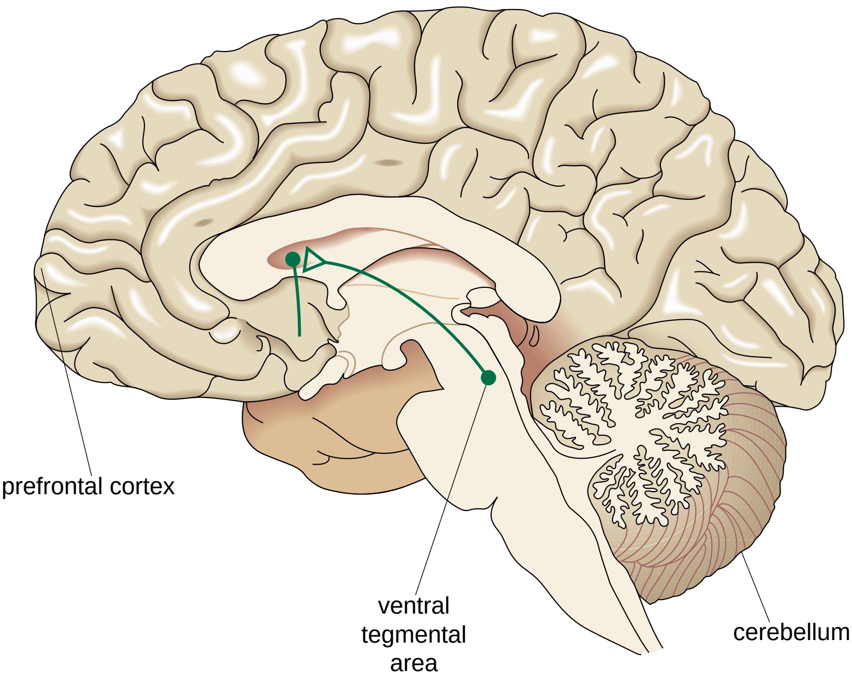


Figure 3 Brain regions of particular interest when studying the effects of ethanol

The region towards the back of the brain, called the cerebellum,is vital in motor coordination, including the ability to balance. Ethanol affects the function of the cerebellum and can disrupt co-ordination. For example, alcohol consumption makes it harder to walk in a straight line and also makes it dangerous to drive a car. The latter is because co-ordination, including that required to react to an obstacle by braking or steering away, is impaired.

In the middle of the brain is a region called the ventral tegmental area (VTA). This region contains neurons that release dopamine into the prefrontal cortex (PFC), which is at the front of the brain. The neurons within the PFC are associated with self-control and restraint. Moderate doses of ethanol selectively depress the activity of these neurons and so people who are intoxicated with ethanol are less restrained. This lack of restraint explains ethanol's effectiveness as a 'social lubricant', but it can also have negative consequences for behaviour.

The lack of restraint induced by ethanol consumption is part of a broader behaviour called alcohol myopia. Myopia means literally 'short-sightedness'. By analogy with the visual impairment, the term 'alcohol myopia' refers to alcohol's ability to induce a 'psychological short-sightedness'. It biases an individual's attention towards their immediate needs and desires and against considering more remote events or the consequences of their actions.

2 What is a hangover?

Ethanol can have both acute (short duration) and chronic (persisting for a long time or constantly recurring) effects on the body. You will look at the chronic effects in Week 7. The acute effects increase as more alcohol is consumed, and are short-lived. These effects arise through the immediate actions of ethanol on different parts of the body.

For example, ethanol has the effect of irritating the stomach and intestinal lining which can result in inflammation of these areas. Ethanol also increases the production of gastric acid and intestinal secretions, and the after-effects of these processes include abdominal pain, nausea and vomiting, all of which can be associated with hangovers. A hangover is the term used to describe the collection of signs and symptoms that someone usually experiences on the day following a heavy drinking session.

- Can you list some typical signs and symptoms of a hangover?
- The causes of a hangover are not well understood, but typical signs and symptoms are: headache, nausea, dry mouth and thirst, flushing on the skin, abdominal pain, diarrhoea, anorexia (lack of appetite), tremor (dizziness), fatigue and a poor sense of well-being.

Some of these are related to dehydration. An imbalance in electrolytes (your body's salt levels) is generated which has knock-on effects causing nausea, dizziness, dry mouth, high levels of thirst and fatigue. Alterations in salt and water levels can lead to diarrhoea as the body adjusts to the environment.

Fatigue is also caused by a decrease in blood sugar levels. At its most severe, hypoglycaemia can lead to a coma state and death, similar to a diabetic situation. Sadly, while drinking a lot of water can help with these symptoms they will not fully stop the effects.

- What was the product of the first enzymatic reaction for the breakdown of ethanol in the liver?
- In the first enzymatic reaction in the liver, ethanol forms acetaldehyde.

Acetaldehyde is significantly toxic itself and, combined with the genetic factors you briefly read about earlier, its concentration can be elevated in the bloodstream for a significant amount of time. This causes the flushing of the skin (redness). It can also cause cellular stress by affecting a number of other receptors in cells.

Ethanol also has an effect on a group of chemicals in the body called cytokines. These play a highly important part in cell signalling (how cells talk to each other) and the immune system. Alcohol causes changes in their concentration with some of these compounds exhibiting higher levels. These have been implicated in nausea, headache and fatigue as the immune system is activated.

In addition to ethanol, a significant number of alcoholic beverages contain congeners. These are substances produced during the production process that contribute to the taste and smell of a drink. These are a mix of small organic compounds, some of which are harmless, but others such as methanol are highly toxic. Methanol (CH_3OH) breaks down in a similar fashion to ethanol in the body but the products of this reaction are highly toxic (formaldehyde and formic acid). Congeners have been shown to mitigate or aggravate the hangover effect.

- Which do you think has more congeners in? Whisky or vodka?
- Whisky has significant amounts of congeners, which aid with the complex taste and smell that is associated with these drinks, whereas the clear vodka has hardly any, hence its ‘pure’ status among beverages.

Several scientific studies have explored the severity of hangovers with respect to the type of alcohol consumed. It is considered that dark drinks (such as whisky, dark rum, red wine, ale) will give a greater hangover than clear ones (vodka, gin, white wine, lager). One such study found an average of fourteen standard units of beer was needed to produce a hangover, but only seven to eight units was required for wine or liquor.

2.1 A hangover cure? You wish!

You have probably heard of (or even tried!) various treatments that are reputed to alleviate the symptoms of a hangover.

Activity 1 Hangover cures

Allow about 5 minutes

Make a list of some of the so-called hangover cures you are aware of.

Provide your answer...

Discussion

You may have listed some of the following – drinking water or coffee, sleeping, eating carbohydrate rich food, taking pain killers for a headache.

While many of these remedies have not been subject to systematic scientific testing, some are likely to be partly effective based on what is known about hangover physiology:

- Consumption of food containing the sugar fructose, such as fruit or fruit juices, or bland food rich in carbohydrates, may help to counter symptoms arising from low blood sugar.
- Sleeping is likely to relieve symptoms associated with fatigue. This gives the body a chance to direct energy towards metabolic functions (sleep it off).
- Drinking copious volumes of water reduces dehydration. As you have seen, this will help with the diuretic issues but it cannot clear all symptoms.
- Anti-inflammatory drugs such as aspirin or ibuprofen are commonly used to relieve the symptoms of headache. This helps respond to the increased cytokine levels, reducing the inflammation. However, there is a risk that since they can irritate the gut lining they might compound ethanol-induced stomach disturbances.
- Caffeine is traditionally widely used and may counteract tiredness but it will have no effect on the chemical imbalances in the body.
- Run it off. Some studies suggest that exercise will help. In principle, increasing metabolic function and blood flow will aid but this has to be weighed against the nausea and other delicate symptoms.

A famous belief is that the further consumption of alcohol known as ‘the hair of the dog (that bit you)’ will relieve symptoms. This may hold true in a way in that ethanol is metabolised before some congeners such as methanol (hence alleviating the effects of the associated toxicity), but effectively this just postpones the symptoms until later.

3 Your homebrew experiment

Your homebrew experiment should be over half way complete at this stage – you may wish to repeat the hydrometer readings from Week 4 to check on its progress, but otherwise you will return to your homebrew experiment in Week 8 to check the final alcohol content.

4 This week's quiz

Well done - you have reached the end of Week 5 and can now do the quiz to test your learning,

Week 5 practice quiz

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click the link. Return here when you have finished.

5 Summary of Week 5

In this week you have learned how ethanol travels through the body and is eventually removed by metabolic processing. You have also studied some of its effects on different organs of the body, including the brain, and briefly looked at acute signs and symptoms of ethanol on the human body overall.

You should now be able to:

- describe the process by which the ethanol molecule (alcohol) is broken down by the body
- explain how the body reacts to the presence of alcohol and why it dulls the senses
- discuss the reasons for a hangover and what is the 'best' way to get rid of one.

Next week you will return to the brewing process and consider the wider issues associated with scaling up commercial beer production. You will also look in more detail at how alcohol is removed from beer – so one definite way to drink beer and ensure you are not the recipient of a hangover the following day!

You can now go to Week 6.

Week 6: Distillation and spirits

Introduction

This week you will read about how spirits such as gin are produced.

You will look at the importance of the industry in historical and economic terms, setting the context for this week. You will then be introduced to the distillation process which is used to produce beverages which contain much higher amounts of alcohol than beer – a typical gin, for example, is around 40% alcohol by volume.

You will explore a gin distillery, as you did the brewery earlier in the course, and learn how the flavours are infused into the drink. You will also be introduced to the botanicals used to give gin its unique flavours and further explore the chemistry of taste and smell.

By the end of this week, you will be able to:

- discuss the economic and historical importance of spirits
- explain the process of distillation and how it is used to produce alcoholic drinks
- explain the process by which drinks such as gin are made
- describe how natural flavours and botanicals are used to produce the unique tastes in the gin industry

- describe where the futures of both the brewing and distillery industries may be heading.

1 The historical significance of gin

The name gin is derived from either the French *genièvre* or the Dutch *jenever*, which both mean ‘juniper’. As you will learn in this week’s study, the juniper berry is the predominant component of gin.

Gin is, without a doubt, one of the most popular and widely consumed spirits. In fact, Franciscus Sylvius, a Dutch physician and scientist, is often credited with its discovery in the seventeeth century, although references to gin exist as far back as the eleventh century.

By the eleventh century, Italian monks were flavouring crudely distilled spirits with juniper berries. During the Black Death in the mid to late fourteenth century this spirit was used, although ineffectively, as a remedy. As the science of distillation advanced from the Middle Ages into the Renaissance period, juniper was one of many botanicals employed by virtue of its perfume, flavour, and suspected medicinal properties. Sylvius himself originally conceived it as a remedy for the treatment of kidney ailments, lumbago, stomach ailments, gallstones and gout.

However, gin started to increase in popularity as a recreational drink in England after the Government allowed unlicensed gin production and at the same time imposed a heavy duty on all imported spirits. As a result, thousands of gin shops sprang up throughout England in a period known as the Gin Craze in the first half of the eighteenth century. Due to its popularity, gin was blamed for various social problems as depicted by William Hogarth in his ‘Gin Lane’ illustration (Figure 1).

Figure 1 A representation of ‘Gin Lane’ by William Hogarth (1751)

This negative reputation survives today in the English language in terms like ‘mother’s ruin’, a common British name for gin. Paradoxically, the negative connotations are now becoming associated with positive connotations – with the resurgence in the popularity of gin, upmarket bars now frequently refer to ‘mother’s ruin’, where printed copies of Hogarth paintings may also sometimes be found.

2 Types of gin

A visit to the spirits aisle in your local supermarket will no doubt reveal a variety of different gins. But how do these types of gin differ from each other?

There are three fundamental types of gin:

- distilled gin
- London Dry Gin
- flavoured gin.

You will now look at each of these in turn.

Definition of gin

The legal EU definition of gin means that a drink must be a juniper-dominated spirit, with an agricultural origin and at least 37.5% alcohol by volume (ABV). You will learn about how the strength of an alcoholic drink is measured by volume in Week 8.

So, for a substance to be classed as gin, the main natural flavouring (known as a botanical) must be juniper, the base alcohol must be made from something natural such as wheat, barley, rye, molasses, potatoes or grapes, and there must be at least 37.5% of pure alcohol in the total volume of liquid.

Distilled gin

Distilled gin is the first of our three types of gin and is produced exclusively by redistilling ethanol of agricultural origin with an initial strength of 96% ABV in the presence of juniper berries and of other natural botanicals, provided that the juniper taste is predominant. Gin obtained simply by adding essences or flavourings to ethanol of agricultural origin is not distilled gin. You will learn more about this distillation process later in this week's study.

London Dry Gin

London Dry Gin is the second of our three types of gin. This type of gin is not exclusive to London geographically but simply refers to a gin which is deemed to be the highest-quality gin you can produce. It has to comprise only natural ingredients, be made with high-quality alcohol and only contain 0.01 g of sugar per litre of alcohol. London gin is distilled with botanicals to get the flavour, and no artificial flavourings or additives can be added after distillation. London Dry Gin and regular distilled gin are essentially made in the same way, except for one significant difference – distilled gin can have any flavourings added to it after the distillation process.

You may recall seeing bottles of Plymouth Gin on the supermarket shelves – this was essentially London Dry Gin but was manufactured exclusively in Plymouth up until 2014. This type of gin has now essentially been rebranded as London Dry Gin.

Flavoured gins

A visit to the supermarket shelves in the gin aisle will also likely reveal a variety of so-called ‘flavoured’ gins. Strictly speaking, these do not represent a separate type of gin as such, since some flavoured gins simply add additional flavours to the gin post-distillation. Examples of readily available flavoured gins include rhubarb, raspberry, lemon and even chocolate flavoured gins.

At this point, it is also worth mentioning sloe gin. Despite the name, sloe gin isn’t actually a gin but a liqueur. This is because the ABV is in the range 20–25%, well below the minimum requirement of a spirit. Sloe gin also tends to have a much higher sugar content than is permitted in a London Dry Gin.

3 The process of distillation

As you have just discovered, the process of distillation is fundamental for the production of gin. Distillation is an example of a chemical process that is commonly utilised both in a laboratory setting and also on massive industrial scales – such as for gin production!

By definition, distillation is a process that exploits differences in the volatility of the components of a mixture. It is widely used both on a laboratory and an industrial scale to separate the components from a liquid mixture by selective boiling and condensation. Different components of a mixture have different boiling points, and it is these differences which enable the process of distillation to perform the separation.

So, distillation may be applied for the complete separation of pure components, or for partial separation to control the concentration of selected components within the mixture.

A typical apparatus set-up is illustrated in Figure 2.

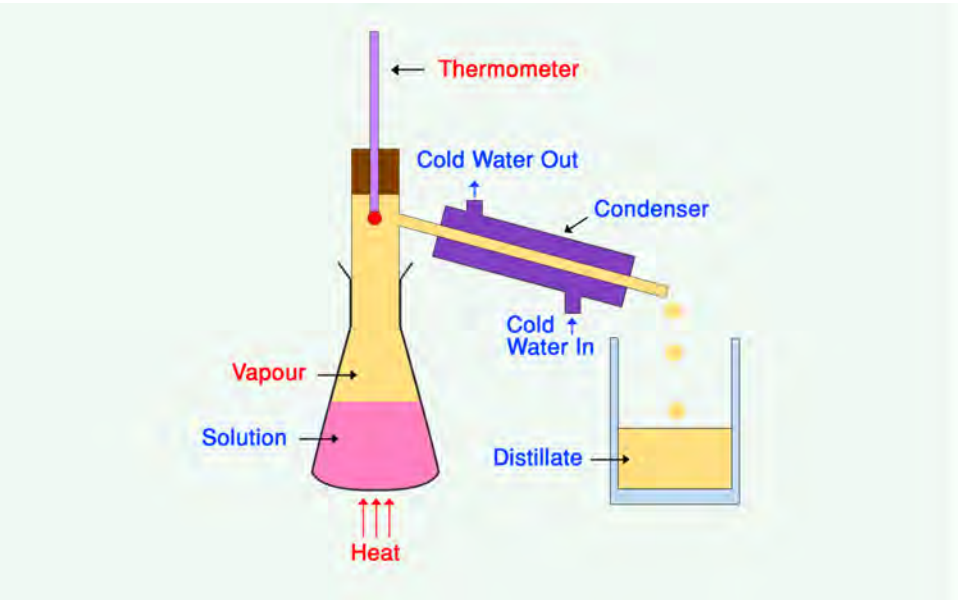


Figure 2 A simple laboratory distillation set-up

Distillation is commonly used to separate ethanol – the alcohol in alcoholic drinks – from water. An example of such a distillation is illustrated in the following video on a laboratory scale.

Video content is not available in this format.

Considering what you have observed in the video, answer the following questions.

- In a mixture of ethanol and water, which will evaporate first upon heating from room temperature?
- Ethanol has a lower boiling point than water, so it evaporates first. The ethanol vapour is then cooled and condensed inside the condenser to form a pure liquid known as the distillate.

- How do you know when it is ethanol that is boiling in the distillation process?
- Assuming you know that the boiling point of water is 100°C, and you know that the solution contains only ethanol and water, when you start to see the distillate collecting in the receiving flask, you can read the temperature corresponding to the boiling point of this substance from the thermometer. If this temperature is lower than 100°C then the distillate must be something other than pure water, in this case it will be the ethanol.

- Arrange the following stages into the order in which they occur during the distillation process: condensation, evaporation, heating, cooling
- Heating – evaporation – cooling – condensation.

Distillation of alcohol can be done anywhere, whether it's in the home or a laboratory, but in most countries it is illegal to distil alcohol without a licence. You may have heard illegally-distilled alcoholic drinks referred to as 'moonshine'. You will learn more about counterfeit alcohol in Week 8.

4 Exploring a working distillery

The Cotswold Distillery located in the Cotswold village of Shipston-on-Stour has been producing gin and whisky commercially on a small scale since 2014 using the process of distillation (Figure 3).

Figure 3 The Cotswold Distillery, Shipston-on-Stour

In the following video, distiller Sarah MacLellan from the Cotswold Distillery explains the distilling process used to produce their unique gin.

Video content is not available in this format.

- Looking back to our laboratory-scale distillation, can you make a list of the similarities between the two processes, despite their obvious differences in scale?
- The basic principle of distillation remains the same, whether the distillation is occurring on a laboratory or on a commercial scale. At a temperature corresponding to the boiling point of ethanol (78 °C) the distillate is collected for conversion into the final gin product. A similar apparatus is used for the distillation, for example a water-cooled condenser to condense the vapour back into the liquid phase again.

The process of gin distillation is actually far simpler than you may think and, although different distilleries will have different production methods for their own specific gins, the process starts off in the same way.

Gin always starts from a blank canvas – a completely flavourless base spirit, typically around 96% ABV in strength. This is known as neutral grain spirit.

Different distilleries will distil this base spirit in the presence of a closely guarded recipe of botanicals to produce their own unique products.

Typically, distillation will occur within a copper still (Figure 4). The copper itself actually plays a number of important roles in the distillation process. The copper is an excellent conductor of heat and it disperses the heat evenly over the surface of the still, allowing the distillation process to be very efficient. But the copper is also thought to strip out any volatile sulfuric compounds which are produced as the gin distils, a process which removes any unwanted flavours and aromas from the final product.

Figure 4 The Cotswold Distillery's copper still

So, during the distillation process, with this ability of copper in mind, the still is only filled to three-quarters capacity to ensure that there is sufficient space for the volatile vapours to have plenty of contact with the copper during distillation. The base botanicals are then added – the all-important juniper berries, coriander seed and angelica root – and these macerate (soften) for fifteen hours overnight. It is important that the botanicals are not 'cooked' and are instead allowed to infuse into the neutral grain spirit. The following morning the remainder of the botanicals are added.

You will now learn about how unique flavours and aromas are incorporated into specific gins.

5 Natural flavours in gin

Apart from water and ethanol, the only other raw materials used for distilled gin-making are natural flavourings referred to as botanicals. The predominant flavour is always juniper (Figure 5), but this is complemented by a wide range of other botanicals, as you will see.

Figure 5 The juniper berry, the predominant flavour of gin

The ethanol is able to draw out the flavour of many different oils of the juniper berries. The exact flavour molecules, and especially their proportions, vary between juniper species and can also depend upon where the juniper grew, which has an obvious knock-on effect on how the berries taste and smell. Gin producers often, therefore, have favourite farmers from whom they directly source their entire juniper – and other botanicals – supply.

5.1 The chemistry of the juniper berry

A class of organic compounds commonly found in the juniper berry is known as the monoterpenes. By definition, the monoterpenes represent a large group of volatile compounds found in the essential oils of plants, especially conifers and citrus trees. They are based on a cyclic molecule having the formula $C_{10}H_{16}$.

Examples of such monoterpene compounds present in the juniper berry which contribute to the flavour of the gin include: α (alpha)-pinene, β (beta)-myrcene, limonene, terpinene, para-cymene and sabinene. The structures of each of these are illustrated, together with the tastes they impart, in Figure 6. In Week 3 you learned about how different compounds manifest different taste sensations, so you may wish to go back and revisit that section for a reminder of how your body interprets the flavours imparted by different compounds.

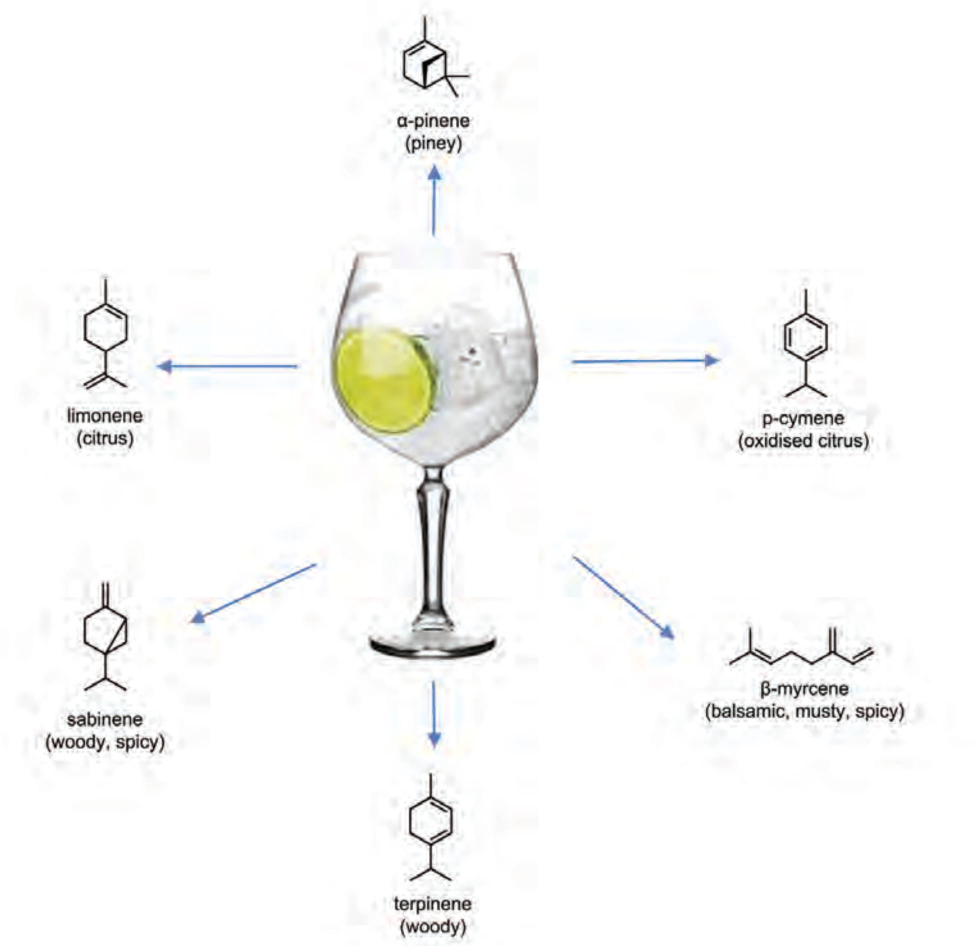


Figure 6 Some predominant flavours in the juniper berry contributing to the taste of gin

5.2 Other botanical flavourings

The juniper in gin can be complemented by a wide range of other botanicals to bring many more flavour molecules into the mix. Different distillers use different mixtures of botanicals to flavour their gin and these recipes are closely guarded secrets by each distillery!

There are potentially hundreds of different botanicals which could be added to gin but one of the more common botanicals may surprise you. Coriander seeds, more usually associated with Indian cuisine, are commonly added to many gin formulations.

A compound known as linalool (Figure 7a) is the major component of coriander seed essential oil and is one of the most volatile components of gin to which coriander seeds have been added. Linalool imparts a woody, spicy tone to the gin. Geranyl acetate (Figure 7b) is another coriander-derived compound often found in gin and is used to give a more floral aroma and taste. Other compounds, such as polyphenols, for example, impart a citrus flavour into the gin from the coriander seed.

Figure 7 Coriander-derived (a) linalool and (b) geranyl acetate flavourings

- What do you notice about the structure of linalool?
- Linalool possesses an −OH functional group and hence, like ethanol, is an example of an alcohol.

Other botanicals that are used in some varieties of gin include anise, angelica, almonds, cinnamon, cassia root and nutmeg, amongst many others. All of these can add their own flavour compounds to the mixture, resulting in a complex cocktail of flavours. Like most other alcoholic beverages, no single brand of gin will have the same chemical composition as another. The Cotswold Distillery uses coriander seed, angelica root, lavender, bay leaf, hand-peeled fresh lime, pink grapefruit zest, cardamom and black peppercorn in their copper still to formulate their unique gin. Next, you will learn a little more about why this is – bearing in mind of course that the exact recipe used by the Cotswold Distillery is a closely guarded secret!

5.3 Taste sensations in gin

As you have just learned, gin can contain a whole variety of compounds, all of which are capable of imparting a particular taste to the final product. Thinking about the combination of flavourings is where the taste sensation gets a bit more complicated. The taste of the final gin will not just be the sum of its component parts. Instead, it will be a reflection of how the different botanicals interact with each other. Attractions between similar flavour molecules influence how each of them interacts with the flavour receptors in your body. Furthermore, this can be complicated by competition between different flavours for the same taste receptor.

It is not just different flavours interacting and competing with each other which contribute to the overall taste imparted by the gin. Those same molecules interacting within the water and ethanol of the freshly distilled gin can also prevent them from interacting so strongly with your taste receptors and this will limit the taste experienced by the drinker. Adding mixers to your gin also changes the way it tastes for the same reasons. In tonic water, for example, quinine is attracted to a number of the flavour molecules in gin. The aggregates of flavour molecules create a taste sensation that is completely different from just gin or tonic on its own.

Sarah MacLellan from the Cotswold Distillery will now tell you about how the different flavours within their gin interact with each other, but also with mixers such as tonic water.

Video content is not available in this format.

This all explains why gin formulation is such an exact science. It is not possible to simply decide what flavours you would like in your gin and mix them together. Formulating a new gin can be a very lengthy process demanding exact combinations of specific botanicals in specific quantities to give the taste sensation desired – and this explains why gin distilleries guard their formulations so closely!

Sarah MacLellan from the Cotswold Distillery will now tell you about how the final taste of their gin is derived from their unique combination of botanicals.

Video content is not available in this format.

6 The stages of gin production

The process used to produce gin is relatively simple (in comparison to the brewing process you met in Weeks 2 and 4) – and is based mostly on the fundamentals of distillation that you met earlier this week.

6.1 Commercial distillation

Once the addition of the botanicals is complete, the actual distillation begins within the copper still (Figure 4). The still is heated to a sufficient temperature to start boiling. If you recall from our laboratory still earlier, once a sufficient temperature is reached to enable a single component of the mixture to boil, this component alone boils, evaporates and condenses. In doing so, it is separated from the remainder of the mixture which has not yet reached boiling temperature.

The same principle is operating here in the production of gin, but on a much larger scale. Initially when the still is heated, the first distillate to appear is called the 'heads' of the run – it is quite harsh and astringent and often contains impurities so it is discarded.

The middle or 'hearts' of the run is the only distillate that is used by the distillery to produce their gin and it is carefully collected. A drop in the % ABV is usually an indication of the end of the hearts component of the distillation.

The final section of the run is the 'tails', and this is also discarded. By being selective in this way, only the finest part of the run makes it into the final gin. This does, however, mean that only small quantities of gin can be produced from a single distillation run, but the quality of this gin will be superior.

- At what temperature do you think the hearts of the run distils?
- As the distillate is composed primarily of ethanol, this will boil at a temperature of around 78°C.

6.2 Producing the final gin – the final taste

The hearts, which are at 83% ABV, are then rested for five days to allow the various flavours to come together and settle. The very last stage in the gin production process is to reduce the alcohol content. To do this, filtered water is added to reduce the strength to the Cotswold Distillery-desired ABV of 46%. The gin is then bottled in-house at the distillery.

Commercially, this is known as 'single-shot distillation' and results in the best possible flavour and quality of the final product. Some larger-scale distilleries produce gin for the mass market by adding more neutral grain spirit to the distilled batch to increase the number of bottles made from each run.

Some gin distilleries chill-filter their gin in order to remove oils and esters to make sure the gin stays crystal clear. The Cotswold Distillery leaves their gin unfiltered as they believe that this imparts a specific flavour into their gin. In this next video from the distillery, Sarah MacLellan describes how the Cotswold Distillery aims to produce a gin that can be taken neat, without the need for any additional mixers.

Video content is not available in this format.

- According to the Cotswold Distillery, why can their gin be drunk neat without the need for any mixer?
- The high purity of the raw starting materials used in the Cotswold gin means that higher quality spirits can be made which do not require a mixer.

7 The future of distillation and the gin industry

In this final video from the Cotswold Distillery, Sarah MacLellan talks about the development of the gin industry and where the future of distilling may be heading.

Video content is not available in this format.

- Thinking back to the end of Week 4 and James Clarke's opinion on the future of the brewing industry, can you see any similarities with the gin industry here?
- Both James Clarke from Hook Norton and Sarah MacLellan from the Cotswold Distillery agree that it is consumer demand which is driving the development of both industries. Consumers are continuously looking for novel products in a market with increasing competition between breweries and distilleries. Keeping up to date with consumer demand and changes in the market are key to remaining at the forefront of their respective industries.

8 Your homebrew experiment

Your homebrew experiment should be well over half way complete at this stage – you may wish to repeat the hydrometer readings from Week 4 to check on its progress, but otherwise you will return to your homebrew experiment in Week 8 to check the final alcohol content. However for any scientific experiment it is always good practice to keep an eye on your apparatus and keep a note of any observed changes as they occur – so for example any changes to the colour or appearance of the brewing beer, along with the date and times these are observed.

9 This week's quiz

Well done – you have reached the end of Week 6 and can now do the quiz to test your learning,

Week 6 practice quiz

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click the link. Return here when you have finished.

10 Summary of Week 6

During this week of study, you have been introduced to the process of distillation and how this is used on an industrial scale to produce gin. You will have seen that, although different products are obtained in both brewing and distillation, there are some similarities between the two processes. For example, the nature of the raw materials used very much influences the nature of the final product.

You should now be able to:

- discuss the economic and historical importance of spirits
- explain the process of distillation and how it is used to produce alcoholic drinks
- explain the process by which drinks such as gin are made
- describe how natural flavours and botanicals are used to produce the unique tastes in the gin industry
- describe where the futures of both the brewing and distillery industries may be heading.

Next week you are going to return to the impact alcohol can have on human health. In Week 5 you learned about the *short*-term effects of excessive alcohol consumption. In Week 7, you will see the *longer*-term effects of consuming excessive alcohol.

You can now go to Week 7.

Week 7: The long-term effects of alcohol consumption

1 Calculating alcohol consumption

In 1989, the UK's leading alcohol producers formed the Portman Group to:

- promote responsible drinking
- help prevent alcohol misuse, and
- foster a balanced understanding of alcohol-related issues.

In the early 2000s, they established the Drinkaware campaign which gives comprehensive, online advice to the public on responsible drinking. Since then, the website (www.drinkaware.co.uk) has been widely promoted by the industry on drinks packaging and advertisements, leading to it becoming the primary source of sensible drinking information for consumers.

One of the challenges for consumers is to identify exactly how much alcohol they are drinking.

Activity 1 Calculating your alcohol consumption

Allow about 5 minutes

Think about the alcohol you have consumed over the past week. Are you able to record how much you have consumed? If you don't consume alcohol yourself you could always ask a friend or colleague to do this for you. Write down any difficulties you can think of that could be associated with calculating how much alcohol you (or anyone else) consumes?

Provide your answer...

Discussion

There are a number of reasons why it is difficult to measure the amount of alcohol that people consume. Some possible reasons are:

- The concentration (strength) of alcohol varies between different types of drink and few people are aware of the difference. Does a glass of red wine contain more or less alcohol than the same volume of vodka?
- How have you recorded the amount of alcohol consumed? Have you recorded number of glasses, pints, or approximate volumes of spirits added to a mixer? Are you sure about the exact amount of spirit added to a drink served at home (as opposed to a fixed measure of spirits dispensed via an optic)?
- The standard volume of a 'drink' varies between types of drink and between countries. How does the alcohol content of an English pint of real ale compare with a half-litre of German lager? Or an American 'ounce' or a British 'gill' of spirits? In Australia, beer is sold by the pint (US 16 fl oz instead of the imperial UK 20 fl oz), called the 'schooner' or a 'pot'. It can be quite confusing.
- Different ways of referring to the amount of alcohol in a drink can also make comparison difficult. For example, wine, beer and spirit labels usually give the alcohol content as a percentage of the liquid in the bottle. 'Drink safely' advice generally refers to units of alcohol defined in terms of 'a glass of wine' or a 'half-pint of beer' or a 'measure of spirits'. Other units of measurement include grams per day, although this is less common.

Simply asking people to estimate how much alcohol they drink in (say) a typical week often produces inaccurate results. When drinks are poured at home, the measure is usually uncontrolled so estimates of total consumption tend to be even more inaccurate.

Figure 1 shows red wine being poured into three different sizes of wine glass – how would you know how many units of alcohol are present in each one?

Figure 1 Glasses containing 125 ml, 175 ml and 250 ml of wine respectively – the standard volumes of wine sold in UK bars and restaurants. How would you know how many units of alcohol are in each?

Population surveys consistently find that drinkers' own estimates of the total amount consumed account for only 40–60 per cent of the alcohol sold. People who drink a lot of alcohol may claim they drink less when asked because excessive drinking is disapproved of in some societies. Conversely, some individuals may exaggerate their drinking because it carries high status among their peers.

The pattern of alcohol consumption is even more important than the total amount consumed in terms of the impact on health. For example, drinking while eating seems to result in less harm to health than drinking at other times. Drinking large amounts in one go – particularly of spirits such as whisky or vodka – also has a much higher health risk than drinking the same quantity of alcohol in a more dilute form (e.g. beer or wine) in smaller amounts spread over several days. So-called 'binge drinking' of large amounts of alcohol, as illustrated in Figure 2, is linked to an increase in the risk of injuries and cardiovascular diseases.

Figure 2 A representation of ‘binge drinking’

Any protective effects of low-risk drinking patterns are completely lost if someone engages in a heavy drinking episode at least once a month – even if the average level of alcohol consumption is low. A heavy drinking episode is defined by the World Health Organisation as consumption of more than 60 g of pure alcohol on at least one single occasion a month (see the article Heavy episodic drinking among drinkers from the WHO).

However, of all these, you may be most familiar with guidelines for alcohol consumption described in terms of the number of units of alcohol. The next section explains what these units are and how they relate to grams and millilitres of alcohol.

1.1 Units of alcohol

A unit of alcohol is a measure of the volume of pure alcohol contained in an alcoholic drink. In the UK, one unit of alcohol is equivalent to 10 ml of pure alcohol, regardless of what type of drink is involved. Table 1 gives some examples of drinks and the approximate number of UK units of alcohol they contain.

Table 1 Number of units of alcohol in common alcoholic drinks in the UK, where 1 unit equals 10 ml of pure alcohol.

A pint of ordinary strength lager (4% ABV)	2 units
A pint of strong lager (5.5% ABV)	3 units
A pint of ordinary bitter (4% ABV)	2 units
A pint of best bitter (5.2% ABV)	3 units
A pint of ordinary strength cider (5% ABV)	2 units
A pint of strong cider (5.2% ABV)	3 units
A 175 ml glass of red or white wine (12% ABV)	~ 2 units

A pub measure (optic) of spirits (25 ml)	1 unit
An alcopop	~ 1.5 units

In the early 1990s, the UK Government recommended that men should not drink more than 21 units per week while women should not drink more than 14 units per week.

However, after the initial guidance was provided, it quickly became apparent that many people were not distributing this consumption equally throughout the week and, as you have seen, this can be harmful. Therefore, more recent (2014) advice recommends a maximum number of units of alcohol per day. For men, this is 3–4 units of their weekly maximum of 21 units and, for women, this is 2–3 units of their maximum of 14 units per week.

In 2016, new guidance was issued by the Department of Health. The Chief Medical Officers' guideline for **both** men and women states that:

> To keep health risks from alcohol to a low level it is safest not to drink more than 14 units a week on a regular basis
>
> If you regularly drink as much as 14 units per week, it's best to spread your drinking evenly over three or more days. If you have one or two heavy drinking episodes a week, you increase your risk of long-term illness and injury.

Even with this guidance, it still remains a challenge for individuals to calculate the number of units they are drinking, even if they consider it a valuable exercise to keep track.

The Portman Group has a code of practice stating that a product must have the following labelling on it to promote responsibility:

- unit alcohol content per container (and optionally per typical serving)
- pregnancy logo and message – to alert drinkers to the dangers of drinking while pregnant
- active signposting to the Drinkaware website.

The labelling used by the Cotswold Distillery on the reverse of their gin bottles is illustrated in Figure 3.

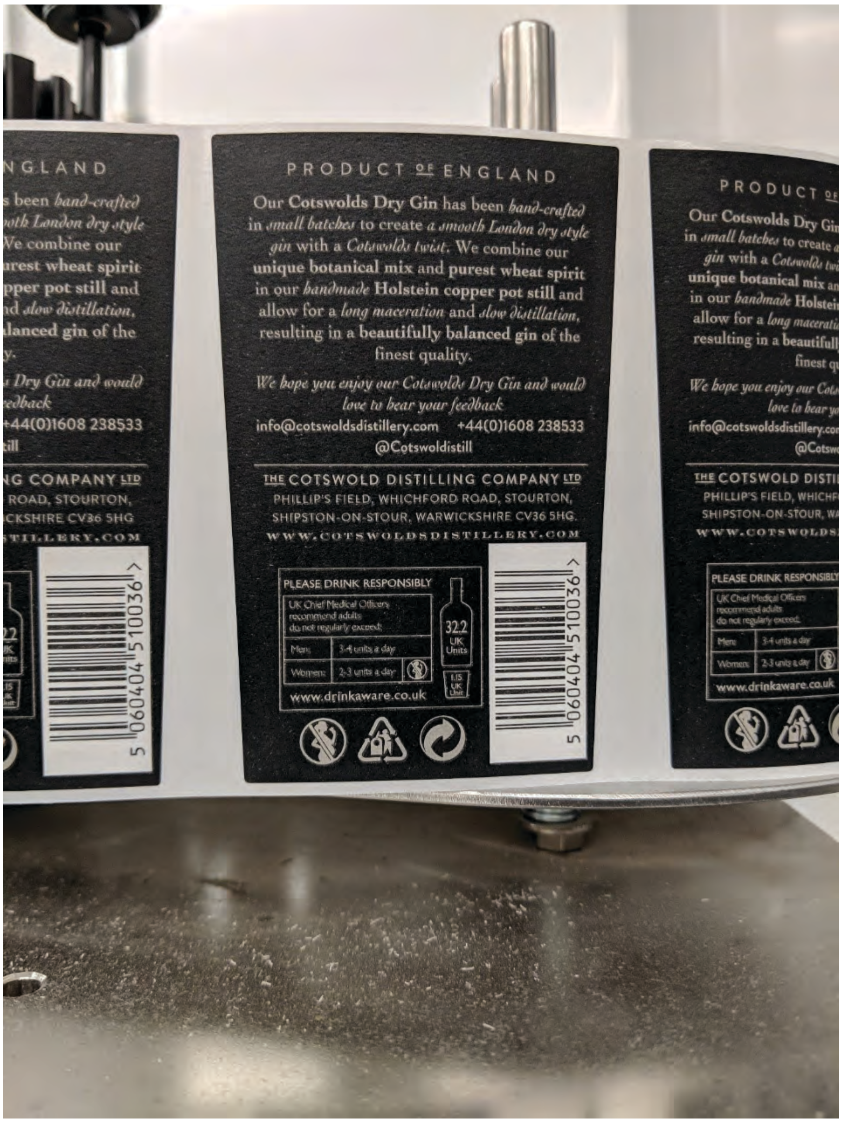


Figure 3 Product labelling to promote responsible drinking

Activity 2 Consumption awareness

Allow about 10 minutes

Watch the following video in which two different groups of students at an English university discuss their alcohol consumption including their understanding of UK units.

Video content is not available in this format.

What do you notice about their understanding? Note any thoughts you have in the box below before reading the discussion.

Provide your answer...

Discussion

Both groups of students can recall what they drink but very few had an awareness of how many units this equated to, with one student commenting that she did not know what a unit was. Estimations for the number of units in a bottle of wine varied from three to ten units, whereas it is actually eight to ten units in the UK. Some students also described alcohol in terms of percentage volume, rather than units. In most cases, what students reported drinking in one evening exceeded the recommended amounts.

2 The effects of alcohol on health

You may be familiar with the fact that the excessive use of alcohol can result in liver disease but you may not know that alcohol can also damage the pancreas, the gastrointestinal system, the cardiovascular system and the nervous system. There are in fact 25 chronic diseases and conditions attributable to alcohol consumption. In addition, the World Health Organisation (WHO) has identified over 200 diseases, injuries or other health conditions that have an association with alcohol consumption, including a range of mental and behavioural disorders; intentional and unintentional injuries and non-communicable conditions including cardiovascular disease, diabetes and several cancers.

As a consequence, worldwide in 2012, about 5.9% of deaths (amounting to 3.3 million deaths) and 5.1% of the illness due to disease and injury were attributable to alcohol use.

A further way in which alcohol can impact on health is through its intoxicating effect which is known to increase the risk of unintentional injury as a result of, for example, road traffic collisions and industrial accidents. An increased risk of intentional injury, to others or yourself, is also associated with alcohol. It is reported that, of those committing suicide in a US national sample, 37% of males and 29% of females had positive blood alcohol levels at the time of death. In addition, risk-taking behaviours such as unprotected sex are greater in those who are intoxicated.

Lastly, alcohol use can result in alcohol use disorders (AUD). AUD is a relatively new term that replaces the terms ‘alcohol abuse’ and ‘alcohol dependence’ (or ‘alcoholism’) with which you may be more familiar.

2.1 Physiological changes and the effects of chronic alcohol consumption

In this section, you will take a brief look at three of the major disease states linked with chronic alcohol consumption. This is by no means a comprehensive list as excessive alcohol plays a part in a high number of diseases and conditions, as you have learned. The NHS currently defines excessive alcohol consumption as drinking more than 14 units of alcohol per week for both men and women. Chronic alcohol consumption can be defined as consuming more than 14 units of alcohol per week on a regular basis.

2.1.1 Alcoholic liver disease (ALD)

With the exception of the brain, the liver is perhaps the most complex organ in the body, carrying out a wide range of essential body functions.

- Describe one function of the liver that you have learned about earlier in the course.
- In the context of this course, you know that the liver is where the body metabolises alcohol. It also carries out a great many other processes, including removing toxic chemicals and metabolising drugs. The liver also makes hormones and proteins important for blood clotting and other functions.

The liver is very resilient and is capable of regenerating itself by replacing damaged cells. But excessive alcohol use over many years can reduce regeneration, resulting in serious damage to the liver. The liver receives three-quarters of its blood supply from the portal vein which carries blood directly from the gut, complete with nutrients and other dissolved substances (alcohol, toxins, drugs etc). This means that the liver is exposed to high concentrations of alcohol and therefore is very susceptible to alcohol-related damage.

It is therefore perhaps unsurprising that the best-known harmful long-term side effect of drinking excessive alcohol is damage to the liver in the form of alcoholic liver disease (ALD), as illustrated in Figure 4.

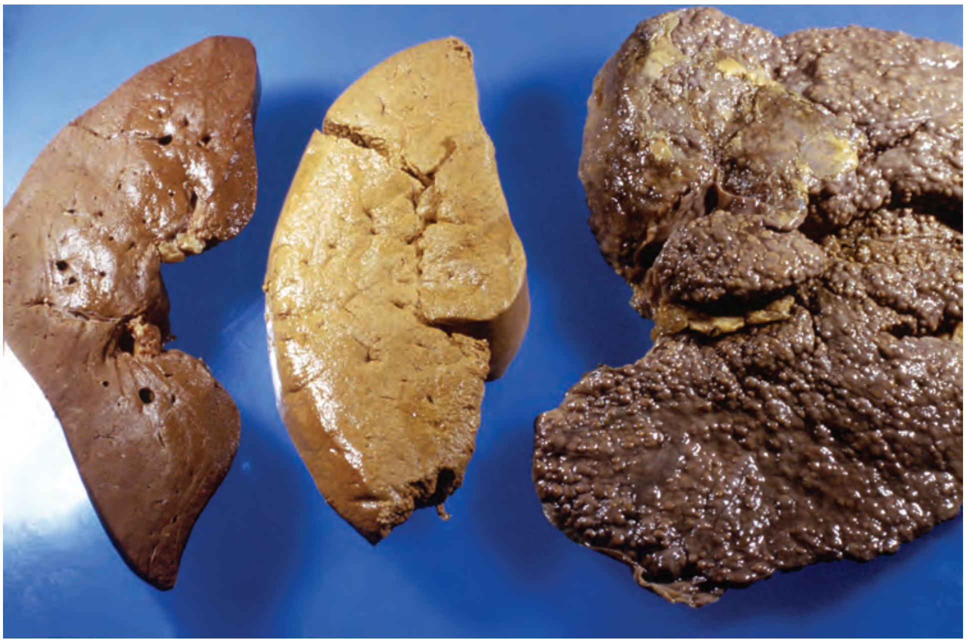


Figure 4 Comparison between samples of liver from three people showing (from left to right): normal liver, fatty liver and cirrhosis

Alcoholic liver disease is categorised into three progressive stages of increasing severity: fatty liver, hepatitis and cirrhosis.

The first stage of ALD, fatty liver, is an early and reversible consequence of excessive alcohol consumption, during which fat accumulates within the cells of the liver. Fatty liver in itself does not cause long-term damage to the liver and can be reversed by abstaining from drinking alcohol. However, it can be an important early indication that harm is being done and that continued excessive alcohol consumption could lead to the more serious conditions of hepatitis and cirrhosis.

Hepatitis means ‘inflammation of the liver’ and can range from mild – only detectable through blood tests – to severe, causing nausea and vomiting, jaundice (yellowing of the skin) and pain. Hepatitis is also reversible if an individual stops consuming alcohol. However, very severe hepatitis can lead to liver failure which is often fatal.

In the third stage, cirrhosis, liver cells are gradually and irreversibly replaced by scar tissue. This occurs in about 10% of chronic heavy drinkers. Not only does this decrease the ability of the liver to perform its many essential biological functions, it also disrupts the blood flow through the liver tissue. This in turn causes serious complications such as damage to the spleen (an organ involved in blood maintenance) and the circulatory system of the gut (as blood pressure increases in the portal vein because the blood flows more slowly through the liver).

2.1.2 Alcohol and cardiovascular disease

The relationship between the consumption of alcohol and heart function is complex. There is a large amount of evidence that long-term excessive alcohol consumption increases the risk of developing cardiovascular disease, but a few studies have suggested that drinking a moderate amount of alcohol may be beneficial for the heart.

Excessive alcohol consumption can raise blood pressure. Constant high blood pressure (or hypertension) means the heart works harder to pump blood into the arteries. In some people this causes the muscular wall of the left ventricle of the heart to grow and thicken. As a result, the heart then cannot relax normally between beats, so it becomes difficult to fill the heart with enough blood to supply the body's organs, especially during exercise.

Heavy drinking can also weaken the heart muscle in some people, causing a condition called alcoholic cardiomyopathy. A weakened heart cannot contract effectively and, in some cases, the blood flow shortage resulting from this can damage organs and tissues. The heart itself will start to swell to hold the blood that cannot be efficiently pumped back out of the left ventricle. In this case blood pressure rises as a response to compensate, and so alcoholic cardiomyopathy can bring about other health conditions caused by raised blood pressure, such as stroke.

Either of these conditions (heart muscle weakening or heart muscle thickening) can eventually bring on heart failure (as illustrated in Figure 5). Symptoms of heart failure include shortness of breath, fatigue and swelling of the tissues because blood backs up trying to get into the heart and fluid can't move into the blood.

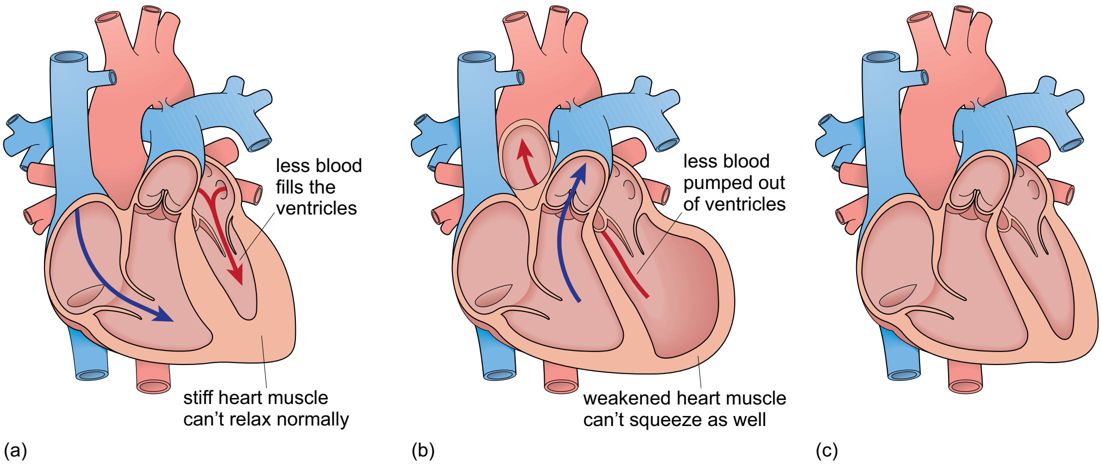


Figure 5 Potential causes of heart failure (a) thickened heart muscle and (b) weakened heart muscle, together with (c) a normal heart

Over the past few decades, several studies have suggested that moderate alcohol consumption has health benefits, including reducing the risk of cardiovascular disease and type II diabetes. Scientists have suggested two possible mechanisms for the protective effect on the circulatory system. Firstly, alcohol appears to increase the level of 'good' cholesterol (HDL) in the blood, which may reduce the amount of fatty deposits on the walls of arteries. Secondly, alcohol can reduce the production in the liver of a protein called fibrinogen which is involved in blood clotting. Both of these effects may reduce the risk of blocked arteries.

However, the picture is currently unclear. While moderate amounts of alcohol appear to be protective for people over 45, the pattern of alcohol consumption is probably more important than the amount consumed, or the length of time of consumption. In addition, other factors seem to moderate the risk of developing cardiovascular disease such as lifestyle (diet) and genetic inheritance.

2.1.3 Nervous system damage

Chronic consumption of high levels of alcohol can cause irreversible damage to the nervous system. The majority of individuals who consume alcohol excessively have some degree of dementia, which is a general loss of intellectual abilities including memory, judgement and abstract thinking. They may also experience personality changes associated with this condition. Dementia that is specifically related to the chronic consumption of alcohol is known as alcohol-related dementia.

- Consider Figure 6 which compares MRI scans of the brain of a normal and an alcoholic individual of the same age. What is the main difference between them?

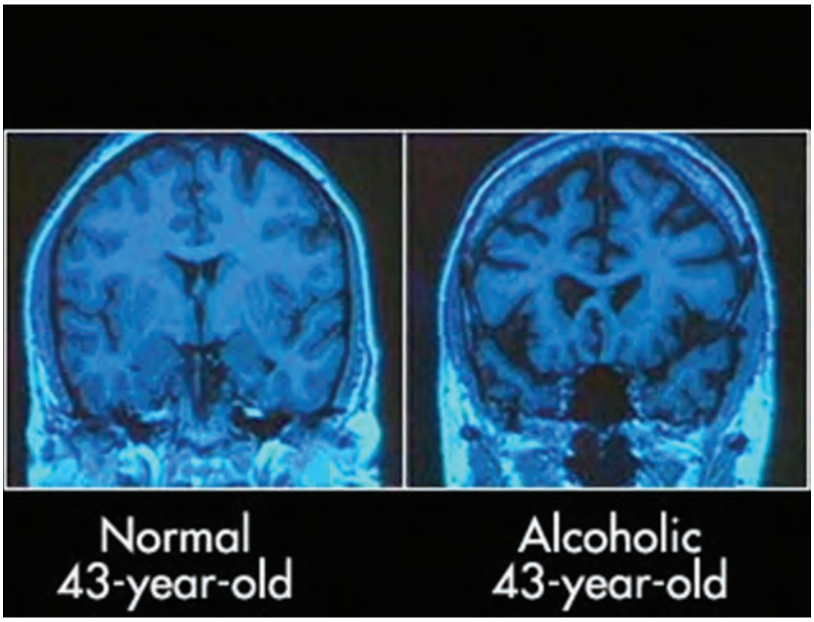


Figure 6 MRI images illustrating the effects of chronic alcohol consumption

- The MRI scan of the alcoholic brain seems to show shrinking of the brain tissue

The physiological cause of alcohol-related dementia seems to be shrinking of brain tissue, revealed by brain imaging techniques or post-mortem studies, and which is illustrated in the MRI (magnetic resonance imaging) images shown in Figure 6. The extent of shrinkage is associated with the amount of alcohol consumed.

Shrinkage also occurs in several parts of the brain including those areas linked with movement, balance and memory.

However, dementia in people who chronically consume alcohol may also be caused by head injuries, for example, as a result of falling while intoxicated or from being involved in a fight. Therefore, the link between alcohol and dementia is not necessarily a direct one as it can be the result of the social and psychological effects of alcohol consumption.

Alcohol-related dementia can also be linked with vitamin deficiency (B1) as malnutrition is common in individuals who drink excessive amounts of alcohol – alcohol is highly calorific, but it is missing vital nutrients.

Finally, chronic alcohol consumption can also be associated with damage to the peripheral nerves (i.e. those connecting the brain with the rest of the body). This condition is known as alcoholic neuropathy. Peripheral nerve damage can cause signs and symptoms such as sensory disturbances (numbness or pain), motor disturbances (weakness and muscle wasting), and problems with speech, swallowing, heart rate, pupil function, erectile function, and breathing during sleep. The mechanism by which alcohol consumption damages peripheral nerves is not clear and could be associated with a direct toxic effect of ethanol on the nerves, or it could occur indirectly via nutritional deficiencies associated with chronic alcoholism.

2.2 Alcohol use disorder (AUD)

AUD is the term now used for the conditions formerly referred to as alcohol abuse and alcohol dependence. AUD is the diagnosis given to someone who is showing signs and symptoms of addiction to alcohol. This is often referred to as ‘alcoholism’ and the individual concerned may be called an ‘alcoholic’. Someone with AUD would show several characteristics common to all addictive behaviours, but there are three key features:

- **Tolerance** – this refers to increasing engagement with the object of addiction (in this case, the ‘object of addiction’ is alcohol) in order to keep achieving the same effects. For example, an individual who might have been drinking half a bottle of spirits per day in the past may gradually escalate their drinking to consuming a whole bottle of spirits per day.
- **Withdrawal** – this refers to the signs and symptoms that occur when an individual refrains from addictive behaviour. The withdrawal signs and symptoms of alcohol addiction can include irritability, insomnia, shaking, and changes in heart rate and body temperature.
- **Craving** – this refers to the persistent nagging desire to engage in the addictive behaviour.

Psychologists use a series of criteria to diagnose AUD on the basis of psychological and behavioural effects. The list of considerations is seen here in Figure 7 (taken from the Diagnosis and Statistical Manual from the American Psychiatric Association).

It is important for diagnostic criteria to be reliable because so much depends on the process. For example, for anyone attempting to understand the nature of a condition, the prevalence or incidence rates would be misleading if diagnosis of that condition were not reliable. For anyone who might receive treatment for a condition, the implications of unreliable diagnosis might be more extreme. They may be prescribed the wrong treatment, or a treatment, such as a drug, that they do not need and which may cause other problems. Diagnosis is therefore vital, but experts do not always get the criteria right and the criteria themselves constantly evolve. It is important to be aware of this issue.

<table>
<tr><th colspan="3">DSM–5</th></tr>
<tr><th colspan="3">In the past year, have you:</th></tr>
<tr><td>1</td><td>Had times when you ended up drinking more, or longer, than you intended?</td><td rowspan="11">The presence of at least 2 of these symptoms indicates an Alcohol Use Disorder (AUD).

The severity of the AUD is defined as:

Mild:
The presence of 2 to 3 symptoms

Moderate:
The presence of 4 to 5 symptoms

Severe:
The presence of 6 or more symptoms</td></tr>
<tr><td>2</td><td>More than once wanted to cut down or stop drinking, or tried to, but couldn't?</td></tr>
<tr><td>3</td><td>Spent a lot of time drinking? Or being sick or getting over other aftereffects?</td></tr>
<tr><td>4</td><td>Wanted a drink so badly you couldn't think of anything else?
This is new to DSM–5</td></tr>
<tr><td>5</td><td>Found that drinking—or being sick from drinking—often interfered with taking care of your home or family? Or caused job troubles? Or school problems?</td></tr>
<tr><td>6</td><td>Continued to drink even though it was causing trouble with your family or friends?</td></tr>
<tr><td>7</td><td>Given up or cut back on activities that were important or interesting to you, or gave you pleasure, in order to drink?</td></tr>
<tr><td>8</td><td>More than once gotten into situations while or after drinking that increased your chances of getting hurt (such as driving, swimming, using machinery, walking in a dangerous area, or having unsafe sex)?</td></tr>
<tr><td>9</td><td>Continued to drink even though it was making you feel depressed or anxious or adding to another health problem? Or after having had a memory blackout?</td></tr>
<tr><td>10</td><td>Had to drink much more than you once did to get the effect you want? Or found that your usual number of drinks had much less effect than before?</td></tr>
<tr><td>11</td><td>Found that when the effects of alcohol were wearing off, you had withdrawal symptoms, such as trouble sleeping, shakiness, restlessness, nausea, sweating, a racing heart, or a seizure? Or sensed things that were not there?</td></tr>
</table>

Figure 7 AUD diagnosis criteria (American Psychiatric Association, May 2013)

AUD can be explained through several physiological and psychological conditions.

Firstly, ethanol affects many brain regions by altering the activity of neurons. This is the underlying reason for some of the acute effects of alcohol such as reduced coordination and reduced self-restraint which you discovered in Week 5. However, as you learned in

Week 5, alcohol is also able to stimulate the brain's reward system releasing dopamine – the brain's 'happy' and 'rewarding' messenger molecule. With frequent consumption of something rewarding like alcohol, dopamine release can start to occur earlier, so is released at the point of *anticipation* that something rewarding is about to happen (i.e. before the alcohol is actually consumed). Over time therefore dopamine starts to act as more of a wanting signal. In psychology this is known as classical conditioning, but you may already be familiar with this concept due to the experiment carried out by the Russian scientist Pavlov in the 1890s.

2.2.1 Pavlov's dogs

Like many scientific breakthroughs (such as the discovery of penicillin), the concept of classical conditioning was discovered accidentally.

During the 1890s, Ivan Pavlov was researching salivation in dogs in response to being fed. He predicted the dogs would salivate in response to the food placed in front of them, but he noticed that his dogs would begin to salivate whenever they heard the footsteps of his assistant who was bringing them the food. Therefore, the dogs started to *anticipate* the arrival of food (resulting in salivation) with the footsteps of the person bringing them the food – an example of classical conditioning. This initial work of Pavlov's has also led to this behaviour being referred to as 'Pavlovian conditioning'.

Another example of Pavlovian conditioning is illustrated in Figure 8.

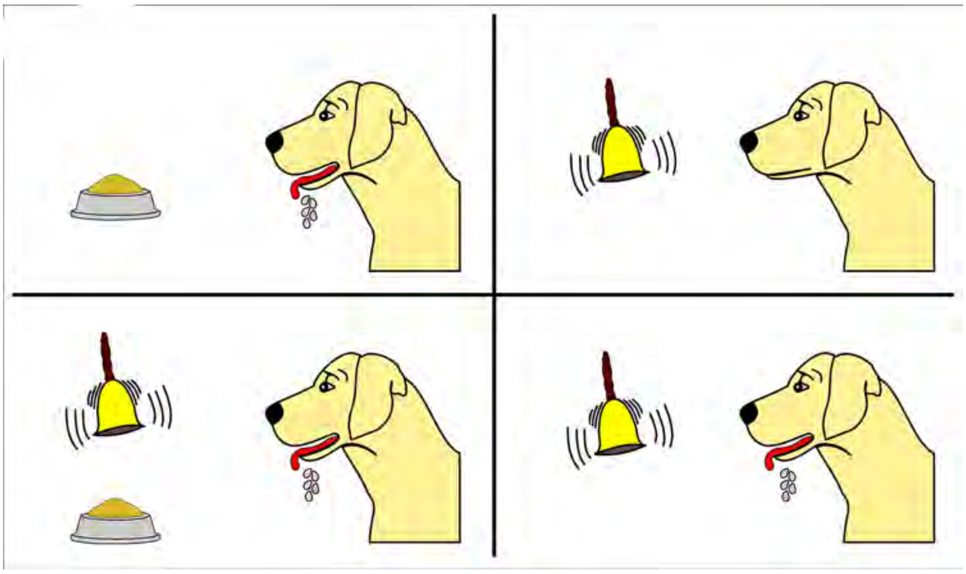


Figure 8 Pavlovian conditioning using a bell as the stimulus

- Can you number these images 1–4 to show the order in which the conditioning has occurred?
- Figure 9 shows the order of conditioning as it occurs.

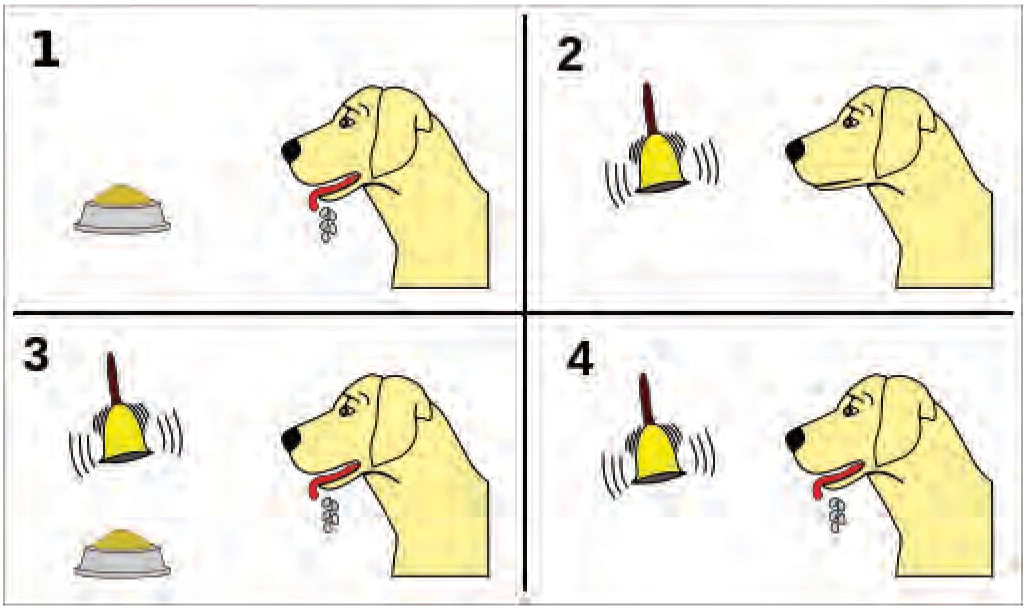


Figure 9 Pavlovian conditioning using a bell as the stimulus (numbered panels)

In this example, a bell is being used to ‘train’ the dog to associate food with the sound of the bell:

1. In image 1, the dog is introduced to the food alone – and so salivates to the presence of the food.
2. In image 2, the dog is introduced to the sound of the bell alone – and since the dog cannot associate this sound with anything rewarding, there is no salivation response.
3. In image 3, the food is re-introduced at the same time as the bell is rung, and the presence of the food induces the salivation. Eventually over time this repeated pairing of food and bell means the dog learns the association between food and the sound of the bell.
4. Eventually, as in image 4, the sound of the bell alone is sufficient to elicit the salivation associated with the food.

In brain terms, dopamine would usually be released in image 1 in response to the presentation of food but, over time, after learning the association between the food and the bell, dopamine would start to be released just to the sound of the bell.

In real terms what this means is that a person who repeatedly drinks, for example, in a particular pub, will find it very difficult to walk past that pub without being motivated by the release of dopamine to go in for a drink.

2.2.2 The role of the prefrontal cortex in AUD

So far you have been learning about the role that dopamine plays in AUD, and you may remember from Week 5 that dopamine is released by a region of the brain known as the ventral tegmental area.

However, another brain region that plays an important role in AUD is the prefrontal cortex (PFC). The PFC is important for self-control or restraint and, in particular, inhibiting behaviour that is not socially appropriate or acceptable. Parts of the PFC are therefore thought to be involved in imposing the restraint that prevents most people from developing an addiction. However – importantly – the long-term use of alcohol can change the structure of the brain, including the structure of the PFC. In individuals who consume alcohol chronically, the PFC is reduced in size and so this affects self-control.

2.2.3 AUD and relieving the stresses of life

Not all explanations for AUD are physiological (e.g. dopamine and the PFC). Many different psychological explanations have been proposed, some of which link to physiological factors. One theory that proposes a psychological explanation for addictions like AUD is known as the adaptive orientation model of addiction. Originally developed to explain opiate addiction, this model proposes that some people develop addictive behaviours because they are attempting to compensate for the stresses and strains of everyday life. In other words, some people go on to drink alcohol excessively and chronically because they are using alcohol as a form of self-medication.

The adaptive orientation model of addiction suggests that alcohol consumption compensates for stresses in their life. This is a psychological explanation of AUD because it concerns the cognitive process of making the decision to consume alcohol. According to this model, even though addictive behaviours like excessive and chronic alcohol consumption have negative effects on an individual, the beneficial effects of relieving the stresses and strains of everyday life are perceived to outweigh the negatives, so the individual makes the choice to drink. This is a highly contentious issue as some researchers think this suggests that some people choose to have an addiction.

Another problem with this model of addiction is that the ultimate negative effect of chronic alcohol use – death – should outweigh the relief of stress. Yet many people do continue to drink knowing that they are risking death by doing so.

You might have your own opinions about this psychological explanation for addictions like AUD, but a lot of research has shown that individuals are generally not very good at recognising the harmful long-term effects of behaviours that bring *immediate* rewards.

- Can you think of any other addictive activities in which long term effects are overlooked for short term rewards?
- One other activity you may have thought of is cigarette or cigar smoking. Illicit drug use could also be considered.

3 Checking your homebrew

Your homebrew experiment should now be nearing completion. During your study of Week 8 you will be encouraged to check the final strength of your homebrew which will determine whether the fermentation is complete. However, if you wish you could take another hydrometer reading now for comparative purposes.

4 This week's quiz

Well done – you have reached the end of Week 5 and can now do the quiz to test your learning,

Week 7 practice quiz

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click the link. Return here when you have finished.

5 Summary of Week 7

In this week you have learned about some of the effects that continued excessive intake of alcohol can play on the human body, and how addiction occurs and can be diagnosed. Chronic exposure to high levels of alcohol is highly damaging, so intake should, on health grounds, be within recommended levels set by Government and medical professionals.

You should now be able to:

- explain how alcoholic intake is measured in terms of units
- describe the features of alcohol use disorder (AUD) and explain why it can be thought of as a psychological and behavioural condition
- describe some of the physiological conditions associated with the long-term harmful effects of drinking excessive alcohol.

Next, in the final week of this course, you will look at some of the ways that analytical science is used to protect consumers from counterfeit products. You will also complete the final quiz.

You can now go to Week 8.

Week 8: Product protection and maintaining product provenance

1 Are you getting what you are paying for?

The alcohol industry is, like many others, very highly regulated. After all, if you are purchasing a pint of premium beer you want to be confident that what you are served is consistent with what you think you have paid for.

Look at Figure 1 below which illustrates two pints of beer. One of these is a budget supermarket brand, the other a premium craft beer.

Figure 1 A supermarket own-label budget beer and a premium craft beer

If you ordered a pint of premium beer, would you necessarily be able to tell whether you had received what you had ordered? How could you be sure that the vendor had not served you a budget-label value beer but charged you a premium price?

In Week 3 you looked at taste and smell and how these are linked to alcohol. So if you are a beer connoisseur it is very possible that you may be able to tell that you had been served a different beer simply by its taste, by how it smells or even by its appearance.

But if you are not an expert, then don't worry. It is very unlikely that you will be served a different, lower-quality beer to the one you were expecting. The brewing industry is regulated and has seen a large increase in legislative pressure in the twenty-first century. The sale of alcohol in licensed premises in England and Wales is subject to the requirements of weights and measures, fair trading, licensing and underage sales legislation as enforced by Trading Standards.

There are legal requirements for licensed premises concerning the quantities and measurement of alcoholic drinks and how they are described, as well as on informing customers about the prices they will be charged. There are also mandatory licensing conditions, which include minimum quantities and irresponsible pricing promotions.

1.1 Measuring alcoholic strength

Different brands of alcoholic beverages can also be distinguished from each other on the basis of their alcoholic strength. Consider the two bottles of gin shown in Figure 2.

Figure 2 Two commercially-available gins

The bottle of gin on the left is labelled as 47% ABV whereas the one on the right is labelled 37.5% ABV. But what do these numbers mean in reality?

Measuring the alcohol content of your drink is one of the most important analytical measurements made on all alcohol which is intended to be sold, as duty is imposed on alcohol content. In the European Union, the strength of alcohol is expressed as 'alcohol by volume' or 'ABV' on alcohol packaging. So, looking again at Figure 2, it is clear that the gin on the left has a higher alcohol content than the gin on the right, and you are likely to pay more for this particular gin.

All drinks with an alcoholic strength of more than 1.2% ABV must be labelled with an indication of alcoholic strength by volume.

1.2 Alcohol proof and alcohol volume

In the US, the alcohol content is measured by ‘alcohol proof’ which is twice the percentage of alcohol by volume (ABV), used in Europe.

So, in the US, 'eighty proof' spirit is actually only 40% alcohol. This isn’t the alcohol producers trying to over-inflate their numbers – there is a historical reason why we have measurements of both alcohol proof and alcohol volume, both of which relate to the actual content of alcohol in a drink.

It began when sailors in the British Navy came up with the idea of mixing alcohol and gunpowder. When the sailors did this, they noticed that gunpowder in alcohol would ignite – but only when the alcohol was not too watered down. Sailors would ‘prove’ the rum acceptable by pouring some onto gunpowder and lighting it. If it burned steadily with a blue flame, it was considered ‘100 proof’. If it did not burn, it was ‘underproof’. And if it burned too quickly it was ‘overproof’. The flame was considered the 'proof' of the alcohol content.

Historically, sailors weren't the only people interested in determining the alcohol content of various drinks. Spirits were taxed according to their alcohol content. Tax collectors used hydrometers, similar to those you saw in Week 1, to measure alcohol content.

1.3 Hydrometry and specific gravity

Just as the early tax collectors did, people still use hydrometers to measure alcohol content today. If you are taking part in the homebrew experiment, you probably used a hydrometer in Week 1. You may well have taken another specific gravity reading (the ratio of the density of the fermenting liquid to the density of water) in Week 4, half way through the brewing experiment.

You can now check if your homebrew is complete by taking a final specific gravity reading as illustrated by Louise MacBrayne in the following video.

Video content is not available in this format.

As you saw in Week 1, when the beer is undergoing fermentation the sugars in the liquid are converted by the yeast into alcohol and carbon dioxide. Alcohol in water is less dense than sugar in water and so this will result in a change in the specific gravity – the hydrometer will now sink in the liquid compared to the original gravity. It will now have a specific gravity closer to that of water.

The beer has finished fermentation when the hydrometer reading remains constant over a period of two days and does not decrease any further. This reading is called the 'final gravity' or 'FG' and is used, in conjunction with the original gravity, to work out the alcohol by volume content of the liquid. For beers the final gravity is around 1.015–1.005.

To convert the final gravity to ABV, a simple calculation is needed, as illustrated in Equation 1.

(Eqn 1)

So, using the example from the video above:

Original gravity before fermentation = 1.04

Final gravity after fermentation = 1.015

Although this may seem a little on the low side, this is possible for a homebrew!

1.4 Alcohol counterfeiting and contamination

Yet another consideration in brewing beer is product quality and ensuring that alcohol has not been contaminated with any other substances.

- Have a look at the following two compounds illustrated in Figure 3. Thinking back to Week 1, can you list some similarities between them? Can you identify one or both of these compounds?

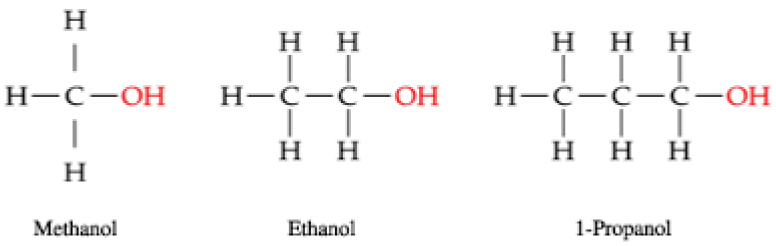


Figure 3 Comparison of two compounds

- The two compounds:

  - are both examples of alcohols as they possess the −OH functional group
  - both consist of C (carbon), H (hydrogen) and O (oxygen) atoms
  - both consist of single bonds.

  From Week 1, you may recall that the compound on the left is methanol and has the formula CH_3OH. The compound on the right is ethanol and has the formula C_2H_5OH.

While these compounds may look similar, they do in fact have very different properties. Ethanol is the key component of alcoholic beverages, and you looked at the effects of ethanol on human health in Weeks 5 and 7.

Methanol, in comparison, is the simplest form of alcohol – it is closely related to ethanol but much more toxic. Methanol is a very undesirable compound in alcoholic beverages as it is very harmful to the human body. Methanol is converted in the body into formic acid, the same toxin that is found in the venom of ants. It is this accumulation of formic acid in the blood that causes the symptoms of methanol poisoning – kidney failure, heart and circulation problems, liver damage, and visual disturbances (blurred and tunnel vision, changes in colour perception, and temporary or permanent blindness).

Rather worryingly, there have been cases of methanol poisoning which have arisen from consumption of alcohol contaminated with methanol. As little as 30 ml could be fatal. Methanol is used in antifreeze, as a solvent, as fuel, and as a denaturant (an additive that makes otherwise potable alcohol unfit for human consumption), for example in methylated spirits. All of these sources of methanol have been – and are still being – used by spirits counterfeiters since they are cheap and easily accessible.

So it is obviously important to be able to detect the presence of methanol in alcoholic beverages. One analytical chemistry technique that can detect the presence of methanol (and other contaminants) in alcohol is mass spectrometry.

1.4.1 Principles of mass spectrometry

Mass spectrometry is an important analytical method and a major tool for analysing and identifying unknown compounds.

If you subject a moving object to a sideways force, the object will be deflected away from its original straight-line path, into a curved path. You can apply exactly the same principle to atomic-sized particles in order to measure their mass.

Atoms and molecules can be deflected by magnetic fields – provided the atom or molecule is first turned into an ion. Electrically-charged particles are affected by a magnetic field but electrically-neutral ones aren't. You were first introduced to ions in Week 1 of this course.

- What is the charge on an atom if a negatively charged electron is removed?
- If an electron is removed, the atom no longer has an equal number of protons and electrons. There will be an excess of one positively-charged proton in the nucleus of the atom. The atom will now be a positively-charged ion because the proton is not being neutralised by the presence of an electron. This is illustrated in Figure 4 for the metal sodium.

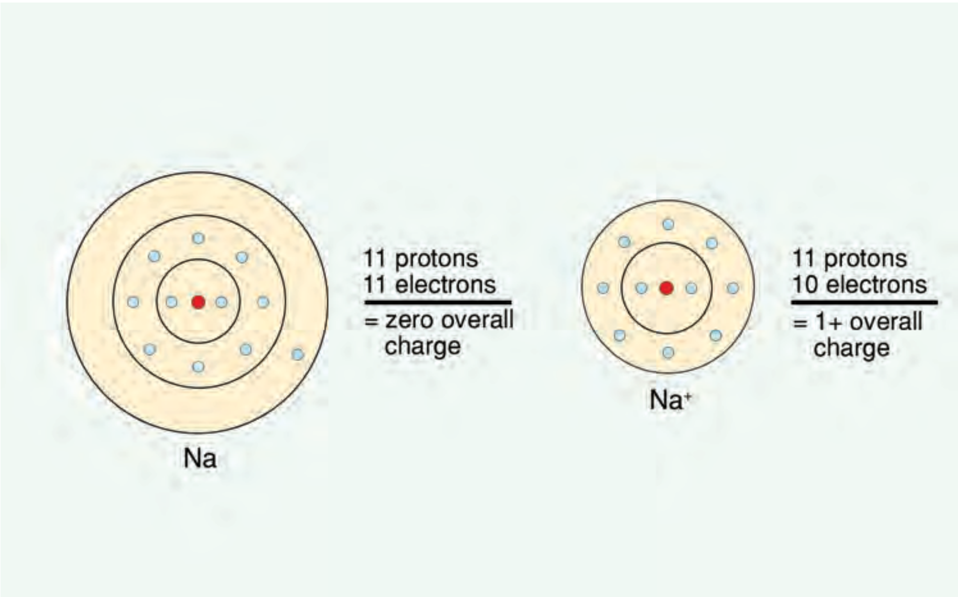


Figure 4 Formation of a positively-charged sodium ion

Sodium is a highly reactive metal and one you may unknowingly be very familiar with already.

- What common household substances contain sodium?
- Sodium is a key constituent of common table salt (as sodium chloride, NaCl), baking soda (as sodium bicarbonate, $NaHCO_3$) and of bleach (as sodium hydroxide, NaOH).

Sodium has an atomic number of 11. This means that it has a total of 11 positively-charged protons in the nucleus. The positive charge associated with these protons is balanced by 11 negatively-charged electrons in shells which orbit around the nucleus (a bit like the rings of the planet Saturn). A very reactive metal such as sodium will readily lose an electron - you now have 11 positively-charged protons in the nucleus but only 10 negatively-charged electrons orbiting it. The charge is no longer balanced, so sodium is now positively-charged and has become an ion. Less reactive metals such as copper or silver will not readily lose electrons and hence are used in every day objects such as jewellery or coins.

Molecules of different masses and structures will produce different ions, and hence different mass spectra, which can be used to identify them.

So, methanol and ethanol will each produce different mass spectra because these two alcohols are different compounds with different masses. If you separate a sample of alcohol containing both ethanol and methanol into its constituent components, and subject each component to mass spectrometry, you should be able to differentiate between a methanol contaminant and the ethanol that you would expect to see.

The characteristic mass spectrum of both methanol and ethanol are illustrated in Figure 5 below.

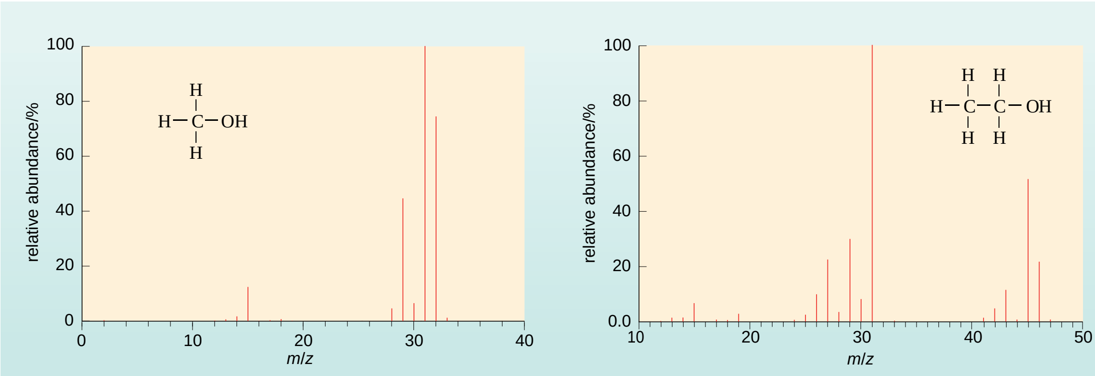


Figure 5 The mass spectra of methanol (CH_3OH) and ethanol (C_2H_5OH)

- What do you notice about the complexity of the two spectra?
- The ionisation of methanol produces a spectrum with far fewer peaks.

Note that the detector of the mass spectrometer has counted the ions as they are generated to give a percentage relative abundance of ions with particular m/z (mass/charge) values.

In addition to detecting methanol in alcoholic beverages, mass spectrometry can also be used to detect and quantify other contaminants, for example undesirable substances such as pesticides. Heavy metals (for instance lead, mercury and arsenic) are also detectable.

2 Testing for the presence of alcohol

As you have learned throughout this course, alcohol is a drug that has a depressive effect on the nervous system and excessive exposure can lead to various short-term and long-term effects.

- Where might the presence of alcohol need to be tested outside an analytical laboratory setting?
- Driving while under the influence of alcohol is considered a criminal offence in many countries, and it may be necessary to test suspect drivers at the roadside.

Alcohol is not digested when absorbed in the gut, nor is it chemically changed in the bloodstream. As the blood goes through the lungs, some of the alcohol moves across the membranes of the lungs' air sacs (alveoli) into the air in the lungs because alcohol is volatile. The concentration of the alcohol in the alveolar air is related to the concentration of the alcohol in the blood. As the alcohol in the alveolar air is exhaled, it can be detected in the breath. This allows for a non-invasive analysis of blood alcohol concentration (BAC) at the roadside using an instrument known as a breathalyser, an example of which is illustrated in Figure 6.

Figure 6 An example of a breathalyser used for roadside BAC testing

If a positive result to a roadside breathalyser test is obtained, a second sample will be taken for legal purposes at a police station to confirm the result. This further test is usually performed on either a blood or a urine sample. As the excretion rate of alcohol by the body can be calculated, this second measurement can be extrapolated backwards (retrograde) to the time of the first measurement, thereby confirming the result of the initial roadside test.

- Why do you think it is important for a breathalyser to be able to produce rapid results?
- Since blood alcohol levels decease over time, rapid results are important to inform law enforcement personnel of the driver's condition at the roadside and whether further action should be taken.

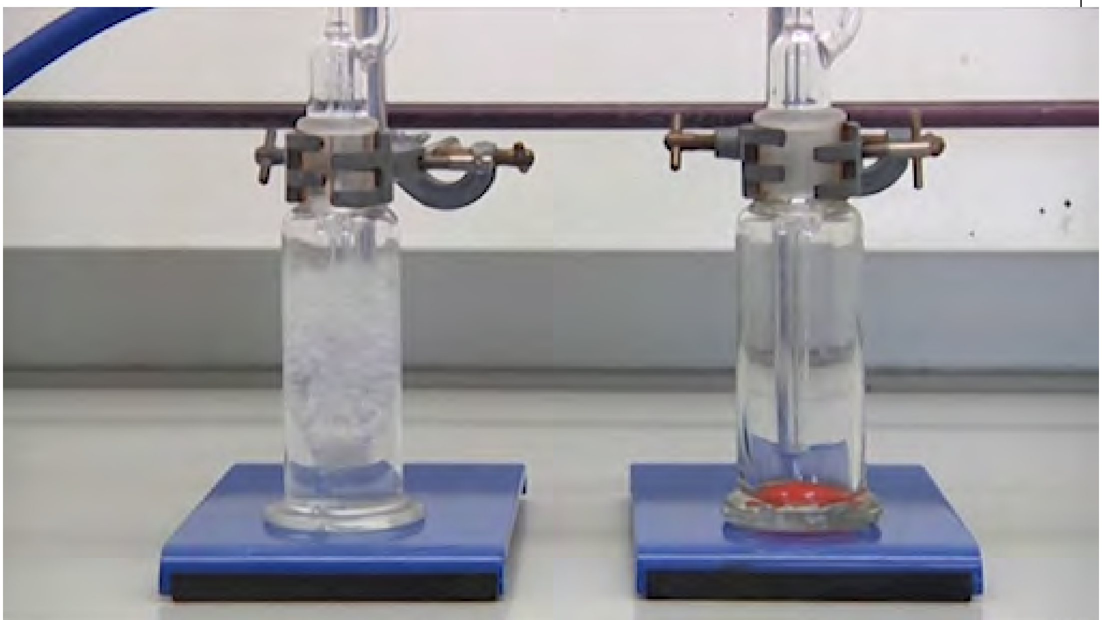
In this final part of the course, you are going to look at the chemistry of the breathalyser – the same methodology as that used in versions of the kit you can buy yourself over the counter.

2.1 Analysing ethanol by wet chemistry

As you learned in Week 1, the alcohol in alcoholic drinks is ethanol, and a molecule classes as an alcohol if its chemical structure includes the –OH functional group.

The following video demonstrates the chemistry used in roadside testing breathalysers. The breath of a test subject is exposed to an acidified purple solution of a substance known as potassium dichromate. If alcohol is present, the solution changes colour from orange to brown, and finally to green. The depth of the colour change can indicate how much alcohol is present although normally this is not sufficient for quantitative analysis – therefore, the secondary blood or urine test is required for law enforcement reasons.

Video content is not available in this format.



At this stage it is worth pointing out that sometimes this test does not give the results we would expect.

- What do you think is meant by the term ‘false positive’?
- A false positive arises when a positive result is obtained for a substance without this substance being present.

You may be familiar with the concept of drug testing in athletes. Sometimes, a test subject may test positive for a particular substance that the athlete denies ingesting. If the athlete is telling the truth and has not ingested the substance – but the substance is detected anyway – this is a false positive.

The same concept applies to alcohol testing. Several factors can cause false positives in breath tests for alcohol. These tests assume a particular ratio of blood alcohol to breath alcohol. If the concentration of alcohol in the mouth is artificially increased, this ratio is invalid. For example, recent use of mouthwash – which contains ethanol – can lead to false positives. Stomach gases brought up by belching will also contain alcohol. This means that, while these tests are generally qualitative (i.e. tell you whether or not alcohol is present), quantification (determining the exact amount of alcohol) is required by law.

The wet chemistry principle (that is, using a solution to test breath) described here is one very simple method of detecting alcohol and has been in use since 1938 when the first breathalyser – known as a ‘drunkometer’ – was produced. In recent years, however, this technology has been superseded by more advanced fuel cell technology, capable of accurate quantification of blood alcohol levels. These fuel cells systems are small, portable and highly accurate and consequently now represent the gold standard for roadside alcohol testing. However, the chemistry you have learned about here is still often used in commercial over-the-counter single-use test kits.

2.2 Principles of IR spectroscopy

You have just learned about the detection of alcohol by a chemical technique. However, an alternative method can be used for this purpose both for in situ roadside testing and also in the laboratory.

Earlier, you looked at mass spectrometry. Another very commonly-used analytical chemistry technique is infra-red spectroscopy, which is based on the absorption by a molecule of a particular type of light.

In the 1670s, Sir Isaac Newton (1643–1727) determined that light is composed of a spectrum (rainbow) of colours. Nowadays we refer to this spectrum of colours as the electromagnetic spectrum, as illustrated in Figure 7.

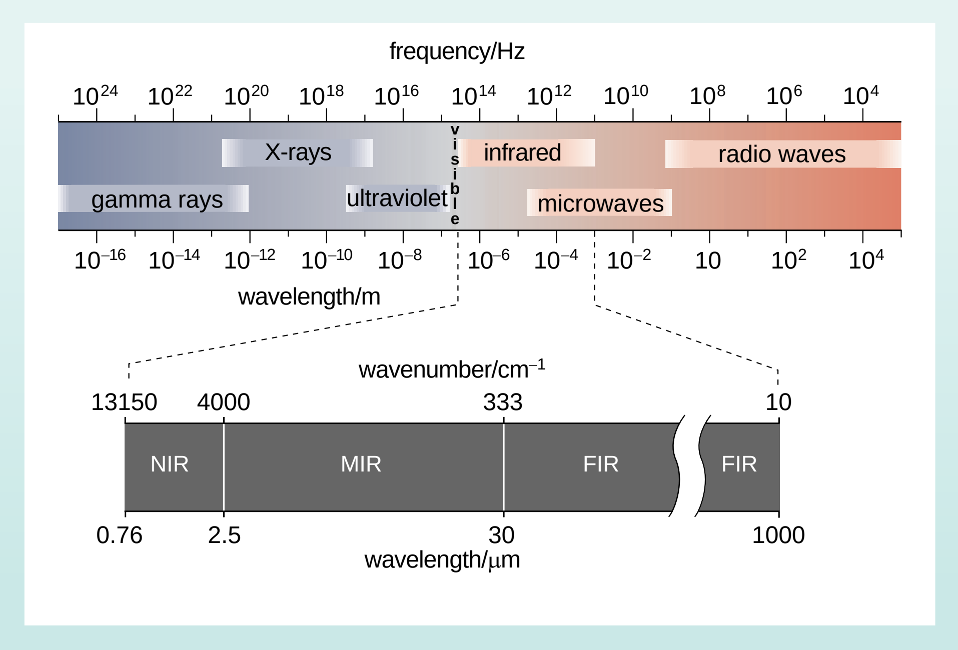


Figure 7 The electromagnetic spectrum

In 1800, a German astronomer called Sir Frederick William Herschel (1738–1822), most famous for the discovery of the planet Uranus, discovered the part of the electromagnetic spectrum known as the infra-red region when he was observing the Sun. In building his telescopes, Herschel began experimenting with different coloured filters which could help him observe the Sun. While using a red filter to reduce the Sun's glare, he noticed that heat was generated, and these rays he deemed to be 'calorific rays' – later these were renamed infra-red (IR).

IR spectroscopy detects the absorption of light by a compound, in the IR region of the electromagnetic spectrum. To absorb light a molecule must have a bond within its structure that can exhibit what is referred to as a 'dipole moment' which means electrons within a bond are not shared equally.

Revisit the structure of water from Week 1 in Figure 8 below.

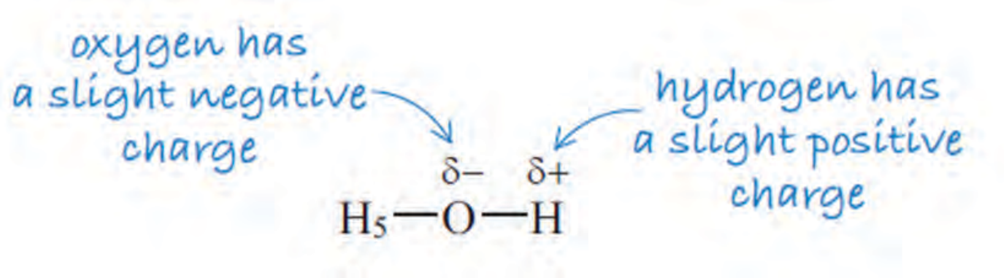


Figure 8 Creation of a dipole moment in the O–H bond of water

Electrons within the O–H bond are not equally shared meaning that the electrons are more closely attracted to the oxygen than the hydrogen. As electrons are negatively charged, this leads to the O of the bond bearing a slight negative charge and the H a slight positive charge. It is this charge difference which enables the IR light to be absorbed by this particular bond, giving rise to a peak within an IR spectrum.

Different bonds within functional groups which possess a dipole moment will absorb at different areas of the IR spectrum, referred to as wavenumbers.

An IR spectrometer is a relatively simple device consisting of a lamp or heated rod that will emit light in the IR region. A detector then collects all wavelengths of IR radiation that have passed through the sample and converts these to wavenumbers. Each chemically distinct molecule will have a different absorption pattern made up from the number and different types of bond present and the presence of differing functional groups.

2.2.1 Analysis of ethanol using IR spectroscopy

Ethanol is a relatively small molecule with only four types of bond.

- Thinking back to the structure of ethanol, can you list the four types of bond present?
- The four types of bond in the structure of ethanol are:
    - C–O
    - O–H
    - C–H
    - C–C

  where C represents carbon, O represents oxygen, and H represents hydrogen.

The simplicity of the ethanol molecule means that the IR spectrum is relatively easy to measure and so it is possible to identify ethanol in a complex sample such as a breath sample containing water and other organic compounds.

The IR spectrum of ethanol is shown in Figure 9 below.

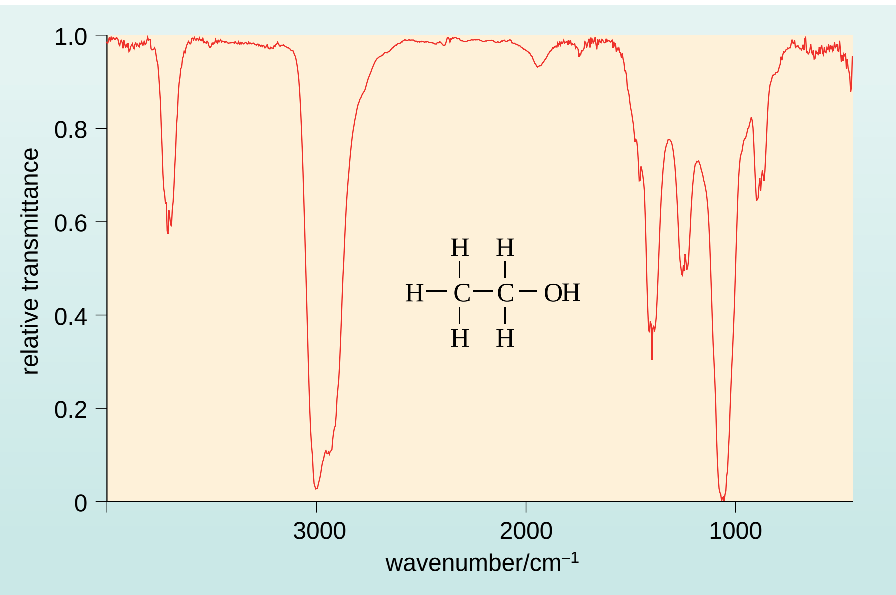


Figure 9 The infra-red spectrum of ethanol

An IR spectrometer that is being utilised to detect ethanol – and therefore alcohol – will do so based on the absorbance of a specific peak. This is usually the absorption band at a wavenumber of approximately 3000 cm^{-1}. The intensity of this signal in that region will be directly proportional to the ethanol concentration.

This absorbance is attributable to the C–H bond of ethanol. The absorbance of light is directly proportional to the concentration of ethanol and can therefore be used for quantification.

- Can you remember one of the limitations of the breathalyser test you looked at previously?
- The breathalyser test – based on the potassium dichromate solution – could possibly identify a false positive, in other words give a positive result for ethanol even if no alcoholic drinks have been consumed.

Unfortunately, using an IR spectrometer does not overcome this problem either. A compound called acetone is produced by the human body in cases of ketosis (acidosis) which is common if the test subject has not eaten for some time. Furthermore, diabetes mellitus is a very common disease affecting blood sugar levels, and ketosis can be a common manifestation of the disease.

Acetone also absorbs at 3000 cm^{-1}. This means that, if it is present, it will interfere with the measurement of ethanol, leading to a false positive.

In reality, this is not a problem practically, as acetone has other functional groups which give rise to characteristic peaks in its IR spectrum which would not be present in the IR spectrum of ethanol. This means that the presence of acetone can easily be identified and its concentration measured from an alternative peak.

- How would this allow you to measure the concentration of ethanol?
- If both acetone and ethanol are present in a test sample, then the absorbance at 3000 cm^{-1} will be attributable to both substances. If you are able to work out the concentration of acetone based on an alternative peak, the value obtained for this concentration could be subtracted from the total concentration calculated from the peak at 3000 cm-1. This would then yield a value for the concentration of ethanol alone.

Portable IR spectrometers are now also commonly used for roadside breath testing, and furthermore this technology has also been integrated with fuel cell technology allowing for two analytical tests to be performed simultaneously.

3 Homebrew finale

In this final video, Danny Allwood considers the end result of your homebrew experiment.

Video content is not available in this format.

- How could you tell if your homebrew is ready?
- Your homebrew should yield consistent specific gravity readings from your hydrometer over the period of a couple of days. Consistent specific gravity indicates that the fermentation is complete and your homebrew is ready.

At the end of this video, Danny raises an important point about reflecting on your experiment. If your homebrew does not taste quite how you would expect, hopefully by studying this course you will now understand more of the underlying science, so you can evaluate what might have gone wrong and what you would change should you repeat the experiment.

If you didn't take part in the homebrew experiment, maybe this will encourage you to try it for yourself in the future – or even to visit your nearest brewery to see the science in practice.

4 This week's quiz

It's now time to complete the Week 8 badged quiz. It is similar to the previous quizzes but this time, instead of answering 5 questions there will be 15, covering Weeks 5–8.

Week 8 compulsory badge quiz

Remember that the quiz counts towards your badge. If you're not successful the first time, you can attempt the quiz again in 24 hours.

Open the quiz in a new tab or window by holding down Ctrl (or Cmd on a Mac) when you click the link. Come back here when you are done.

5 Summary of Week 8

In this final week of the course you have learned about how modern analytical chemistry techniques are used throughout the brewing and distillation industries to check product quality. You have also learned about how the presence of alcohol can be detected using a variety of techniques and the chemistry that underlies these.

You should now be able to:

- illustrate the importance of product protection
- describe how a hydrometer works to measure specific gravity
- discuss how modern analytical instruments are used towards product protection
- explain how a breathalyser works and how the presence of alcohol can be detected in commonly-used roadside tests.

Congratulations, you have now completed this free 8 week course. In learning about the science of alcohol you have been introduced to some fundamentals of chemistry and biology which you may wish to explore further.

Where next?

If you've enjoyed this course you can find more free resources and courses on OpenLearn. You might be particularly interested in the free OpenLearn course *Discovering chemistry*.

New to University study? You may be interested in our courses on science.

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Tell us what you think

Now you've come to the end of the course, we would appreciate a few minutes of your time to complete this short end-of-course survey (you may have already completed this survey at the end of Week 4). We'd like to find out a bit about your experience of studying the course and what you plan to do next. We will use this information to provide better online experiences for all our learners and to share our findings with others. Participation will be completely confidential and we will not pass on your details to others.

Acknowledgements

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Week 4

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Week 8

Images

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