# Chemistry of Chocolate Slide Notes

Before you begin, make up the solutions in advance according to the instructions on the glossy card in the pack.

\*Note that vanillin is solid, so just tip it all in!\*

You have ~60 strips: enough for example, for 1 class of 36 to smell all 6 samples in groups of 4 and one for you.

It’s also great to purchase a couple of different chocolates – one dark and one milk, to see if you can detect any of the aroma compounds in the actual chocolate.

Or compare two different brands of milk chocolate – very different if you have them side by side. (e.g. Dairy Milk and Galaxy make a good comparison)

This is still a prototype so we especially welcome your feedback. There are two QR codes at the end – one for you as teachers, and one for the students.

Depending on the age of you audience, you may find that 6 is too many and may like to skip one or two. We recommend you retain the smelly one (number 6) as this is fun, and it’s incredible how important this molecule is in chocolate.

## Slide 1 – Intro slide

Hello and welcome to all those attending.

## Slide 2 – History of Chocolate

Let’s start with a very brief history of chocolate, and its introduction into Britain.

## Slide 3 – Chocolate comes from the Americas

Cocoa is very old, and was being used to prepare a drink in Central America by the Mayans even in the 1300s. This drink was called xocolatl (pronounced chocolatl), which is where the word chocolate comes from. When the Spanish conquered what is today Mexico, and the Aztecs who ruled it at the time, cocoa beans and the newly-discovered cocoa drink were brought back by Don Cortes in 1528. This new drink became very fashionable in Spain, where it was flavoured with spices such as cinnamon and nutmeg, and sugar. From there this drink spread to the rest of Europe, and eventually England in the 1650s, where the first chocolate house, a place to drink chocolate, opened in 1657.

## Slide 4 – Chocolate spreads in Great Britain

Chocolate however was mainly restricted to being consumed as a drink for nearly 200 years, and then by only the very rich as all the ingredients were very expensive. It was only in the second half of the 19th century that chocolate for eating, the first chocolate bars, started appearing in Britain, thanks to companies such Cadbury (in Birmingham), Fry’s (in Bristol), today both forming part of Mondelēz, and Rowntree’s (in York), today part of Nestlé.

*For an older audience: It is interesting to note that all these here companies were founded by Quakers. The reasons for this were twofold: as Quakers they weren’t allowed to study for the professions, and hence a lot opened businesses, and also they didn’t drink or smoke, but chocolate consumption was allowed.*

## Slide 5 – Introduction to Chocolate

Let’s start discussing why we are here today.

## Slide 6 – Types of Chocolate (*Animated slide*)

Nowadays, there are 4 types of accepted chocolate, even though they may not all be officially recognised as such. We are all familiar with dark, milk and white chocolate, but in the past few years ruby chocolate has also been introduced by a Belgian company called Barry Callebaut. The differences between these types of chocolate are discussed in later slides.

Milk chocolate can be further classified as crumb chocolate and non-crumb, or powder, chocolate. Again, these are described in later slides.

## Slide 7 – Differences in the Types of Chocolate

All 4 types of chocolate must contain cocoa butter.

Dark chocolate (or as it is officially known, chocolate) however cannot contain non-fat milk solids (top right), or in other words, skimmed milk powder. This stands to reason as it’s not a milk chocolate. What is interesting however is that can contain milk fat (butter) (top, second from right). This can be added for flavour and texture, and still be classified as a dark chocolate.

White chocolate cannot contain non-fat cocoa solids (second from left, second from bottom), commonly known as cocoa powder, which again is a bit obvious.

Ruby chocolate however does contain cocoa powder, and yet looks pink, not brown. This is because the way the beans are processed makes the powder actually have this pinkish-reddish colour.

## Slide 8 – Crumb Chocolate (*Animated slide*)

Crumb is the product obtained when cocoa liquor/mass (the product obtained when pressing roasted cocoa beans or nibs), sugar and milk are cooked until most of the water has been removed. This was a technique developed in the 1870 s in Switzerland to be able to produce milk chocolate all year round. Milk was only available for a number of months every year, so the options were either to stop making milk chocolate or use sour milk. By making crumb, the milk was “preserved”, while also ensuring a supply of crumb to make chocolate at any time.

Crumb-making involves a lot of chemistry, as the high temperatures involved in making crumb means that the added sugar starts to caramelise, while reactions between amino acids and lactose from the milk develop “cooked” flavours (the Maillard reaction).

*For an older audience: Given that the Maillard reaction requires a reducing sugar, apart from the proteins, to occur, the lactose is crucial as it is a reducing sugar, while sucrose is not. Different processing conditions (temperature and pressure) will also produce a different flavoured crumb, as the rate of the many reactions occurring will change. When cooking crumb, agglomerates are formed consisting of the constituent components, which then need to be physically broken down again and refined to make chocolate.*

Crumb thus has all of the ingredients required for a milk chocolate – cocoa butter and cocoa powder (from the cocoa liquor), milk fat and non-fat milk solids (from the milk). The fat content is however still too low, and hence more fat (cocoa butter) must be added to make a chocolate bar.

## Slide 9 – Non-Crumb Dark/Milk Chocolate

Non-crumb chocolate, sometimes known as powder chocolate, is made differently. In this case, the individual ingredients are not cooked together, but mixed and refined, and then more fat is added. The word powder doesn’t refer to a powdery texture or mouthfeel, but the fact that *cocoa powder* and *milk powder* and sugar (a kind of powder in itself) are used to make this type of chocolate.

## Slide 10 – How does Chemistry come into all of this?

Let’s get a bit deeper into the chemistry of all of this.

## Slide 11 - Chemistry happens all throughout the chocolate-making process – from bean to bar (*Animated slide*)

Enjoying a chocolate bar is only that last step of a long sequence of processes, starting from the growing of the cocoa beans to actually eating it. Cocoa beans need to be grown, then harvested, fermented and dried. The beans are then roasted, and can then be used to make chocolate crumb or pressed to make cocoa liquor and cocoa powder. The crumb or the powder, along with the cocoa butter are then used to make chocolate. To mould melted chocolate it needs to be tempered, then cooled and stored, after which it can finally be eaten as a bar.

There is chemistry happening in all of these processes, even ones you may not think of as obvious. The growing conditions – the soil, climate, rainfall, cocoa tree variety – all have an impact, as they may lead to different flavour precursor molecules being generated. Flavour precursor molecules may be flavourless themselves, but are broken down into flavour molecules later on, especially during fermentation and roasting.

Fermentation indeed starts to break down these flavour precursor molecules into fruity flavours, as well as producing acids, and other flavour precursors.

During roasting, due to the temperature involved, more of the flavour precursors are broken down, while a lot of roasted and nutty flavours are generated as a result of the Maillard reaction.

We’ve already discussed crumb-making, and the caramelisation of the added sugar, and the “cooked” flavour development between the reaction of lactose (a sugar naturally present in milk) and proteins (mostly from the milk).

During chocolate making there is a lot of flavour refinement, such as removal of the acids to make the chocolate taste less sour, addition of flavours such as vanilla. There is also other chemistry happening when emulsifiers are added to reduce the viscosity of the chocolate.

To have a shiny chocolate bar which has a good “snap” the melted chocolate must be tempered, which means that we need to delve into the chemistry of fat crystal formation and polymorph control.

There is chemistry also happening during storage, where a chocolate manufacturer tries to control the appearance of fat bloom, that harmless whitish haze on the surface of the bar.

Finally, munching on a piece of chocolate takes us to explore the chemistry of flavour release and mouthfeel.

In this session we’ll be focusing on the last three, including an interactive session at the end.

## Slide 12 – Chocolate Tempering and Crystal Polymorph Control

Let’s start off by delving a bit deeper into what are crystal polymorphs and chocolate tempering.

## Slide 13 – What are crystals and different polymorphs?

Crystals are formed when the components making up the material, be they atoms, ions or molecules, arrange in a regular repeating pattern.

Sodium chloride, the crystal shown here, is made up of sodium and chloride ions arranged in a very specific, repeating pattern. This is what makes sodium chloride crystalline. Sodium chloride however is not polymorphic, which means that the sodium and chloride ions cannot be found in any other arrangement when solid.

## Slide 14 – Cocoa Butter is Polymorphic

Cocoa butter, the main fat found in chocolate, however is polymorphic.

This means that different polymorphs are actually a result of how the molecules making up cocoa butter stack together, depending on how the cocoa butter is handled.

There are 6 accepted polymorphs, or forms, of cocoa butter, although there are probably a number of intermediate ones too. To get a nice and shiny bar, the manufacturer aims for Form V cocoa butter.

## Slide 15 – The different polymorphs of cocoa butter

As you can see in this picture, these are the different arrangements, or stacking, that the molecules that make up cocoa butter can form. You can see, going from left to right, that the molecules are more and more tightly packed, and therefore the crystal is more stable.

## Slide 16 – Polymorphs of Cocoa Butter

As can be seen from the table, going from Form I to VI, the melting point increases with increasing form. (*For an older audience: this means that the polymorphs are more thermodynamically stable. In fact, going from Form I to Form VI, cocoa butter is crystallised in the sub-alpha, to alpha to beta-prime to beta forms, and in turn sub-forms of these. Form V is a beta-2 crystal, while Form VI is a beta-1 crystal*).

Having such a low melting point when it’s in Forms I and II, means that the chocolate is very soft and crumbly, and will spontaneously try to go to a more stable, and higher melting point, crystal forms.

Chocolate in Forms III and IV is firmer, but is still dull and doesn’t snap, and will also try and re-crystallise to the more stable Form V.

Form V is the stable form that manufacturers strive for, although it is still not the most stable. Form V also melts at around 34 °C, which means that it melts when put in the mouth, which makes for a very nice eating experience.

Manufacturers can’t make the most stable form, Form VI, directly. This only forms spontaneously during storage, albeit very slowly (in the order of months). Form VI cocoa butter is also very hard and melts slowly in the mouth, so as a manufacturer you would actually want your chocolate to stay in Form V.

## Slide 17 – Chocolate tempering

What is tempering? Tempering is the process where chocolate is melted then cooled down in a controlled manner. This is important because if chocolate is not tempered correctly it doesn’t end up having a nice shiny surface and a good snap, which we all look for when buying and eating chocolate.

Why is this important? Cocoa butter is polymorphic, which means that not only do crystals form when cocoa butter is cooled down and changes from liquid to solid, but it can also form different “forms” of crystals when it cools. Which “form” it crystallises to depends on how it is cooled down.

## Slide 18 – Tempering Chocolate (*Animated Slide*)

Starting with solid chocolate, it needs to be melted out completely by heating to 45-50 °C. At this temperature the cocoa butter molecules are completely disordered, shown by non-aligned grey molecules.

When you then cool the melted cocoa butter you will spontaneously form cocoa butter crystals, however these will be of different forms (shown as blue and pink), which include undesired forms. You thus have to re-heat the chocolate to melt out the undesired crystal forms, as the undesired crystal forms have a lower melting point, as we saw previously.

On letting the chocolate set, the crystals act as templates for the liquid fat molecules, which means that the liquid fat crystals stack on top of the crystallise fat molecules. This leads to the chocolate turning solid.

## Slide 19 – Tempering Chocolate (*Animated Slide*) – for a very advanced audience only

There are two methods to temper chocolate, both involving the careful control of the temperature of the chocolate.

Starting with solid chocolate, it needs to be melted out completely by heating to 45-50 °C. At this temperature the cocoa butter molecules are completely disordered, shown by non-aligned grey molecules.

You then have two options, shown by the solid line and dashed line. If you choose to follow the solid line, once the chocolate has been melted out fully, you then cool it again to around 33 °C, at which point you “seed“ that melted chocolate by adding chocolate or cocoa butter which has already been tempered to contain only Form V seeds. Why is the temperature important? If the “seeds” are added at a high temperature, then the “seeds” would melt out. At a lower temperature you start going into dashed-line territory, i.e. you would spontaneously start forming crystals, including unwanted forms. If you do decide to “seed” the chocolate, and follow the solid line (Method 1) at this point you’ll have some cocoa butter seeds (aligned molecules in pink) and some melted cocoa butter (grey non-aligned molecules).

If you decide to go down the dashed-line route (Method 2), you will spontaneously form cocoa butter crystals, however these will be of different forms (shown as blue and pink), which include undesired forms. You thus have to re-heat the chocolate to melt out the undesired crystal forms, as the undesired crystal forms have a lower melting point, as we saw previously.

Using either method, you end up with properly tempered liquid chocolate, i.e. all the crystals present is in Form V, however not all of the fat crystals are crystalline yet, and hence the chocolate is still liquid, if quite thick.

On letting the chocolate set, the crystals act as templates for the liquid fat molecules, which means that the liquid fat crystals stack on top of the crystallise fat molecules. This leads to the chocolate turning solid.

Which method is used is irrelevant, as long as you’re careful with the temperatures used, as both mean that you end up with well-tempered chocolate. In generally, however, Method 1 is commonly used at home, where one would add grated chocolate to melted chocolate.

Method 2 is the preferred method of chocolate manufacturers and chocolatiers.

## Slide 20 – Fat Bloom (and Control)

Moving on from tempering, and the chemistry of crystallisation from melts, to a different crystallisation phenomenon, that of fat bloom, and how to control it.

## Slide 21 – What is fat bloom (*Animated Slide*)

First of all, what is fat bloom? Fat bloom is usually observed as a “fuzz” on the chocolate surface, or it has patches which are pale and others which are dark.

*For an older audience: fat bloom is actually seen because the fat crystals are so irregular and large that they scatter light, which shows up as a pale colour.*

As you can see in the picture, on the left you have a well-tempered dark chocolate. It’s shiny, and you can “hear it” snap. In the middle you can see a bloomed dark chocolate, with a pale surface. This is the type of bloom that happens spontaneously with time. (*For an older audience: this is generally a result of Form V cocoa butter re-crystallising to Form VI, i.e. the more thermodynamically stable form of cocoa butter*). On the right you can see a dark chocolate which has been thermally abused, i.e. it’s been left in the sun, which has caused it to melt and re-crystallise (re-solidify) on its own.

Bloomed chocolate tends to put people off as it can look a bit like mould. There is however nothing mouldy or harmful about bloomed chocolate in any way. it may just not feel as pleasant in the mouth.

The causes for these two types of bloom are different, but they are both due to the uncontrolled crystallisation of fat crystals.

## Slide 22 – How does fat bloom occur? (*Animated Slide*)

When fat bloom occurs spontaneously, i.e. not because it’s been left in the sun, it can occur for a number of reasons.

As shown in the previous slide, as in the middle chocolate, you can get spontaneous fat crystal re-crystallisation if you leave it in the cupboard for too long.

As we also saw earlier, less stable forms will want to transform to a more stable form. This means that a chocolate which has not been tempered properly will want to reach Form V, and this recrystallisation from lower Forms to form V shows up as bloom, usually as a lot of paler streaks or a blotched appearance.

Fat migration from a filling, or nut inclusions, is a common cause of bloom. This is usually seen in dark chocolate with hazelnuts in, or pralines which are filled with a nut-flavoured filling. This causes oils from the nuts or filling to migrate to the surface of the chocolate. These oils then interact with the fat crystals on the surface of the chocolate, again eventually causing them to re-crystallise in an uncontrolled manner.

Temperature cycling, or temperature abuse, is also another reason. This doesn’t mean that the chocolate has necessarily been melted out, as we could see in the previous slide. The chocolate may still remain solid, however the storage temperature goes up and down multiple times, which again can cause crystal instability.

## Slide 23 – How can we prevent fat bloom developing? (*Animated Slide*)

We’ve already spoken about the first two things a manufacturer, and we, can do – keeping a stable storage temperature, and tempering chocolate correctly.

There is however also a lot of chemistry that can be used to prevent, or slow down, the formation off at bloom.

There’s the formulation of the chocolate itself. Adding milk fat affects not only the flavour and texture of the chocolate, but it has been shown that adding enough also slows down fat bloom formation considerably. Adding too much however will make the chocolate too soft and may actually cause fat bloom.

*For an older audience: cocoa butter is mostly made up long-chain palmitic, stearic and oleic fatty acids, while it has been shown that the addition of a small proportion of medium-chain lauric fats, which milk fat contains, but cocoa butter is poor in, helps to prevent against fat bloom.*

Milk fat however is not the only fat which can be used, and there are other speciality fats which can also be used.

*For an older audience: this includes the rare and expensive BOB triacylglycerides (behenic-oleic-behenic, but also some specific emulsifiers, especially STS (sorbitan tristearate). It is thought that the latter caps the crystals formed, preventing any further templating, and hence the crystals can’t grow any larger, hence can’t scatter light as they aren’t large enough to do so, and hence no bloom is observed.*.

Finally, the filling formulation has also to be taken into consideration. If the filling is made up of too many fats which are considered “incompatible” with cocoa butter, such as liquid oils (e.g. hazelnut oil), or coconut oil (*for an older audience: which is very high in lauric fats*), then the interaction of these, or, in other words, their chemistry, can easily lead to fat bloom formation.

## Slide 24 – What gives chocolate its flavour?

Slide 25 – What is flavour?

* Both taste (which you perceive with the tongue – sweet, salty, sour, bitter, umami)
* and aroma which you perceive with the nose.

## Taste

Further info in case there are questions

Other tastes have been identified :

* Fat taste – CD36 receptors identified which respond to fatty acids (need lipase to break down the fats)
* Kokumi – delicious, rich mouthfullness, calcium ion channels have been discovered CaSR which are activated by g-glutamyl peptides
* Metallic taste
* Water

## Aroma

Our noses are more sensitive to some compounds than even the most sophisticated analytical instruments.

So what type of aromas do you expect in chocolate?

## Slide 26 – What does this one smell of? (2,3-pentanedione)

Questions for the audience

What does it smell of (without the pictures)?

Does it remind you of any of these? (with the pictures)

Usually buttery, creamy, toffee, butter popcorn, but any answer goes!

Do you expect to find it in chocolate?

If so what kind of chocolate – milk chocolate?

## Slide 27 – What does this one smell of? (vanillin)

Questions for the audience

What does it smell of (without the pictures)?

Should be familiar (and you could present this one first)

Does it remind you of any of these? (with the pictures)

Usually vanilla ice cream, vanilla icing!

Do you expect to find it in chocolate?

Did you know if was from an orchid (the flower)

And did you know that before vanilla is fermented, it looks like green beans hanging on a tree.

## Slide 28 – What does this one smell of? (phenylacetaldehyde)

Questions for the audience

What does it smell of (without the pictures)?

Does it remind you of any of these? (with the pictures)

Usually sweet floral hyacinth waxy citrus but any answer goes!

Do you expect to find it in chocolate?

If so what kind of chocolate – some milk chocolates have a rosy note in them.

## Slide 29 – What does this one smell of? (furaneol)

Questions for the audience

What does it smell of (without the pictures)?

Does it remind you of any of these? (with the pictures)

Usually burnt sugar or candy floss

Do you expect to find it in chocolate?

## Slide 30 – What does this one smell of? (delta decalactone)

Questions for the audience

What does it smell of (without the pictures)?

Does it remind you of any of these? (with the pictures)

Usually fruity, peachy, tropical

Do you expect to find it in chocolate?

Not really, but it contributes to the overall aroma

## Slide 31 – What does this one smell of? (3-methylbutanoic acid)

Questions for the audience

What does it smell of (without the pictures)?

Does it remind you of any of these? (with the pictures)

Usually cheese, parmesan,

Does anybody get a vomity note?

Do you expect to find it in chocolate?

No, but incredibly important component of chocolate flavour

## Slide 32 – Let’s taste some chocolate!

At this point the audience should have access to two different chocolates, ideally without any fillings or strong flavours.

Describe the Taste and Texture of Chocolate 1

Describe the Taste and Texture of Chocolate 2

Can anyone recognise any of the aromas that you’ve just smelled?

Maybe not, and that’s the secret of mixing different aromas (none of which smell of chocolate) to get an overall chocolate aroma.

## Slide 34 – QR code for students’ feedback

## Slide 35 – QR code for teachers’ feedback