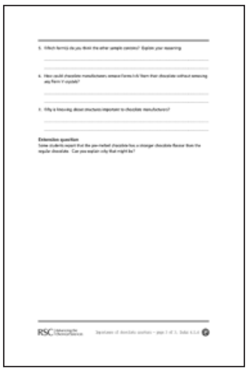
The importance of structure: chocolate



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This activity would be a good introduction to the topic of structure and bonding. It emphasises how important it is to know about the structure of a substance and demonstrates that structure can make a big difference to the properties of a material. The concept of polymorphism is introduced and can be built on later.

The activity is fun to do, interesting and the taste tests are always popular. It is adapted from material on the Seeing Science website of the CCLRC (Council for the Central Laboratory of the Research Councils). The activities on this website are aimed at 11–14s. For more information, see **http://www.seeingscience.cclrc.ac.uk/** (accessed December 2005).

Prior knowledge required

Students need to know about changes of state and be able to interpret graphs showing changes of state.

Background information

Since its discovery in the 1500s when the Spanish sailed to the New World, chocolate has been an increasingly popular confectionery material in Europe. The first bar of chocolate was produced by Fry and Sons in 1847 and milk chocolate was produced for the first time by Henry Nestlé about 30 years later.

Chocolate is made from naturally occurring ingredients. It is a mixture of many chemical compounds, of which about 400 have been identified. Taste, texture, gloss, ‘snap’ and other properties can be varied according to how the mixture is processed and chocolate manufacture is a very complex, multi-step process. Successful chocolate making also requires an understanding of how the consumer perceives the product. Tastes in the UK and the USA are very different and European chocolate is different from both the UK and the USA versions. The taste is only partly dependent on the recipe used; the manufacturing process is also key.

Chocolate is made from cocoa beans, which are the seeds of the *Theobroma cacoa* tree. (Theobroma means food of the gods and is nothing to do with bromine.) The beans form in pods. These pods are harvested and the beans are extracted, fermented and roasted before they are shipped to chocolate manufacturers.

The process of making a chocolate bar begins with mixing and grinding. The ingredients are mixed together and ground until the particles are the correct size. The particle size is critical to the 'mouth feel' of the product and is typically about 0.02 mm. The next stage is known as 'conching' and involves the removal of volatile compounds and adjustment of the moisture content and viscosity. This gives the end product its desired flavour. The mixture is melted, sheared (stirred) and cooled in a complex process known as tempering. The temperature and shearing have to be very carefully controlled or the chocolate ends up brittle, crumbly and with the wrong taste. This part of the process and its effects are modelled in the experiment the students carry out.

The complexity of chocolate is the result of one of its key ingredients: cocoa butter. Cocoa butter is a triglyceride produced by the reaction of glycerol (propan-1, 2, 3-triol) with various fatty acids to form a molecule with the shape of the capital letter E. Cocoa butter fats are polymorphic (they can take on a number of different crystal forms). Each different form has its own characteristic melting point and this affects how the product feels in the mouth. The form favoured by the chocolate industry is Form V which, with a melting point of 33.8 °C, 'melts in the mouth' and is the one generally favoured by consumers.

Assessing exactly which forms are present and the precise conditions under which they are produced is an area of on-going investigation. Scientists at the CCLRC Daresbury Laboratory have used X-rays to investigate the structure of chocolate and a video clip of their experiments is available (see next page).

References and further information

http://www.cclrc.ac.uk/activity/ACTIVITY=SRDAnnualReport9697;SECTION=469 (accessed December 2005) – a report on research into chocolate structure at CCLRC.

P. Fryer and K. Pinschower, *Materials Research Society Bulletin*, 2000, **25**, 25–29 – 'The Materials Science of Chocolate,' an excellent (although long) article on the manufacture of chocolate, with reference to its structure.

G. Tannenbaum, *J.Chem. Ed*, 2004, **81**, 1131–1135 – 'Chocolate: A Marvellous Natural Product of Chemistry.'

http://www.cadbury.co.uk (accessed December 2005).

Equipment required

Chocolate to eat:

- At least two squares of milk chocolate per student. Half needs to be melted and re-hardened first. Take a whole chocolate bar (the ones that are fully wrapped in one sealed wrapper are best). Put it somewhere warm (such as on a radiator) and allow it to melt. Once it has melted, put it in a refrigerator (not the one where the chemicals are stored) to harden quickly. Once it has set, remove it and allow it to return to room temperature prior to the lesson. The remaining chocolate should be of the same make and type but simply stored at room temperature.

Practical work – for each pair or group of students:

- 1 square of milk chocolate
- 1 square of the same type of chocolate which has been pre-melted and re-hardened (see above)
- 2 boiling tubes

- 250 cm^3 beaker or access to a hot water bath
- Kettle (for boiling water)
- Thermometer
- Timer.

Health and safety

Students should not eat in a laboratory.

Check whether any students are diabetic or have other disorders that preclude them eating chocolate.

Boiling water can cause scalding. Warn students to take care.

Suggested lesson plan

- The introduction must be carried out away from the laboratory because students need to eat the chocolate samples. Give each student two pieces of milk chocolate, one from an ordinary chocolate bar and one from a bar of the same kind which has previously been melted and quickly re-hardened. Students should note the differences that they can see, try snapping the pieces and note what happens then eat the chocolate and notice any differences in taste and texture. This should not be a blind trial – they should know which piece is which. Once they have eaten the chocolate they can carry out the rest of the activity in a laboratory. They should be warned not to eat any more of the chocolate during the lesson.
- Discuss the differences between the two pieces of chocolate. Emphasise to students that the chemical composition of the chocolate that was melted is unchanged because it was heated and cooled within the wrapper. Nothing has been added or removed but the chocolate has clearly changed. The way the atoms are arranged and the structure of the components have changed. Ask students how chemists find out what a substance is and what its structure is like. Explain that they will see how scientists at CCLRC in Harwell, Oxfordshire found out about the structure of chocolate, then they will plan and carry out an experiment for themselves.
- Students work through the information on the student sheet and attempt the first few questions.
- Show the video clip from **http://www.seeingscience.cclrc.ac.uk/Activity/Food;SECTION=5237** (accessed December 2005). This clip is also available on a CCLRC CDROM (details are on the website).
- Students plan and carry out the practical work. A set of clue cards is included in this resource to assist students who struggle with the planning aspect of the activity. Photocopy and cut out the clue cards before the lesson. Students should take one at a time and think about how the information helps them to plan an experiment to find out whether chocolate samples contain Form V cocoa butter. A few blank cards have been provided should you wish to create your own clues.

  They should aim to use as few clues as they can when they design their experiment.

Answers

1. Chocolate manufacturers are keen to ensure that their product contains mainly Form V cocoa butter as this is the one that tastes best and has the best texture. It also has a melting point close to body temperature so that the product 'melts in the mouth.'
2. The difference between Form V and the others is the way the molecules are arranged in the structure. They all have the same chemical formula.
3. To test the two samples of chocolate for Form V it will be necessary to measure their melting points. If either melts at around 33–34 °C then it contains Form V. Place each sample in a boiling tube and put it in hot water (50 °C is a good temperature to use). Measure the temperature every 15–30 seconds. The sample should be stirred between temperature readings. Continue until the sample is completely molten. Alternatively, data logging equipment could be used. Plot a graph of temperature against time. If the graph has a plateau at around 34 °C then the sample contains Form V.

Standard chocolate		**Pre-melted chocolate**	
Time (s)	**Temperature (°C)**	**Time (s)**	**Temperature (°C)**
0	23	0	23
30	28	30	33
60	34	60	37
90	35	90	40
120	39	120	42
150	43	150	46
180	46	180	48
210	48	210	50

Table 1 Sample results

Results will vary slightly depending on the type of chocolate used, the temperature of the water, the quantity of chocolate used and how well the mixture is stirred.

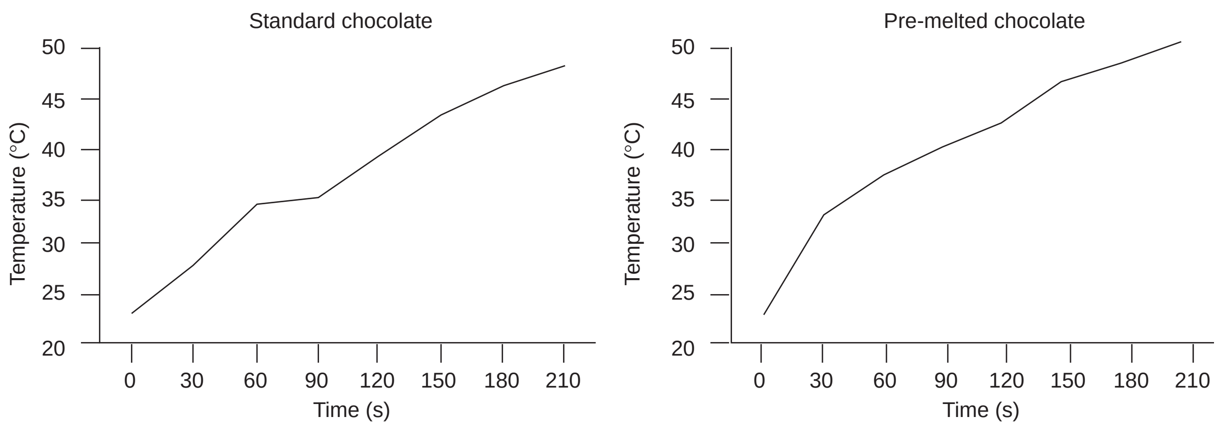

Figure 1 Graphs of sample results

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4. The standard chocolate contains Form V chocolate. On the graph there is a plateau or levelling out at 33–34 °C, which is the melting point for Form V. This is caused by the change of state occuring at this temperature.
5. The other sample melts almost as soon as it is put into the hot water. It is hard to tell from the data which form it contains, but as it is not V or VI it must be one of the others. (It is probably a mixture of Forms III and IV).
6. You could remove Forms I–IV by heating the chocolate above 27.3 °C but keeping the temperature below the melting point of Form V (33.8 °C). The molten and solid components could then be separated.
7. Knowing about structures is important to chocolate manufacturers because they want to sell lots of chocolate. Customers only buy chocolate they know they will like so the product needs to be consistently good. As the structure of the cocoa butter has so much impact on the flavour and texture of the product, it is important that manufactures know how to get the required structure.

Extension question

The pre-melted chocolate has a lower melting point than the other sample. If the chocolate is liquid for longer while it is in the mouth then it is more likely that the volatile flavour compounds will be released and will reach the mouth and nose. If more flavour compound molecules are released, a greater sensation of flavour is achieved. You may wish to discuss why this form of chocolate is not used instead. The answer is that it does not rate as well in terms of texture, 'mouth feel' and 'snap.'

The importance of structure: chocolate

Your teacher will give you two pieces of chocolate. They are both the same type and the same brand but one has been taken from a bar that was melted and re-hardened in a fridge, whilst the other is from a bar that was stored normally. Before you eat the chocolate note its texture and appearance. Try snapping both samples. When you eat the chocolate, note any difference in taste and texture between the two pieces.

Record your observations.

Background information

Chocolate is a common confectionery product sold throughout the world. Making chocolate requires the manufacturer to understand how the consumer perceives it and what they like and dislike. The preferred type of chocolate varies from country to country as you will know if you have tried chocolate from the USA (eg Hershey's and Reese's) or from various parts of Europe. Many people from the USA do not like British chocolate, just as many British people do not like the American varieties. Your favourite chocolate is an individual choice but generally the different tastes and uses for chocolate in different countries reflect the history of the chocolate-making industry in those places. In Mexico, for instance, chilli is added to drinking chocolate.

The taste of the chocolate is partly determined by the receipe used to make it but there is more to it than that. You have tried seemingly identical chocolate bars which were made to the same recipe – but they tasted different. This is because the taste of chocolate is dependent on its microscale structure. Chocolate is made up of tiny particles and crystals which range in diameter from 0.01 mm to 0.1 mm. These particles govern how the chocolate is perceived by the consumer. In order for you to taste the flavour compounds in chocolate, they have to reach your mouth and nose. However, the texture of the chocolate is important too. The way you perceive the texture is a result of how the chocolate melts and breaks up in the mouth.

Ingredients of Cadbury's Milk Chocolate: Milk, sugar, cocoa mass, cocoa butter, vegetable fat, emulsifiers, flavourings.

A key ingredient of chocolate is cocoa butter. Cocoa butter is a fat and it has at least six different crystal forms. This means that the atoms are the same but they are arranged differently. The different arrangements can lead to different properties in the chocolate, including melting point, how easily it snaps, strength, glossiness and texture. You can think of the atoms as being a bit like lego bricks. You can use the same bricks to make different structures – some will be stronger, some will look better.

The ability of a substance to take on many different crystal forms is called polymorphism (poly means many; morph means shape). The details of the polymorphism of cocoa butter are very complex and this is still an area of active research. It is known, however, that one of the six polymorphs has a far superior taste and texture compared to the others – the one known as Form V. Chocolate containing Form V is also the glossiest and snaps well.

The table below shows some of the characteristics of different cocoa butter polymorphs.

Polymorph	Conditions needed to make the polymorph	Melting point (°C)
Form I	Rapid cooling of the molten chocolate	17.3
Form II	Cooling the molten chocolate at 2 °C	23.3
Form III	Solidifying the molten chocolate at 5–10 °C or storing Form II at 5–10 °C	25.5
Form IV	Solidifying the molten chocolate at 16–21°C or storing Form III at 16–21 °C	27.3
Form V	Solidifying the molten chocolate while stirring it. Requires a special process called 'tempering'	33.8
From VI	Storing Form V for four months at room temperature	36.3

1. Why are chocolate manufacturers keen to ensure that their chocolate contains mainly Form V cocoa butter?

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2. What is the difference between Form V and all the other forms?

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3. How could you test the two types of chocolate you tasted at the start to see if they contain Form V? Write a plan and get it checked by a teacher before you carry it out.

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Your results

Record your results clearly in a table. Draw a graph of your results for each chocolate sample.

4. Which (if any) of your chocolate samples contains Form V cocoa butter? Explain your reasoning.

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5. Which form(s) do you think the other sample contains? Explain your reasoning.

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6. How could chocolate manufacturers remove Forms I–IV from their chocolate without removing any Form V crystals?

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7. Why is knowing about structures important to chocolate manufacturers?

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Extension question

Some students report that the pre-melted chocolate has a stronger chocolate flavour than the regular chocolate. Can you explain why that might be?

The importance of structure: chocolate cards

Form V chocolate melts at about 33 or 34 °C

The chocolate could be melted by placing it in a boiling tube in a beaker of hot water.

During melting, the temperature of a substance remains constant.

Which variables will you need to keep constant when testing the two samples of chocolate?

Two variables need to be measured and recorded.

You will need to draw a graph of your results. What will be on the axes?

You will need to take measurements for about 3 or 4 minutes. How often will you take these measurements? What will you measure?

Water at about 50 °C could be used to melt the chocolate.

Stirring during the experiment is a good idea.