

The chemistry of baking powder

Read the passage below, which explains the chemistry of how certain foods 'rise' during cooking and answer the questions that follow.



Sponge cakes made with (right) and without (left) baking powder

Many food products such as bread, sponge cakes and buns have a honeycomb structure which contains many bubbles. During cooking these bubbles are formed by a gas and the mixture 'rises'. In some cases the gas is air which is whipped into the mixture before cooking and which expands during cooking. In other cases the gas is carbon dioxide. This can be formed either from the fermentation of sugar aided by yeast (as in making bread) or by chemicals that react to form carbon dioxide.



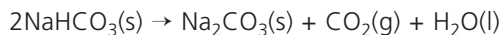
Baking powder



The honeycomb structure of bread is caused by gas bubbles

The most common chemical to do this is sodium hydrogencarbonate, NaHCO_3 (more commonly called sodium bicarbonate, bicarbonate of soda or just 'bicarb'). This can form carbon dioxide in two ways:

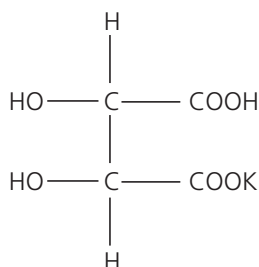
- on heating



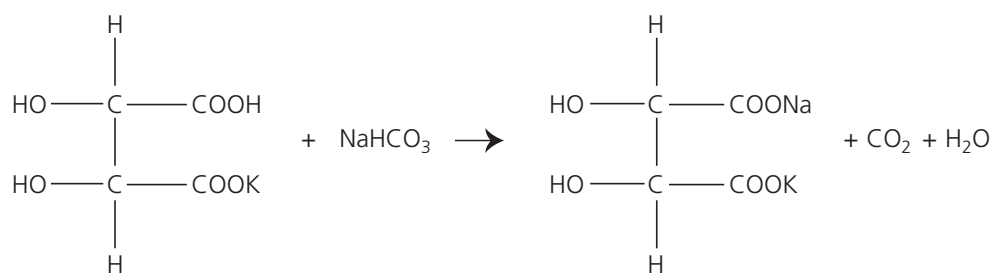
- on reacting with an acid, such as hydrochloric acid (HCl)



Cooks do not use a strong acid such as hydrochloric acid; they use instead a weak acid such as potassium hydrogentartrate (potassium hydrogen-2,3-dihydroxybutanedioate or potassium hydrogen-2,3-dihydroxysuccinate), also called cream of tartar. The formula of this acid is:

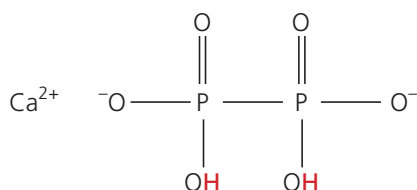


The gaseous product of the reaction is the same as with hydrochloric acid – carbon dioxide – but it is produced much more slowly. Potassium hydrogentartrate is a solid and this means that it is possible to mix it with the sodium hydrogencarbonate without the two reacting – they only react in the presence of water. This dry mixture is the basis of baking powder. The reaction is:



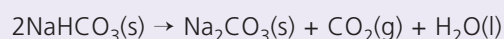
One problem with the use of potassium hydrogentartrate is that it is very soluble in water. So as soon as it becomes wet (when milk is added in a cake recipe, for example) it dissolves and reacts. This risks all the gas escaping while the cake mix is still liquid and before it goes in the oven. Most baking powders nowadays are so-called 'double acting'. This means that, along with the sodium hydrogencarbonate, they use a mixture of potassium hydrogentartrate and calcium dihydrogendiphosphate ($\text{CaH}_2\text{P}_2\text{O}_6$), which is also a solid acid. The potassium hydrogentartrate dissolves and reacts almost immediately (which makes the dish 'rise' on mixing) while the calcium dihydrogendiphosphate is slower to dissolve and will not react until the mixture is in the oven and the gas bubbles are trapped by the cake as it bakes.

Note. Both calcium dihydrogendiphosphate and potassium hydrogentartrate are acidic salts. The hydrogen atoms marked in red in the formulae of calcium dihydrogendiphosphate below are acidic. That is, the salt can dissociate, losing the red hydrogen atoms as H^+ ions.



Questions

1. Baking powder will 'go off' if it is stored for some time in the kitchen, *ie* it will lose its ability to produce gas when moistened. Explain why this happens and suggest a method of storing the powder to minimise the problem.
2. Sodium hydrogencarbonate will decompose when heated, forming carbon dioxide and sodium carbonate:



Sodium carbonate has a somewhat unpleasant 'alkaline' taste, so this method of decomposition must be avoided. Suggest how a manufacturer might formulate baking powder to prevent this problem occurring.

3. Calculate the relative molecular mass, M_r , of sodium hydrogencarbonate and of potassium hydrogentartrate. In what proportions by mass do they have to be mixed to be in the correct reacting ratio?
4. Mark the acidic hydrogen on a copy of the formula of potassium hydrogentartrate.
5. Estimate the radius and height in cm of a sponge cake. What is the volume of the cake in cm^3 ? (You will need to use the equation, volume of a cylinder radius r and height $h = \pi r^2 h$, but for this estimate it will be sufficient to take the value of π as 3.)

One mole of any gas has a volume of $24\,000 \text{ cm}^3$ at room conditions. If the cake were all gas, how many moles of gas would be present? What quantities of sodium hydrogencarbonate and of potassium hydrogentartrate would be required to produce this amount of gas?

6. As well as carbon dioxide, fermentation produces ethanol ($\text{C}_2\text{H}_5\text{OH}$, the alcohol found in alcoholic drinks). One simple sugar is glucose, $\text{C}_6\text{H}_{12}\text{O}_6$. Use this information to write a balanced equation for the fermentation of glucose.

Bread rises because of fermentation. Suggest what happens to the ethanol produced when baking bread.

Use the balanced equation for fermentation and the balanced equation for the reaction of potassium hydrogentartrate to compare the mass of baking powder with the mass of glucose required to produce the same volume of carbon dioxide.

7. Explain the meaning of the terms 'strong' and 'weak' as used to describe acids in the passage. How do these terms differ from the terms 'concentrated' and 'dilute'?
8. Explain why the hydrogen of the -COOH group in potassium hydrogentartrate is more acidic than the two -OH hydrogens.