CHAPTER 1

STATES OF MATTER

DISCOVER...

LEARN...

EXPERIMENT...

DISCOVER: THE CHEMISTRY OF COLA

The chemistry of cola is about a lot more than taste. Cola is instantly recognisable due to its distinctive colour, and that's no accident. Food scientists and chemists have long worked with marketing specialists to come up with products that are a feast for the eyes as well as the mouth. This section takes a closer look at how cola gets its colour.

Imagine you decided to make your own cola using the ingredients listed on the bottle. Mix carbonated water, sugar, phosphoric acid and caffeine, and you will be left with a clear, colourless fizzy liquid. Even adding the flavourings won't change the appearance much. It's not until you add E150d that cola looks like cola. But why do the manufacturers bother to add the colour at all? It's all to do with cola's history.

CREATING THE COLOUR

Since its creation in 1886, manufacturers have worked to preserve cola's distinctive taste and appearance, despite changes in the recipe. The original recipe has become the stuff of legend – it was reportedly shared with only four people before the death of its creator, Dr Pemberton, in 1888. Most of the recipe has been pieced together over the years, and it's known that the blend of flavours comes from various oils (citrus, cinnamon, nutmeg and more), and that the bitter kola nut was used to add caffeine. To mask the bitterness of the kola nut, Pemberton added sugar to make the drink sweet – some sugar he dissolved, and the rest he first turned into caramel. It was the adding of the caramel that gave his cola its distinctive colour.

Dried kola nuts

Although caramel is no longer added to cola, manufacturers retain the appearance of the drink by adding caramel colours. For that purpose, E150d – a soluble colouring agent which can range from yellow to dark brown – is used. You'll find this colour added to many yellow or brown foods and drinks, from coffee to pet food. Adding this colour contributes very little to the taste of cola, but it keeps it looking the way customers expect.

Chemists can change the colour of foods using E numbers 100–199, even making silver and gold foods. People often worry about additives in food, but seeing these numerical codes listed on a label isn't a cause for alarm. The codes are for convenience and to satisfy legal requirements. The numbers refer to specific chemicals – whereas 'brown food colouring' might be considered vague, 'E150d' is specific. The codes aren't just used for colours; E300 is the code for vitamin C.

SEE pages 122-123 to find out what happens when you mix cola with milk!

TRICKING THE EYE

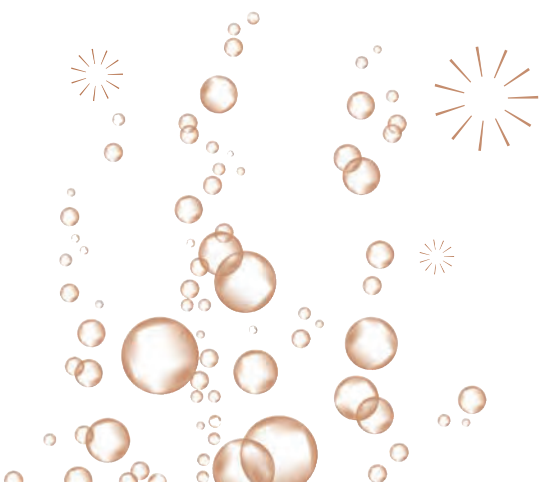
Adding colour to drinks to make them more appealing isn't the only trick in the chemist's book. The next time you go to the supermarket, take a close look at the bottled water. What colour are the bottles? You might think they are all clear, just like cola bottles, but some of the pricier bottles are actually slightly blue. A pigment is added to the plastic bottles during manufacture because people tend to view slightly blue bottles as cleaner and fresher than transparent bottles.

DISCOVER: SOLID, LIQUID, GAS

There are lots of ways we can begin to understand the world around us, and the first step for a chemist is often to think about solids, liquids and gases – the states of matter. With a bottle of cola, we have a solid bottle that holds a liquid, and that liquid holds a gas.

When cola is made, carbon dioxide (CO_2) gas is dissolved in the liquid. The liquid is then kept at high pressure to stop the gas from escaping – until the bottle is opened and you hear that distinctive hiss. When the bottle is open, the CO_2 escapes by forming bubbles, which rise to the surface and pop in the atmosphere. This is also why you burp after drinking cola: the low pressure in your stomach allows the CO_2 to escape from the liquid.

Understanding the states of matter and how substances behave at the particle level (the level of atoms or molecules) is important in helping chemists and physicists understand the world around them.



SOLIDS

In solids, the atoms or molecules (see pages 66–67 and 78–79) touch their neighbours, meaning they are trapped. This is why a solid has a fixed volume and shape. But even though the particles are trapped, they still vibrate a small amount.

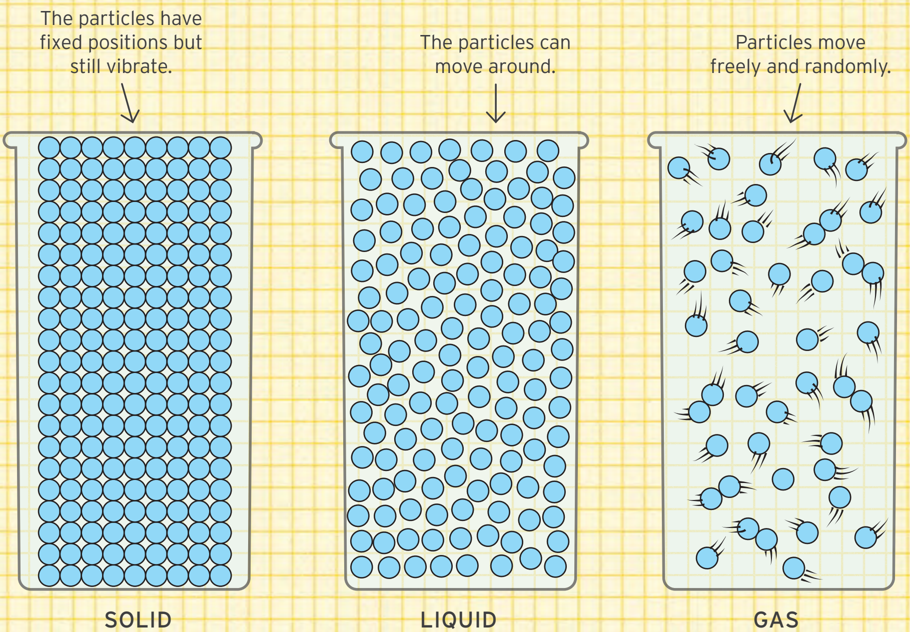
LIQUIDS

In a liquid, the particles have more freedom to move; they can move past each other, and move around randomly. We can see the result of this microscopic particle movement: liquids will take the shape of the container and can be poured.

GASES

In a gas, the particles can be very far apart. They don't cling to their neighbour, as in a solid, or flow past each other, as with a liquid. They bounce around randomly, colliding with each other and with container walls. Gases have a large volume and low density, compared with liquids and solids at the same temperature, making them very light. This is why the bubbles of gas float to the top of your cola.

THE THREE STATES



CHANGING PHASE

A substance can be transformed from solid to liquid, and liquid to gas, by heating. This doesn't mean that gases are always hotter than liquids – different substances change phase at different temperatures. At room temperature, carbon dioxide is a gas, but water (H_2O) is a liquid. The size, shape and charge of the particles in a substance determine what state it will be in at any given temperature.

SUBLIME MATERIALS

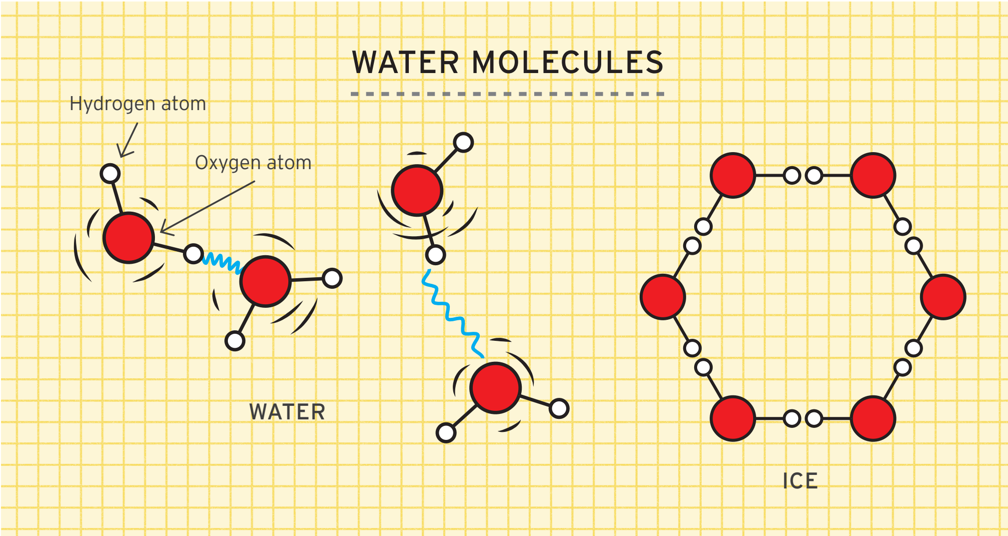
Some substances can move from solid straight to gas, a process that is called sublimation. Water can sublime; you might notice that ice cubes slowly (very slowly) shrink in your freezer. This is because some of the water particles gradually escape as a gas.

DISCOVER: ICE SURPRISE

On a hot summer day, an ice-cold soft drink can be very refreshing. You drop ice cubes into the glass, hear the distinctive fizz as they produce lots of bubbles and then there is the satisfying crack of the ice. For a chemist, this isn't just refreshing, it's fascinating – ice is an amazing and surprising material.

One of the most amazing things about ice is that it floats! This might not seem very interesting at first glance, but ice is one of a few special materials that have a solid form less dense than their liquid form. Pages 12–13 showed that solids are closely packed materials, while liquids have particles that can move around more freely. In almost every case, the liquid has more space between the particles, meaning the liquid is less dense and would float on the solid. Ice is a special exception.

To understand what is happening to make the ice less dense, we need to think about the atoms in the material and how they arrange into molecules. Water (H_2O) has a central oxygen atom with two hydrogen atoms attached. Hydrogen atoms and oxygen atoms are quite different; when they are bonded, the molecules



end up with tiny charges. The hydrogen atoms get tiny positive charges, and the oxygen atoms get tiny negative charges. As negative and positive charges attract each other, the hydrogens of one H_2O molecule will be attracted to the oxygen of another H_2O molecule. These attractions are called hydrogen bonds. At room temperature, the molecules vibrate around so much with thermal energy that these weak hydrogen bonds don't last long before the molecules drift away from each other. This all changes at 4°C (39°F).

HEXAGONAL PATTERNS

As water gets colder, the molecules wiggle less and less, and the hydrogen bonds last a little longer. At 4°C (39°F), the hydrogen bonds start to become stronger than the thermal wiggles and the molecules start to bond to each other in a regular way. The water molecule is shaped like a 'V' and the hydrogen bonds allow the water molecules to form hexagonal patterns which have bigger gaps between the molecules than in liquid water. At 0°C (32°F), a solid has formed that is 8.3% less dense than liquid water.

It's for this reason that ice floats on water. It also stops oceans from freezing from the bottom up, and allows icebergs to float on an ocean's surface, keeping sea levels down. And of course, ice allows us to have a glass of refreshing cola on a hot day.

LEARN ABOUT: KITCHEN CHEMISTRY

Try this quick-fire quiz to test your general chemistry knowledge. You might need to read ahead in the book for help.

QUICK QUIZ: IN THE KITCHEN

1. The bubbles in soft drinks are composed of which gas?

a) Oxygen
b) Nitrogen
c) Carbon dioxide
d) Dihydrogen monoxide

2. Baking powder is a mix of a carbonate, an acid and a filler, which is added to bread to make it rise. What is happening in this important chemical process? (Look ahead to page 46 for more information.)

a) The baking powder reacts with sugars in the bread to produce carbon dioxide.
b) The acidic baking powder reacts with the neutral water, producing oxygen bubbles.
c) Baking powder expands rapidly due to heat, then on cooling to room temperature it rapidly contracts, leaving pockets of air behind.
d) The dried ingredients in baking powder begin to react when exposed to water, producing carbon dioxide.

3. In cooking, the Maillard reaction is incredibly important. But what is it? (Turn to page 31 for more information.)

a) A reaction between sugars and amino acids that causes browning
b) A breakdown of potentially harmful bacteria
c) Evaporation of water, which creates a crisp surface
d) A softening of proteins, which makes meat tender

4. Caffeine is found in tea, coffee and cola. It is also found in over 60 varieties of plants. Why is caffeine present in plants? (See page 110.)

a) It speeds up growth.
b) It is a natural predator deterrent.
c) It strengthens cell walls.
d) It is a by-product of pollen production.

5. Microwaves can be used to heat food very quickly, but how do they do this? (See pages 30–31.)

a) Air molecules trapped in food absorb microwaves and move rapidly.
b) The microwaves break the bonds in the food, causing energy to be released.
c) Through the ionisation (the creation of electrical charge) of particles.
d) They cause the water molecules to spin rapidly, which causes heating.

LEARN ABOUT: SUBSTANCES AND STATES

Test your knowledge of substances and their states with this challenge. Match up the terms on the left with the correct definition on the right.

1. Non-Newtonian Fluids

2. Plastics

3. Sublimed Substance

4. Gases

5. Solids

6. Liquids

a. They are made of long chains that can get tangled up.

b. Their particles move around freely and easily.

c. How solid or liquid they are depends on how much force is applied to them.

d. Their particles are packed relatively tightly together, although the particles are also free to move around.

e. This has changed from a solid directly to a gas.

f. Their particles are tightly packed together.

EXPERIMENT: EXPANDING ICE

In this experiment you will measure the density change when water freezes into ice. For this, you will first need to freeze water and measure the volume change.

YOU WILL NEED:

- 500-ml (1-pt) plastic measuring jug
- 250-ml (8-fl oz) measuring jug
- Water
- Freezer

ADULT SUPERVISION REQUIRED

WHAT TO DO:

1. Add 350 ml (12 fl oz) of room-temperature water to the large measuring jug.

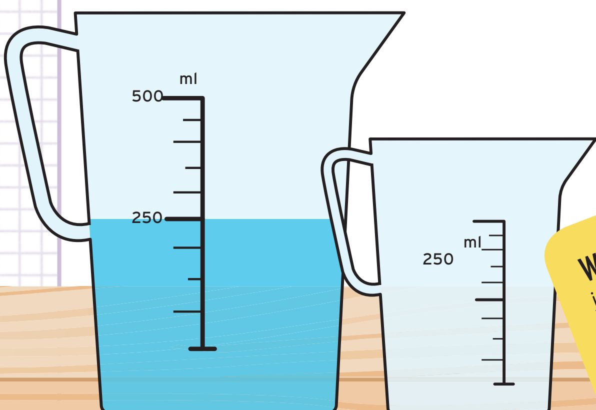
2. Place the jug carefully in the freezer, making sure that it sits flat. (Ask an adult for help.)

3. Wait until the water is completely frozen before removing the jug from the freezer. You need to work out the new volume, but the surface might be irregular, so an extra step is needed.

4. Leave the jug to stand for 5–10 minutes – this will avoid thermal shock (which could break the jug) when extra water is added.

5. Add cold water on top of the ice and fill up to the 500-ml mark. Pour the water you just added into the small measuring jug and record the volume.

6. The volume of the ice is equal to 500 ml, minus the extra water you added.



WARNING: Glass measuring jugs can shatter if exposed to sudden temperature changes. It is recommended that you use a strong plastic jug for the freezing.

MEASURING DENSITY

Density (ρ) is defined as the mass (m) divided by the volume (V). This is written as:

$$\rho = \frac{m}{V}$$

$$\rho = \frac{\text{mass in grams}}{\text{volume in cm}^3}$$

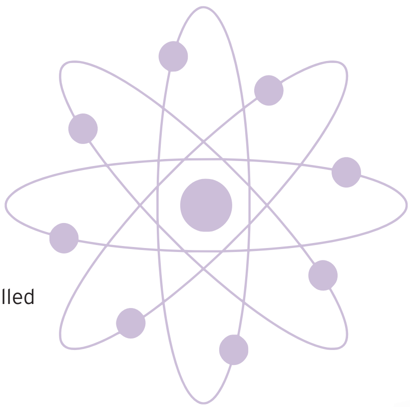
You have measured the volume, and because you are using water, you already know its mass. One millilitre (1⁄5 teaspoon) of water has a mass of one gram (1⁄25 oz) at room temperature, so if you have 350 ml, it will weigh 350 g.

To calculate the above formula, you need to convert millilitres into cubic centimetres (cm^3). Luckily, 1 ml is equal to 1 cm^3, so you can use the numbers you measured.

To calculate the density of water, you must complete the formula:

$$\rho = \frac{350}{350}$$

$$\rho = 1 \text{ g/cm}^3$$



Let's calculate the density of the ice (unless you spilled some, the mass should be the same as the water).

To calculate the change in density, use the formula:

$$\text{Percentage decrease} = \frac{\text{density of water} - \text{density of ice}}{\text{density of water}} \times 100$$

Ice is reported to be 8.3% less dense than water. How close did you get? Where might any errors or uncertainty lie in your experiment?