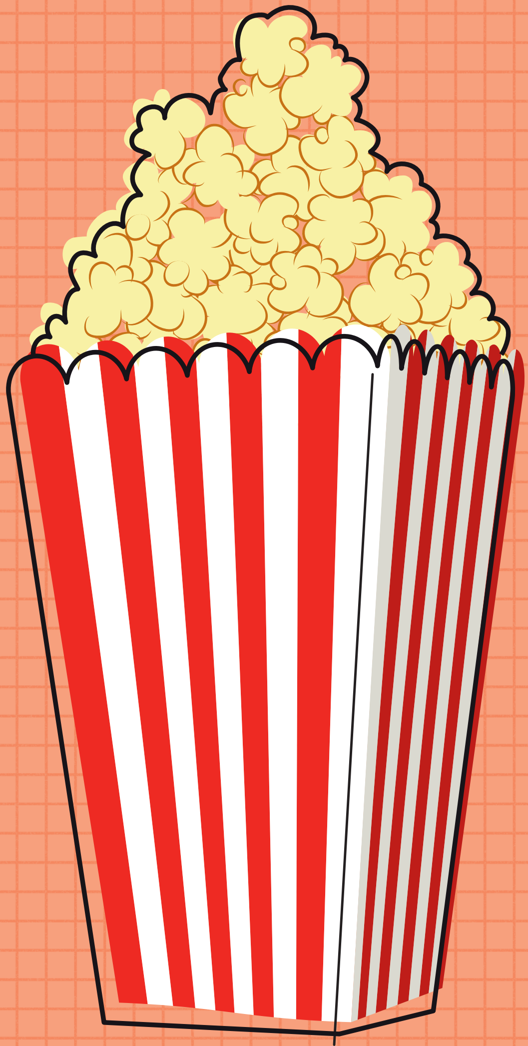


CHAPTER 1

ENERGY AND HEAT

DISCOVER...

LEARN...

EXPERIMENT...

DISCOVER: DENSITY AND FLOATING

Unpopped kernels of popcorn are small and hard. When they pop, a larger, softer, tastier food is produced. What makes a kernel pop? Inside each kernel there is water and hard starch. Heat is needed to soften the starch and break open the kernel.

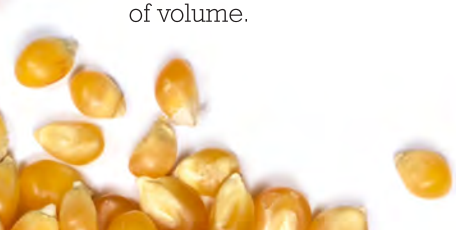
MASS AND VOLUME

The first thing to look at is how the density of the popcorn changes. Density states how much mass there is in a unit of volume. Mass describes how heavy an object is, and volume is a way of measuring how much space an object takes up. For example, if you have a litre of milk, the litre is the unit of volume. A heavy object has a lot of mass, and a light object has little mass. If you assume that every popcorn kernel has the same mass, doubling the number of kernels should double the mass. Another way of saying this is that the mass is proportional to the number of popcorn kernels.

The density is given by the equation:

$$\text{Density} = \text{Mass} \div \text{Volume}$$

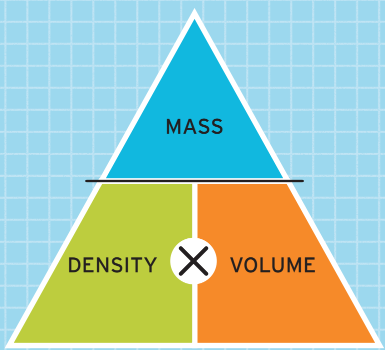
That said, density does not always refer to mass. For example, energy density refers to how much energy there is in a unit of volume. Popcorn kernel density can be defined as the number of popcorn kernels in a unit of volume.

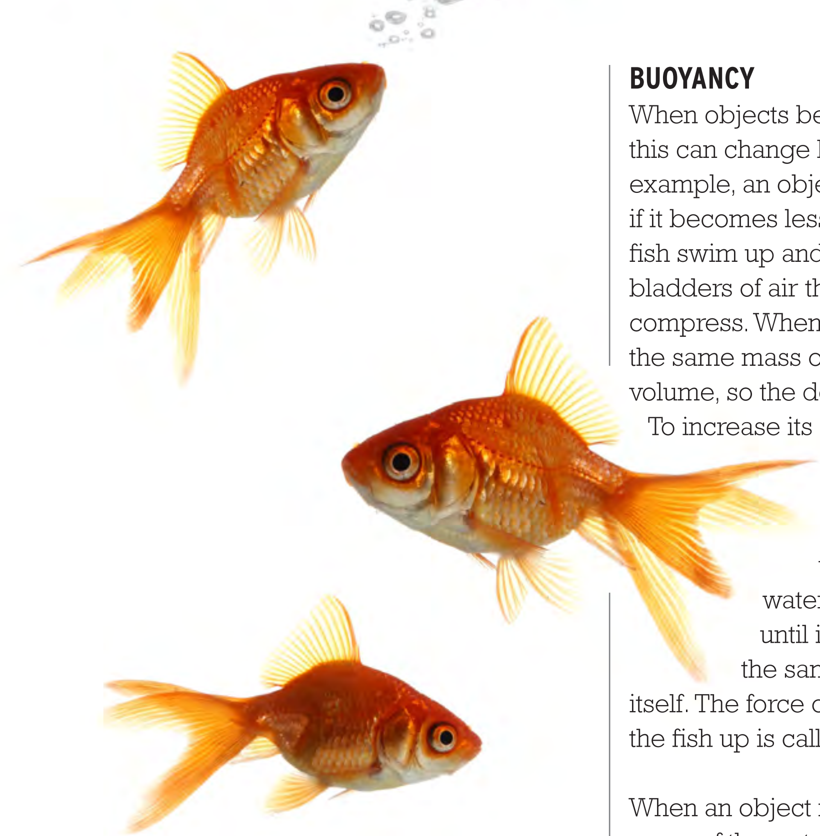


VISUALISING EQUATIONS

Throughout this book you will be working with equations similar to that for density. They can be represented by a triangle. If you know two values, and you need to know the third, you can cover up the unknown value with your hand to find out how to calculate it.

For example, to calculate density, cover it up on the triangle below. You'll find that you need to divide the mass by the volume. If you wanted to calculate the mass, you would cover it up and find you need to multiply the density by the volume.





BUOYANCY

When objects become less dense, this can change how they act. For example, an object might float in water if it becomes less dense. This is how fish swim up and down – they have bladders of air that they can expand or compress. When the bladder expands, the same mass of air takes up a larger volume, so the density decreases.

To increase its density, the fish can compress the bladder of air. If the whole fish is less dense than the water around it, the water will push the fish up until it reaches water that is the same overall density as itself. The force of the water pushing the fish up is called buoyancy.

When an object is placed in water, some of the water has to move out of the way, and we say the water is displaced. The buoyancy is equal to the weight of liquid that the object displaces, so if the fish has a volume of 500 ml, it will feel a force of the weight of 500 ml of water pushing it up. If that force is more than the fish's weight, the fish will rise. To go deeper into the water, the fish must increase its density, so that the weight of the fish is greater than the buoyancy of the fish.

EXPERIMENT: THE FIRST POP

When popcorn is made, one thing you'll quickly notice is how much more space popped popcorn occupies, compared to the kernels. How can you find out the volume of popcorn before and after it has been cooked?

YOU WILL NEED:

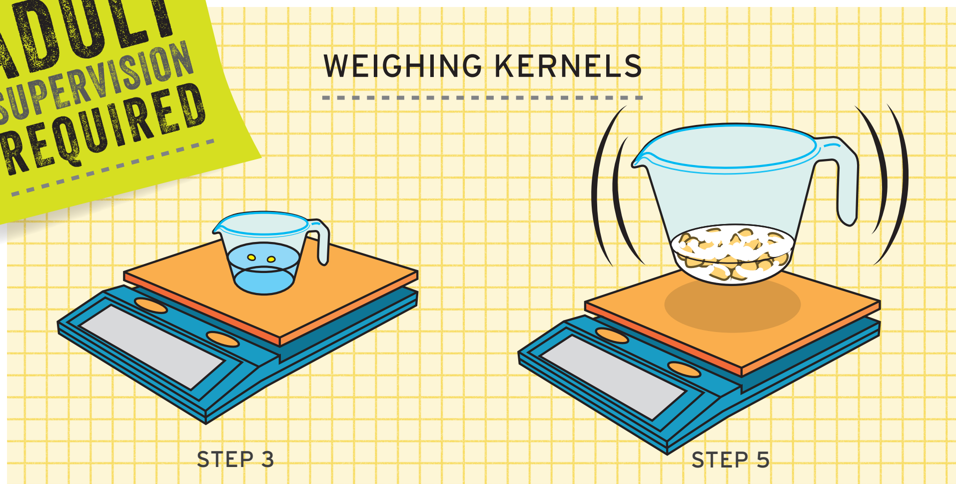
- 1 packet of popping corn
- Kitchen stove and a pan with lid
- Fine filler material (such as sugar, salt, rice or sand)
- Kitchen scale and heatproof mat
- Small measuring jug (able to measure in 10 ml increments)
- Medium-size measuring jug (able to measure 750 ml)
- Large mixing bowl

WHAT TO DO:

1. Empty the popping corn into the pan and close the lid. Set the pan on the stove at medium heat and cook the popping corn until around half of the kernels have popped (ask an adult for help). Place the pan on a heatproof mat to cool (careful, it will be hot). Once the popcorn has cooled, separate out the unpopped and popped kernels.

2. Pour 40 ml of water into the small measuring jug and, using the kitchen scale, record its mass.

ADULT SUPERVISION REQUIRED



3. Add the unpopped kernels to the small jug one at a time until the water level rises to 50 ml. Count how many kernels you added. This tells you how many unpopped kernels take up 10 ml of space. Record this as number N_unpopped. Weigh the jug and its contents again.

4. Subtract the mass of the small jug with only water (see step 2) from the mass of the small jug with water and unpopped kernels (see step 3). Record this as M_unpopped. Dividing this by the number of unpopped kernels added in step 3 will tell you how much a single popcorn kernel weighs on average.

5. Place 25 popped kernels into the medium-size measuring jug. Add enough filler material to cover up the kernels. Shake the jug gently for 30 seconds, then use the markings on the jug to record how much volume is taken up. Weigh the jug, including the filler and the popped kernels, to find the mass.

6. Empty the medium-size measuring jug into the large mixing bowl, take out the unpopped kernels and return all the filler to the jug. Weigh the jug and record the mass, and record the volume of the filler.

7. Subtract the volume of the filler (see step 6) from the volume of the popped kernels and filler (see step 5). You now have the volume taken up by the 25 popped kernels. Record this volume as V_popped.

8. Subtract the mass of the filler (see step 6) from the mass of the popped kernels and filler (see step 5). You now have the mass of 25 popped kernels. Record this mass as M_popped.

WHAT HAPPENS?

How much more space does the popped popcorn take up compared to the unpopped kernels? In order to answer this, you first need to know how much space a single piece of popcorn takes up.

To calculate the average volume of an unpopped kernel, look again at step 3. Divide the 10 ml by the number of unpopped kernels you added (N_unpopped). This gives you a volume that you can call V_unpopped. Divide the volume of the popped popcorn (V_popped, see step 7) by 25 to get the average volume of a piece of popped popcorn. Find the difference by subtracting the smaller volume from the larger volume. Is the difference in volume larger than you expected? (You will use the measurements from this experiment on page 20.)

To find out where the extra volume came from, add some of the popped popcorn to water and see how much the water level increases. Does it increase by as much as you expect? If not, why do you think this is? (For an explanation, see page 148.)

DISCOVER: STATES OF MATTER

Everything you can see and touch around you is made of matter. There are three main states of matter: solid, liquid and gas. For example, the food you eat is a solid, the water you drink is a liquid and the air you breathe is a gas.

SOLID, LIQUID, GAS

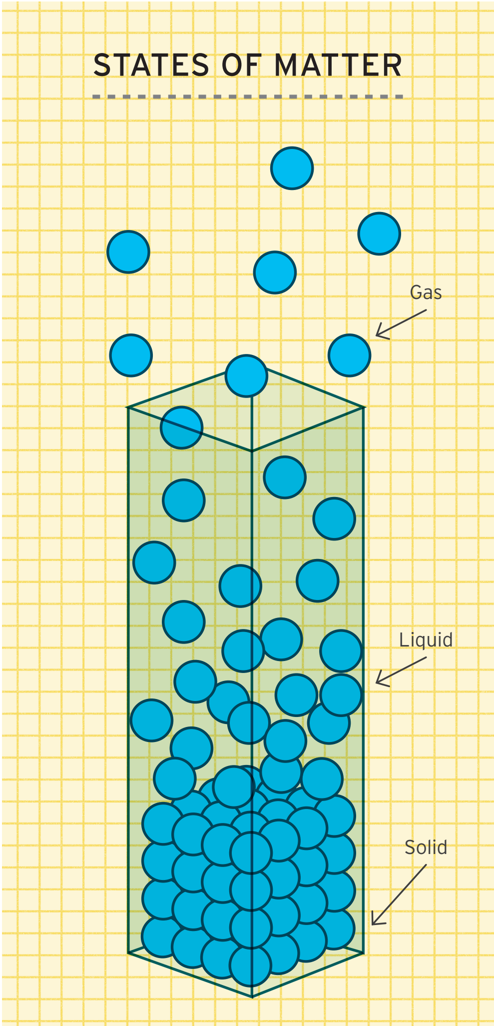
Everything is made up of molecules, which are tiny pieces of matter. Whether something is a solid, a liquid or a gas depends on how these molecules hold themselves to each other.

Solids are hard and keep their shape. The molecules in a solid are arranged like oranges in a box, so that if you try to move one of them, they all move. Solids are usually more dense than gases.

Molecules in liquids are like oranges in a bag. They will tend to stay together, but their shape is not fixed, and they will fill whatever container you put them in. Liquids are normally about as dense as solids.

Molecules in gases are like a bunch of oranges flying around. Gases do not have a fixed shape or density, and they will fill up any available space.

Liquids and gases are fluids. When the molecules of a fluid hit the sides of a container, they will exert pressure.



GAS IN A BALLOON

Imagine you are given a balloon that has air in it, but whose opening hasn't been tied shut yet. If you gently squeezed the balloon while holding the opening closed, you would be able to feel the air inside pushing back at you. This is because of pressure. The gas molecules inside the balloon are flying around at high speed, bumping into each other and the interior of the balloon. When pressure is applied on the surface, you can feel it as a force.

What could you do to increase the pressure inside the balloon? One option would be to add more air to it by blowing it up some more. This can be written down as an equation:

Pressure inside balloon = Constant × Amount of air inside balloon

This means that if you double the amount of air inside the balloon, the pressure will double. The pressure, amount of gas, volume and temperature are all variables, which means they can change. The constant is a number that does not change, and its value depends on the units that are used. For example, imagine you were driving from New York to Los Angeles. The distance would be 2,800 miles, but you want to know what this distance is in kilometres, so you need to multiply 2,800 by a constant of 1.6 (the number of kilometres in a mile). This gives a distance of 4,500 km.

Another thing you could do to increase the pressure is to squash the balloon. If you force it to take up a smaller amount of space, you will feel the pressure inside the balloon pushing back at you. That means that if you decrease the volume, the pressure will increase. The equation can be updated to reflect this:

Pressure inside balloon = Constant × Amount of air inside balloon ÷ Volume

One other option would be to add some heat to the balloon. When you heat something up, it usually expands and tries to take up more space. If the air inside the balloon is not able to expand, the pressure will increase instead. This means that one more part can be added to the equation:

Pressure inside balloon = Constant × Amount of air inside balloon × Temperature ÷ Volume

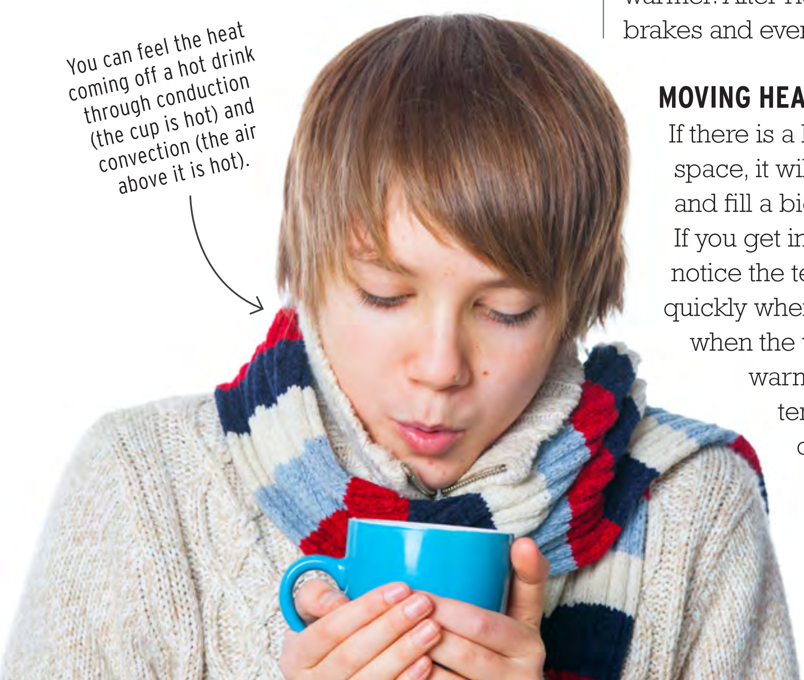
DISCOVER: HEAT AND ENERGY

Energy is all around you. It's in the rays of the sun, and it's used by the cars being driven on the streets. Everything humans do, even breathing, relies on energy, and humans seem to use more and more of it over time.

Energy is used to make popcorn pop. It is a conserved quantity, which means that it cannot be created or destroyed – it can only be transferred from one kind of energy to another. Energy can exist in many forms, and one of them is heat. Heat can be converted into work (which is what happens in a power plant), and work can be converted into heat – which is what happens in an electric heater, or if you rub your hands together quickly.

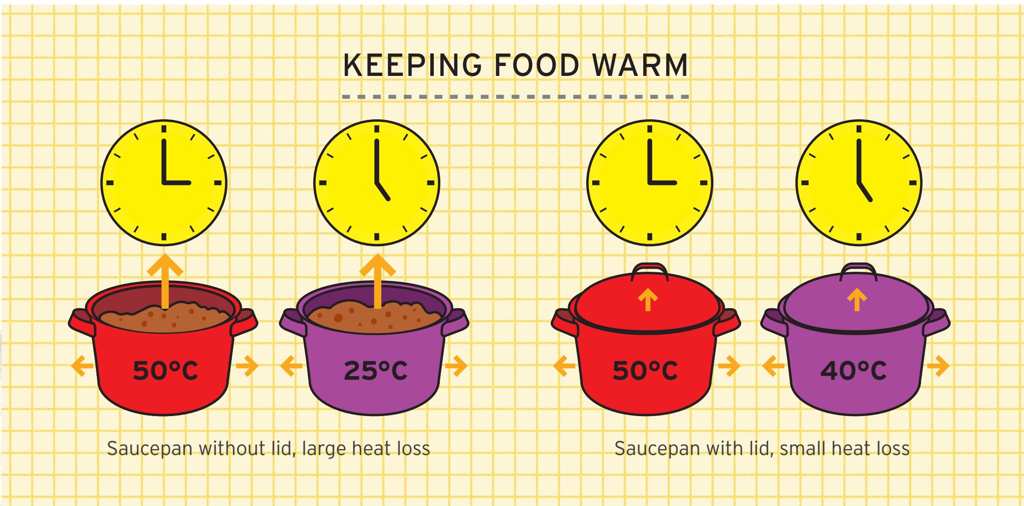
Every time energy is converted from one form into another, some of the energy is wasted in the form of heat. This is because everything gets less well ordered over time. Think about how hard it is to keep a room tidy. You can see this kind of waste heat being generated in a lot of places. Computers use electrical energy to perform calculations, and they need to have cooling fans to remove the waste heat. When you charge a mobile phone, you can usually feel it getting slightly warmer. After riding a bicycle, the tyres, brakes and even the gears are warmer.

You can feel the heat coming off a hot drink through conduction (the cup is hot) and convection (the air above it is hot).



MOVING HEAT AROUND

If there is a lot of heat in a small space, it will tend to spread out and fill a bigger space over time. If you get into a hot bath, you will notice the temperature decreases quickly when it is very hot. Later on, when the water is only slightly warmer than room temperature, it will cool down more slowly.



Heat is transferred in three ways:

- Conduction: heat transferred through a solid
- Convection: heat transferred through a liquid or gas
- Radiation: heat transferred from one place to another, without needing a solid, a liquid or a gas.

When popcorn is heated, all three of these forms of heat transfer take place. Since heat is a form of energy, and energy is conserved, heat is conserved. A hot object will lose heat, and if heat moves out of a hot object quickly, it will cool down quickly. If heat moves out slowly, the object will cool slowly. That is why hot water tanks are covered with insulation – because insulation slows down heat loss.

The speed, or rate, of heat loss relates to how fast heat moves. The bigger the difference in temperature, the faster the heat will be transferred.

COOLING BY HEATING

When ice is added to a drink, it might be thought that the ice cools the drink around it. But is that what really happens? The water is warmer than the ice, and its heat is transferred to the ice. As the ice melts, it produces more water, which helps the convection process deliver yet more heat to the ice. As the water heats the ice, it loses heat energy and gets cooler. (It turns out that adding heat to the ice doesn't just make the ice warmer; it causes it to melt. Most of the heat is lost through the *melting* of the ice, rather than the warming of the ice.)