Kitchen Science! – Stiffening paperclips

Engineering Atoms

What you will need:
At least 4 metal paperclips (none covered in plastic!)
A pair of pliers
A glass of water
A plate
A chefs blowtorch or gas-hob

WARNING – This experiment involves hot metal and naked flames, both of which are dangerous. This experiment should only be performed with supervision from an adult

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What to do:

1) Take the four papers clips and straighten them all out. Put one to the side, to play with later.

2) Take the first paperclip and bend it back and forth, trying to make sure you stay in one place on the piece of metal. What happens to the paperclip as you do this? How does it feel in comparison to when you started moving it?

3) Take the second paper clip and hold it in the end of the pliers. Using the blow-torch, or the gas hob, heat the paper-clip until it is glowing bright orange. BE CAREFUL! Place the paperclip on the plate and leave it to cool. It will stay hot for a long time –even when it has stopped glowing, so be very careful!

4) Take the third paper clip and repeat the process for the second paperclip; however, this time, rather than leaving it to cool drop it into the glass of water. You should hear it hiss!

5) Once all the paperclips are cool, try bending all of them and see how different they feel. Use the paperclip you put to one side for comparison.

   Optional extension:

6) Try taking the first paperclip (the one that you bent over and over again) and putting it in the flame (whilst holding it in pliers!) as you did with the other paperclips. Allow it to cool on the plate. Try bending it again. What has happened now?

Once you've done the experiment have a look at the next page to find out a bit more about what is going on and why!

What you should find:

Paperclip 1 – As you bend the paperclip over and over again, it should become stiffer and stiffer. For those of you who did the extension, you should find that after it has been in the flame and cooled again, it can be more easily bent – like it was originally!

Paperclip 2 – The slowly cooled paperclip should feel less stiff than it did before

Paperclip 3 – This should feel stiffer than it was originally!

The science

There are actually two processes that are taking place here: one that involves the effect when we bend the paperclip and the other caused by the heating and cooling processes. Let's consider the two effects separately:

Bending the paperclip – work hardening and dislocations

Many of the properties of metals are controlled by what is going on the atomic scale (take a look at some of our other demos to find out a bit more about this!). This case is no exception. Atoms in a metal are arranged in a regular way making what is known as a **crystal** structure. When we bend the paperclip we cause the planes or sheets of atoms to move past one another and rearrange. This can create imperfections in the crystal, where the atoms don't quite align or meet up properly. An example of this is shown in the diagram below:

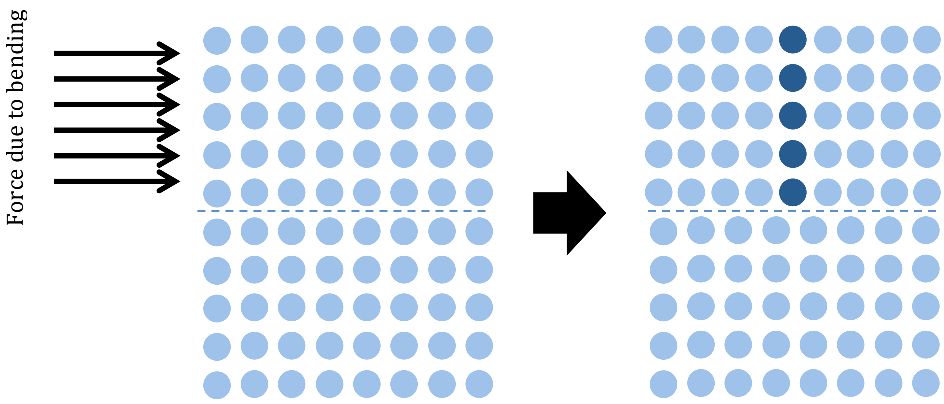
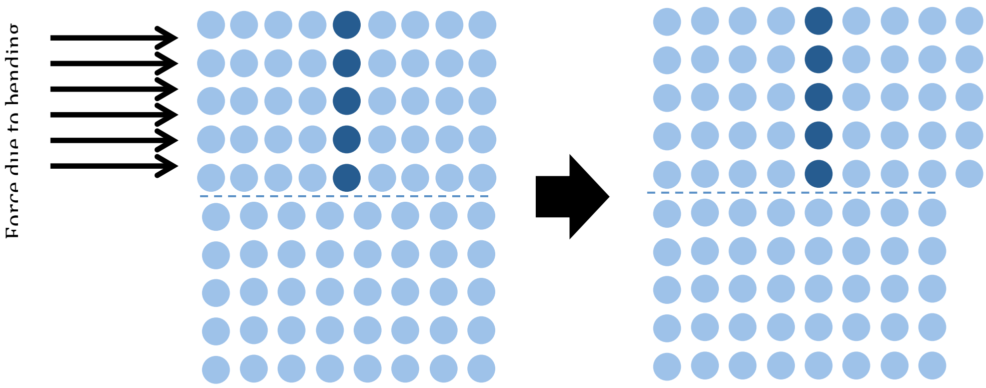


Image of dislocation creation in a metal. Dark blue atoms show the planar defect created.

These sorts of imperfections are known as **dislocations** and their movement through the metal controls many of the strength properties of the metal. As we bend the metal more, the dislocation can then move through the metal and might make it to the edge! This is shown below:



Motion of dislocation with increased force. Plans of atoms slide over one another to reach the edge

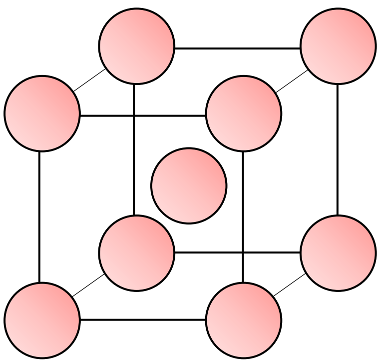
So returning to our paperclip we can imagine that every time we bend the paperclip we create one of these dislocations. However, it may be that the dislocations are created in different directions, depending on how we bend the metal. Therefore it becomes impossible for the dislocations to move past each other, as one dislocation blocks the next one. This means that the metal become stiffer as we bend it more and more. This process of stiffening caused by bending is known as **work hardening**,

Heating and cooling the paperclip – Annealing

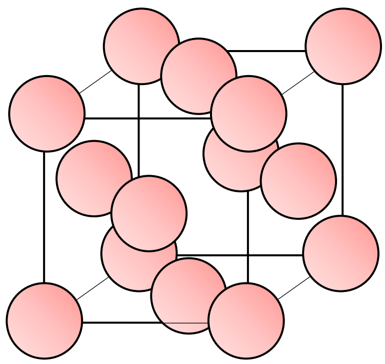
Lets consider now what happens when we heat the second paperclip. The manufacturing process used to make the paperclip obviously involves some bending (to make the correct shape), so the paperclip will already have experienced some work hardening effects. By heating the paperclip we can give the atoms in the structure more energy. This allows dislocations in the structure to readjust and move past one another, to the edge – removing the work hardening effect. Therefore, the paperclip is now much easier to bend than even the original paperclip! The process of heating is known as **annealing** and is very important for the removal of defects in crystal structures.

Heating and water cooling the paperclip – Quenching

We've already said how the atoms in the metal are arranged in a fixed pattern. It actually turns out for iron, and in this case steel, there are two different structures that the atoms like to arrange themselves in, depending on the temperature. At low temperatures iron forms a **body-centred cubic** structure – imagine if you took a cube and placed an atom on each corner and one in the centre of the box (this is shown in the diagram below). At high temperatures it prefers to for a **face-centred cubic** structure – take a cube and put an atom on each corner and one on each face of the cube. This structures are shown below:



Body Centred Cubic Structure



Face Centred Cubic Structure

We can therefore see that on cooling the atoms will need to rearrange themselves from one structure to another. If we cool the system very quickly in water, a process called **quenching**, there is not time for this change to take place. A distorted structure called **martensite** therefore forms as the atoms try to rearrange themselves during the rapid cooling. This distorted structure traps carbon atoms in an irregular way, making the paperclip harder and stiffer than it was originally.