super-conductivity

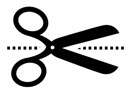
a story about electrøns

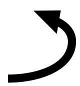
Discovering electrons through folding (for ages 6 and up)

You will find the folding sheets and instructions in the middle of the booklet. Just detach them from the book, and with scissors and scotch tape or glue, you will find your way to the quantum folding world. You will also find a quiz, which you can fill out while reading the booklet. Answers can be found on the web.

instructions

 glue

 cut

 fold

 join

Matter is made of billions of billions of very tiny particles: electrons, neutrons, protons... These particles are invisible and behave in a peculiar way, sometimes like clouds or waves in the sea, other times like small balls. They are known as "quantum" particles.
In this booklet, with scissors and scotch tape, we invite you to build yourself one electron, then a second one, and at the end, the weirdest object in the quantum world: a superconductor, a material able to levitate on magnets! These models are not real electrons of course, but they will help you get a better feeling for what is actually happening inside the matter around us.

The matter that surrounds us, solids, liquids and even gasses like air, is made of billions of billions of atoms. An atom consists of a very tiny and heavy nucleus, and very light electrons which form a cloud around the nucleus, a little bit like the pulp around the pit of a peach or a cherry. But unlike fruit, atoms are more than a billion times smaller than us. Atoms measure less than a nanometer across and a nanometer is a billion times smaller than a meter! Furthermore, the electrons behave in a strange way, sometimes like tiny balls, sometimes like large waves. The electron is a very important particle, since it allows us to understand the matter around us and simple questions such as: how a metallic wire conducts electricity, how does a magnet stick to your fridge, how a LED light works… The electron also allowed us to invent computers or cellular phones which are now used every day.

Welcome to the amazing world of electrons and condensed matter!

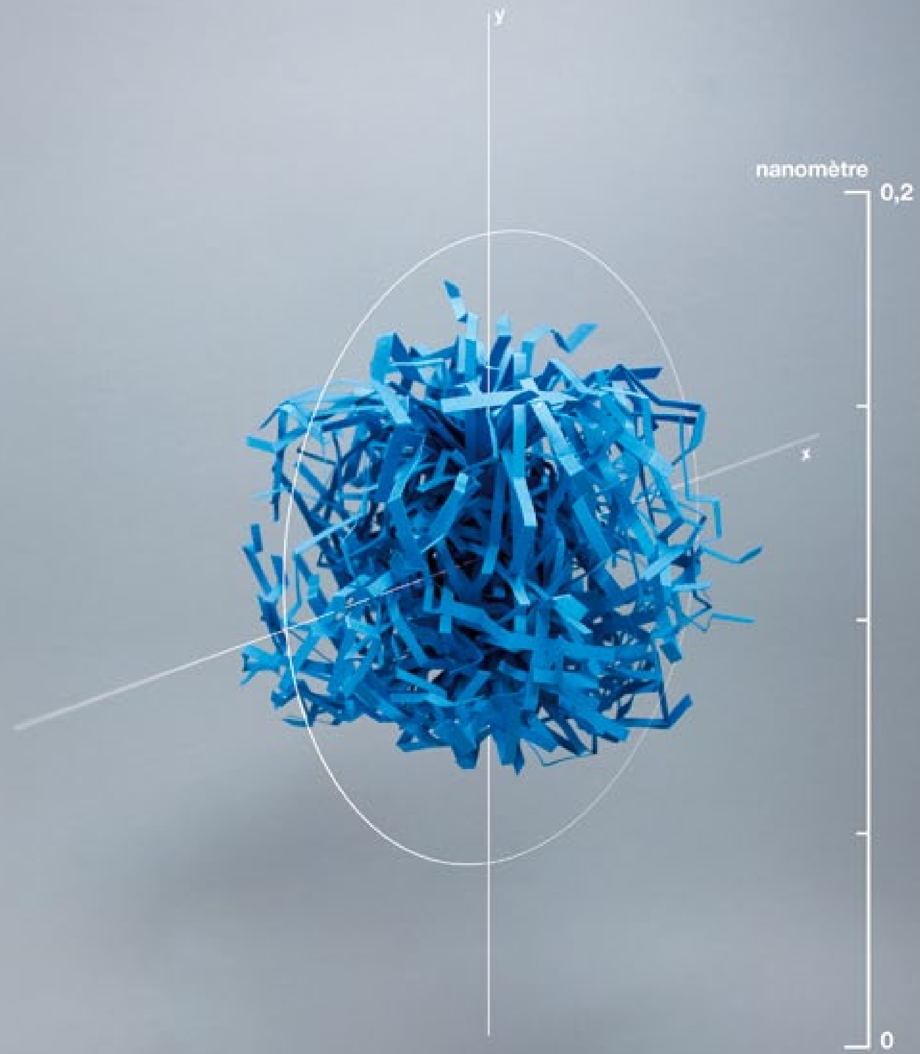
the electron
inside the atom

in an atom

electrøn

What does an electron look like? It is hard to say exactly. This is because it is a very weird object that we describe as “quantum”. It behaves like a cloud, and is, in a way, everywhere in this cloud at the same time. But this cloud is impossible to see and as soon as you try to observe it, even with the best scientific tools, the electron suddenly shrinks into a very tiny ball. How is it possible to figure out what this cloud looks like? A little bit like the crumpled paper ball you see here, something in between a solid ball and a cloud…

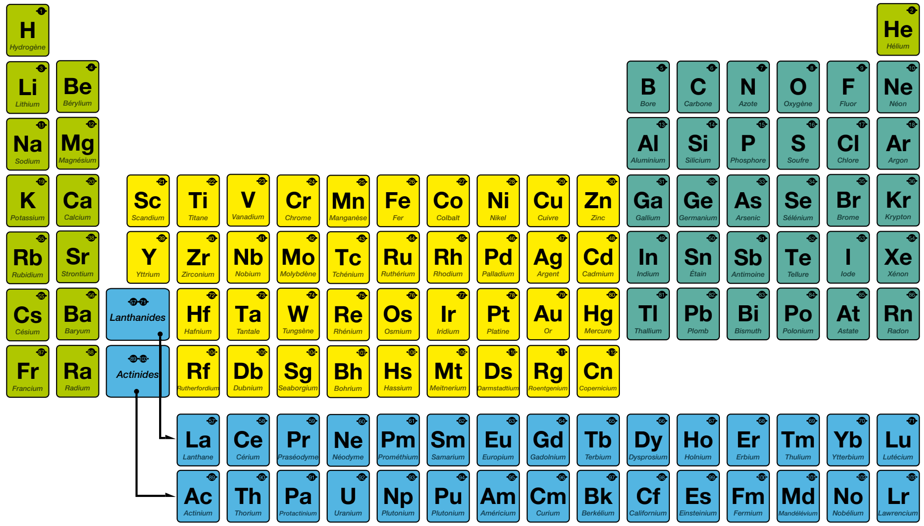
Now it’s your turn to play: Follow the instructions in the folding manual and try to make your own model of an electron. Look at the result: is the electron at a very precise location? Or, on the other hand, is it everywhere at once? Now imagine for a moment that you are a physicist and try to measure exactly where it is.

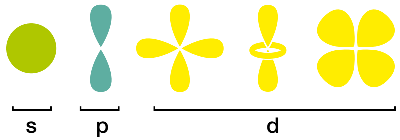


an electron of
s shape

the shapes of electrøns

Not all atoms are equal. The nucleus can be lighter or heavier, depending on the atom. Around this nucleus, there can be one, two, or dozens of electrons. These electrons do not all have the same shape. Those which look like the big crumpled ball are called “s” and they are the simplest ones. Look at the others here. Each of them has a different shape and a different code name, a little bit like secret agents: “p”, “d” or “f”. This shape is very important, since these electrons allow nearby atoms to stick to each other. For example, an oxygen atom in the air or in water has electrons with “s” and “p” shapes. An atom in a metal like copper or silver also has “d” electrons.

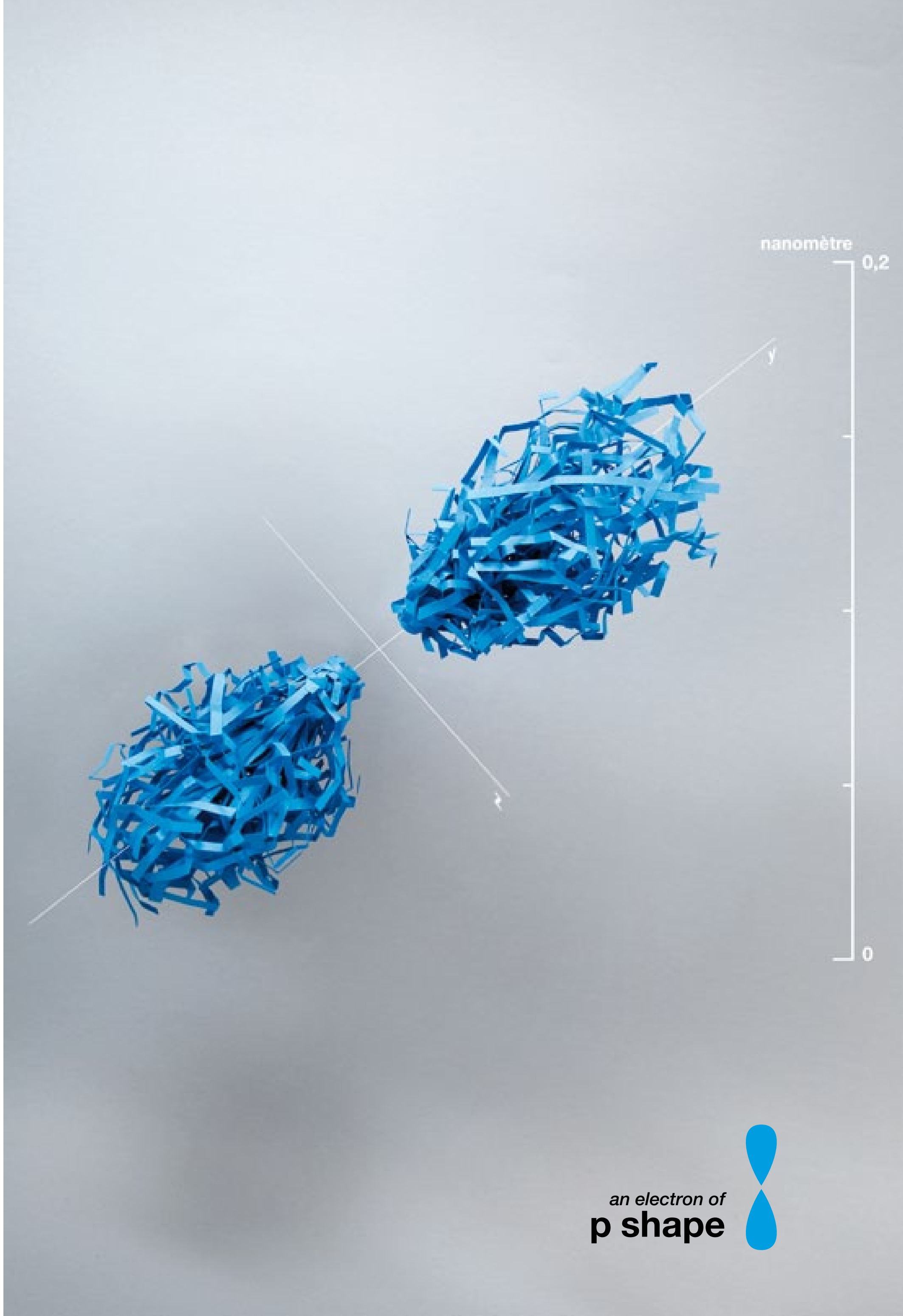


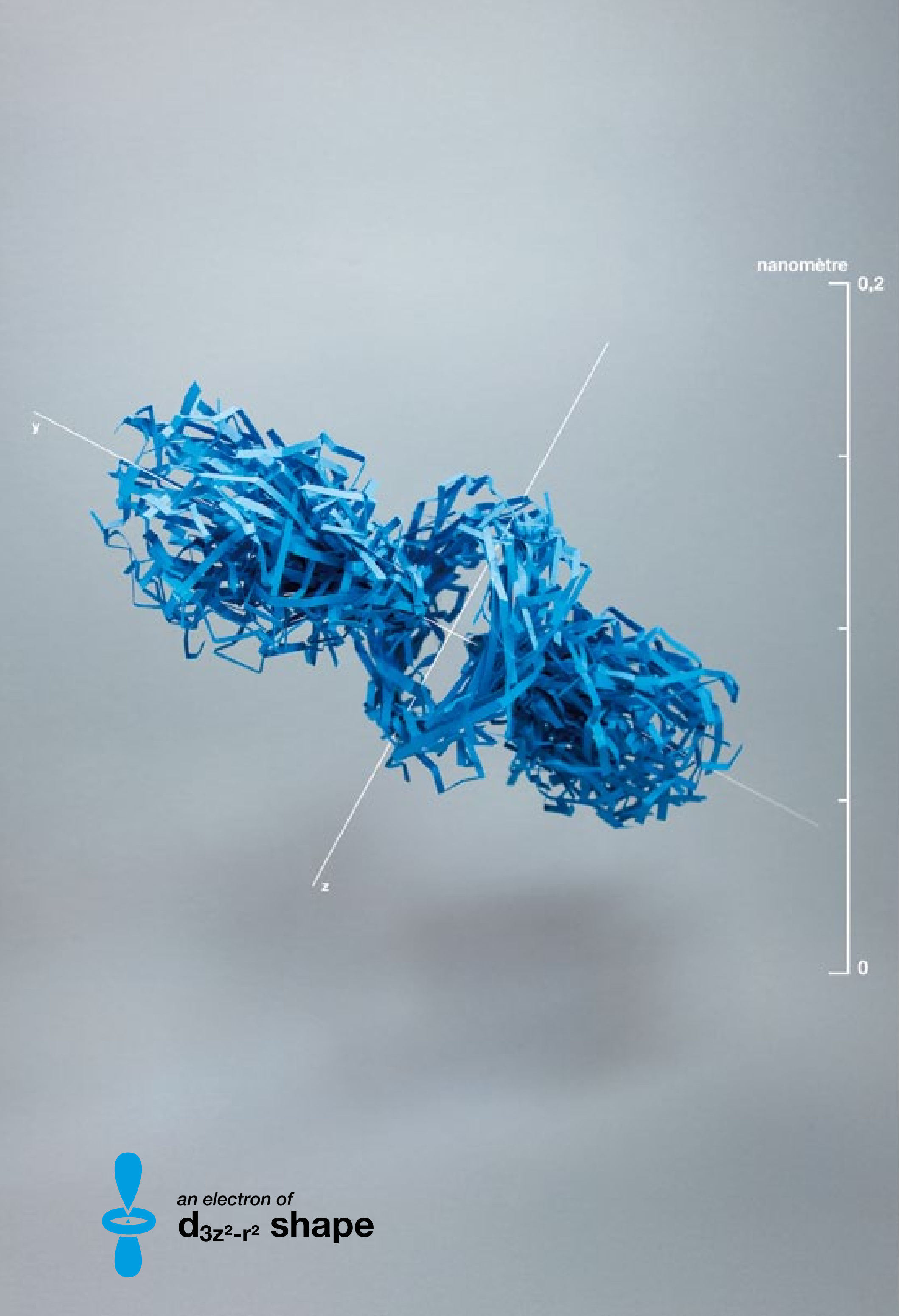


This table is called “the Mendeleiev periodic table of the elements”. It describes all the possible atoms and their electrons. In yellow, for example, the atoms have “s”, “p” and “d” electrons.

the shapes of electrøns

The following pictures represent the three other types of shapes that the electron can form. The patterns for folding the p and $d_{x^2-y^2}$ shapes can be found at *www.supraconductivite.fr*




nanomètre
0,2
y
z
0
an electron of
$d_{3z^2-r^2}$ shape


nanomètre
0,2
x
y
0
an electron of
$d_{x^2-y^2}$ shape

when two atoms meet

the chemical b-o-nd

Atoms can stick to each other and this is what makes solid matter hold its shape and not evaporate like a gas. It is the electrons that are responsible for forming the bonds between atoms.

Now it's your turn to play: Try to build such a bond by bringing two electrons together and making them overlap a little. Done? You just made a hydrogen molecule! This can be done with many different kinds of electron shapes. For example, in a diamond, the atoms are carbons and are bonded strongly together with "s" and "p" electrons. In order to build a new material or induce a chemical reaction, chemists know how to create, manipulate and destroy these bonds in "chemical reactions".

When two atoms get close to each other,their electrons can stick together and form a bond.

the electrøn
in a metal

in a metal

#order in matter

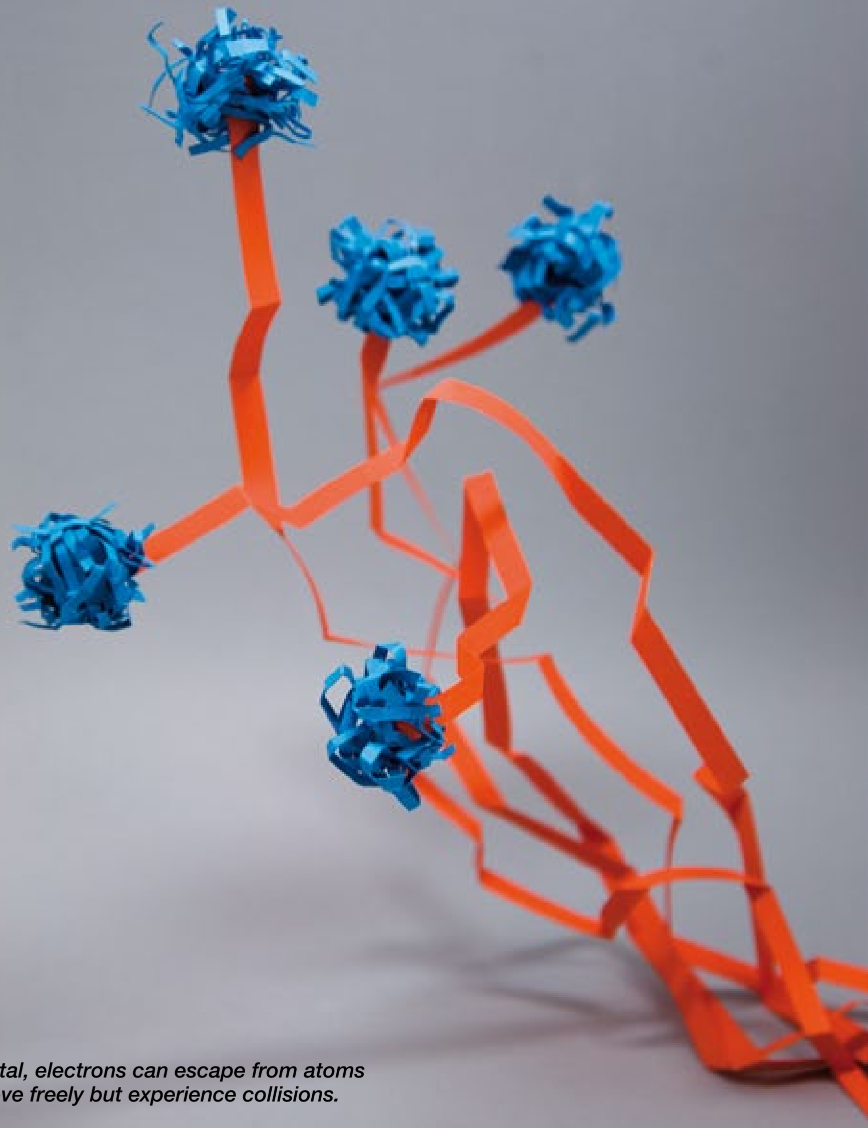
Solid matter around us is made of atoms nicely arranged in an orderly pattern, side by side like soldiers in an army. A liquid or a gas also contains atoms, but they are disordered and moving around rapidly, a little bit like children playing in a courtyard. When a liquid is cooled, it becomes solid because its atoms move around less and finally line up in an ordered pattern. Again, it is the electrons that allow them to stick to each other in that way.

In solid matter, all atoms stick to each other in an ordered pattern using their electrons as the glue.

in a metal

+ electrical current -

In a metal, atoms are well ordered, side by side, but some of their electrons have escaped and move around freely. The other atoms do not bother them because electrons are like a wave in the sea: they can easily slip between the atoms. If a piece of metal is plugged into a battery or an electrical outlet, all the free electrons are forced to move in the same direction. This is what creates the electrical current we use at home. But even when they all move together, they occasionally run into defects inside the metal and are slowed down. This is called electrical resistance. The more the resistance, the more poorly the metal conducts electricity. This also causes some heating of the metal. In fact, that is how your toaster works! In the picture, you can see electrons moving but not parallel with each other, because of all these bounces or collisions.



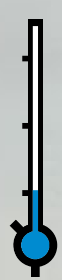
In a metal, electrons can escape from atoms and move freely but experience collisions.

the electrøn
in a
superconductor

in a superconductor

the C(oo)per pair

When some metals are cooled down to very low temperatures, they become superconductors. Suddenly, their electrons no longer feel any resistance when they move. These superconductors therefore conduct electricity perfectly, and do not heat up anymore. How is this possible? First, the electrons attract each other and form a new wave called a “Cooper pair”, named after Leon Cooper, an American physicist who first discovered them. Once the electrons are paired, they succeed in forming a single huge wave. It is a little bit like when many fishes in the sea sometimes form a shoal, or when children pair up and form a nice line when the bell rings at school.
Now it’s your turn to play: Try to build such an electron Cooper pair.

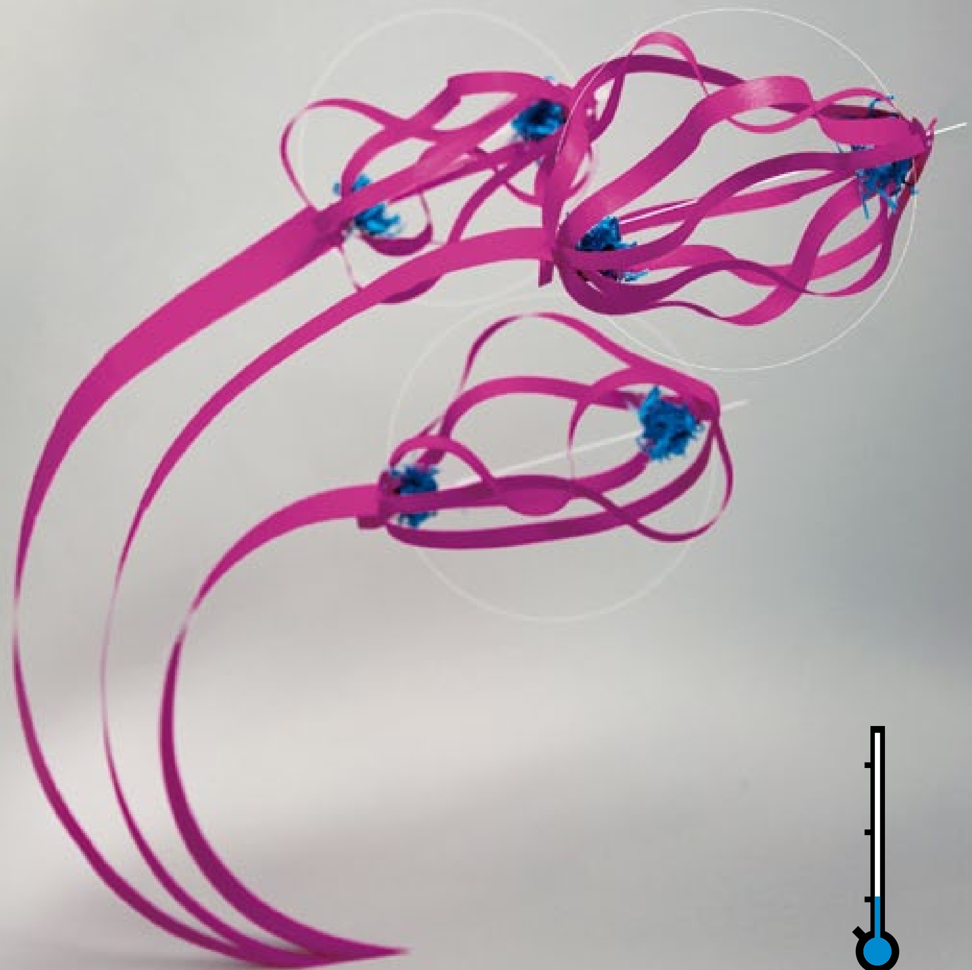


At very low temperature, in a superconductor, the electrons attract each other and form a pair.

in a superconductor

§upercurrent

Remember how electrons move in a metal and bounce around as a result of collisions? In a superconductor, all pairs of electrons move nicely together, as you see in the picture. They do not feel any collisions or resistance anymore. They have become much more powerful by travelling as a group and nothing can block their movement. There is no longer any electrical resistance, nor is heat created. This is why we call it superconductivity. If such an electric current is put into a ring, it will circulate in the ring, like a carousel, forever! This is very useful because it allows us to put much more current into a superconducting cable than in a normal one, since it never heats up at all.



In a superconductor, pairs of electrons move together and no longer feel any resistance.

magnets and superconductors

magnets

((magnetic fields))

What is a magnet? It is a material which creates a magnetic field, a little bit like earth creates a magnetic field that makes a compass turn. This field is invisible, but it really does exist: if you bring a magnetic material such as a screwdriver or a nail close to a magnet, it will stick to it, because it is attracted by this magnetic field. You cannot see it, so scientists usually draw lines to remember where it is.

Now it's your turn to play: Build these lines of magnetic field around a magnet for yourself. In the picture, the magnet is the small metallic rectangle, and its north and south poles are on the top and bottom of it. If you bring a compass close to a true magnet, you will see its needle following these lines!

magnets and superconductors

levitating magnet

When a magnet is brought close to a superconductor, it is repelled and begins to float above it, in levitation! Two magnets will also repel each other, but one of the magnets will quickly turn upside down and stick to the other one. Here with a superconductor, it is different: the magnet does not fall off but remains suspended above the superconductor (see the video). Why? Because the superconductor does not like the magnetic field which tries to break up its electron pairs. It therefore pushes back the magnetic field lines of the magnet, causing it to levitate.

Now it's your turn to play: put your magnet with its field lines on another object. See how the magnetic lines are deformed and how the magnet seems to be levitating? This is actually what happens with a superconductor. This kind of levitation allowed engineers to build the fastest train on earth: the Maglev in Japan!

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