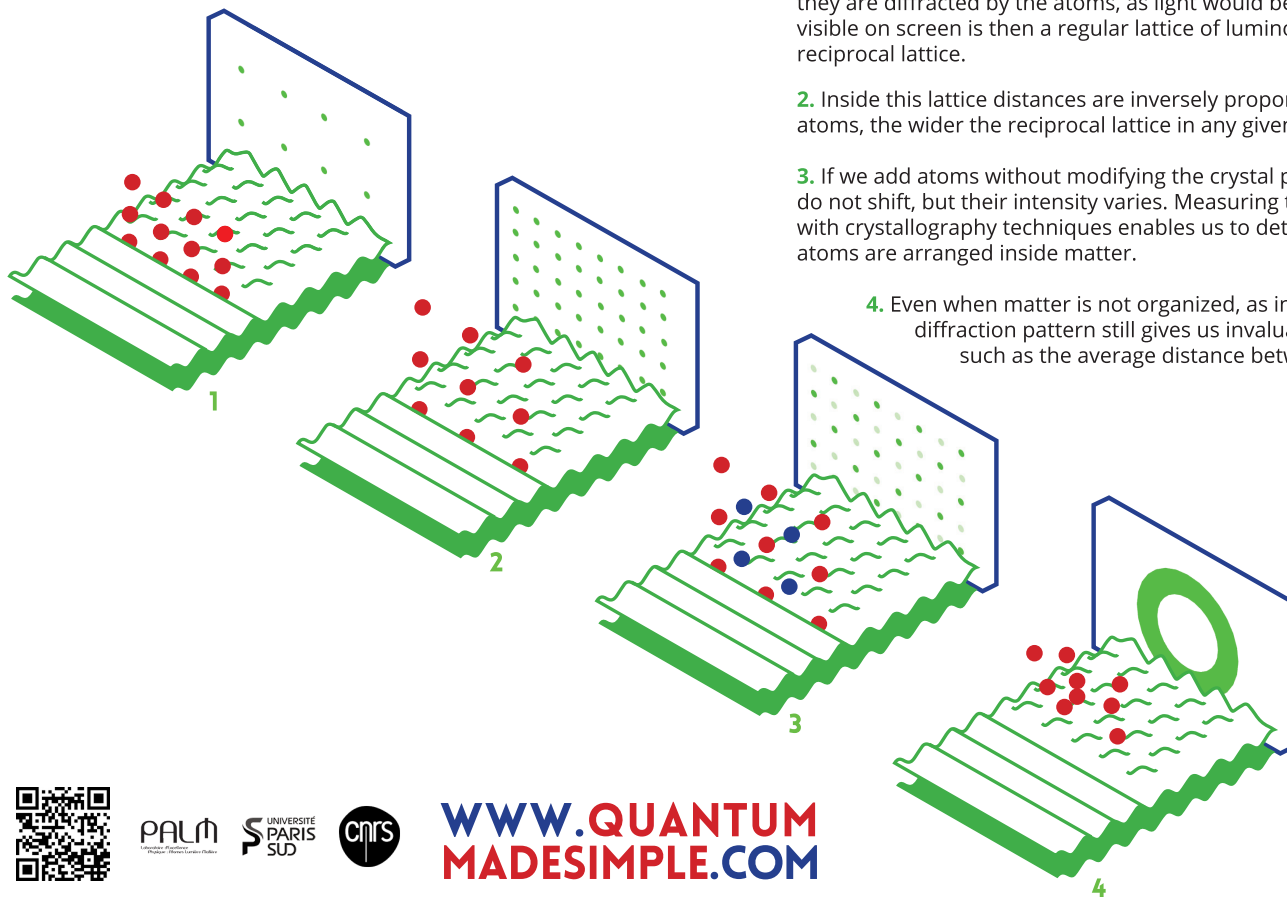


CRYSTALLOGRAPHY AND RECIPROCAL SPACE

MEASURING THE WAY ATOMS ARE ARRANGED INSIDE MATTER.

1. When we send X-rays on a crystal of regularly organized atoms, they are diffracted by the atoms, as light would be. The pattern visible on screen is then a regular lattice of luminous spots: this is the reciprocal lattice.
2. Inside this lattice distances are inversely proportional: the closer the atoms, the wider the reciprocal lattice in any given direction.
3. If we add atoms without modifying the crystal periodicity, the spots do not shift, but their intensity varies. Measuring the reciprocal lattice with crystallography techniques enables us to determine the way atoms are arranged inside matter.
4. Even when matter is not organized, as in liquids, the diffraction pattern still gives us invaluable information, such as the average distance between molecules.

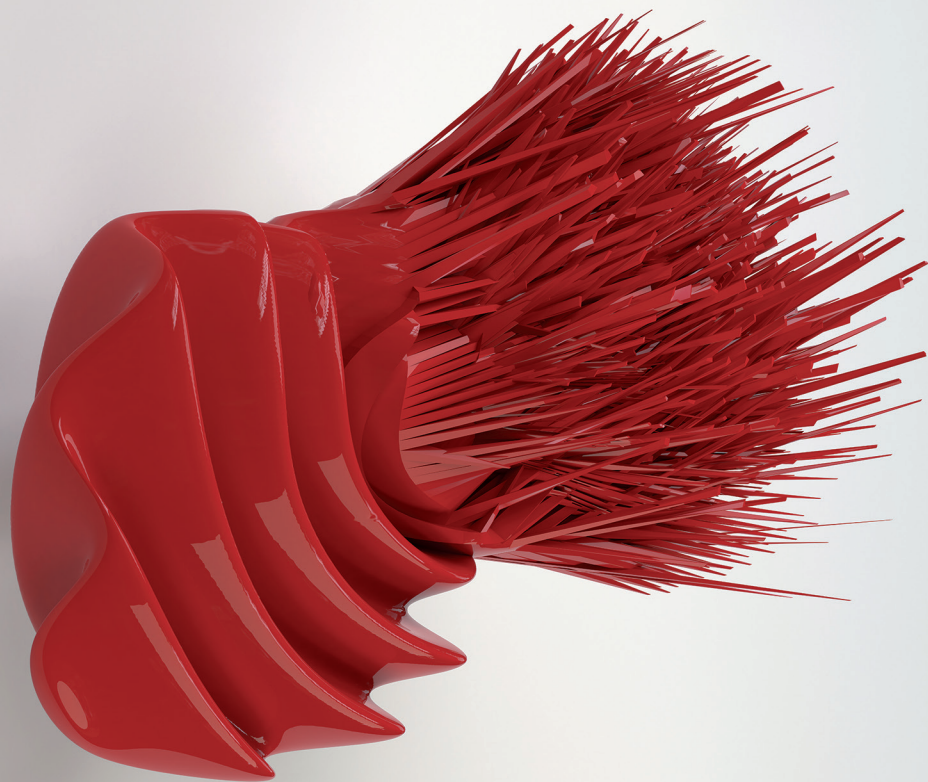


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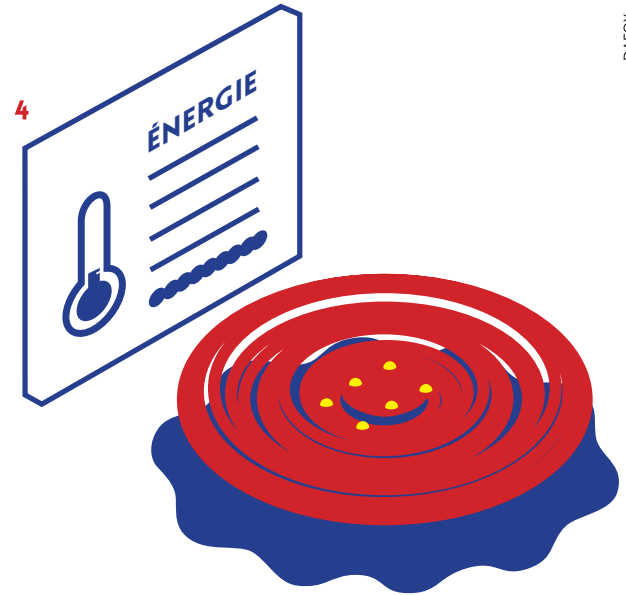
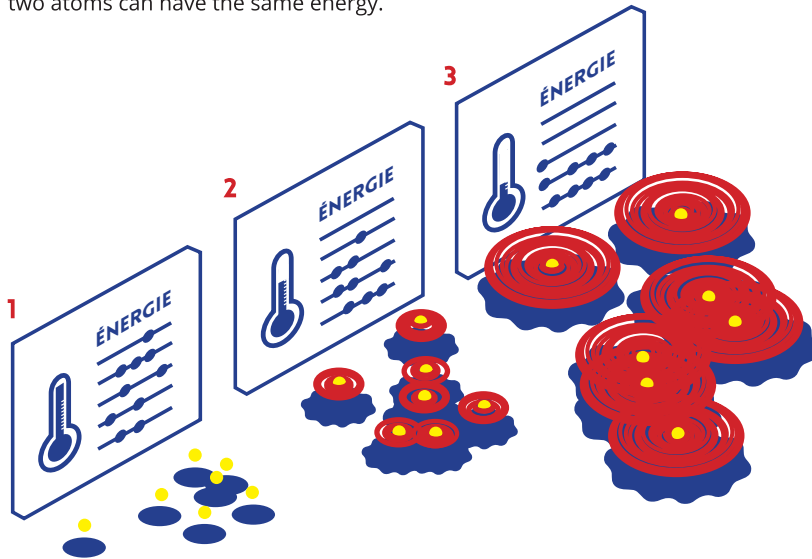
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BOSE-EINSTEIN CONDENSATE

WHEN ATOMS FORM A SINGLE QUANTUM WAVE.

1. Atoms move freely in a gas. In the case of bosons, two atoms can have the same energy.



2. When one cools the gas, the atoms slow down and their energy decreases. These quantum atoms behave like small waves.

3. These waves expand at low temperatures, until they become larger than the average distance between atoms.

4. Bosons can then suddenly all acquire the same energy and be in the same state. They form a single huge collective quantum wave, called Bose-Einstein condensate.

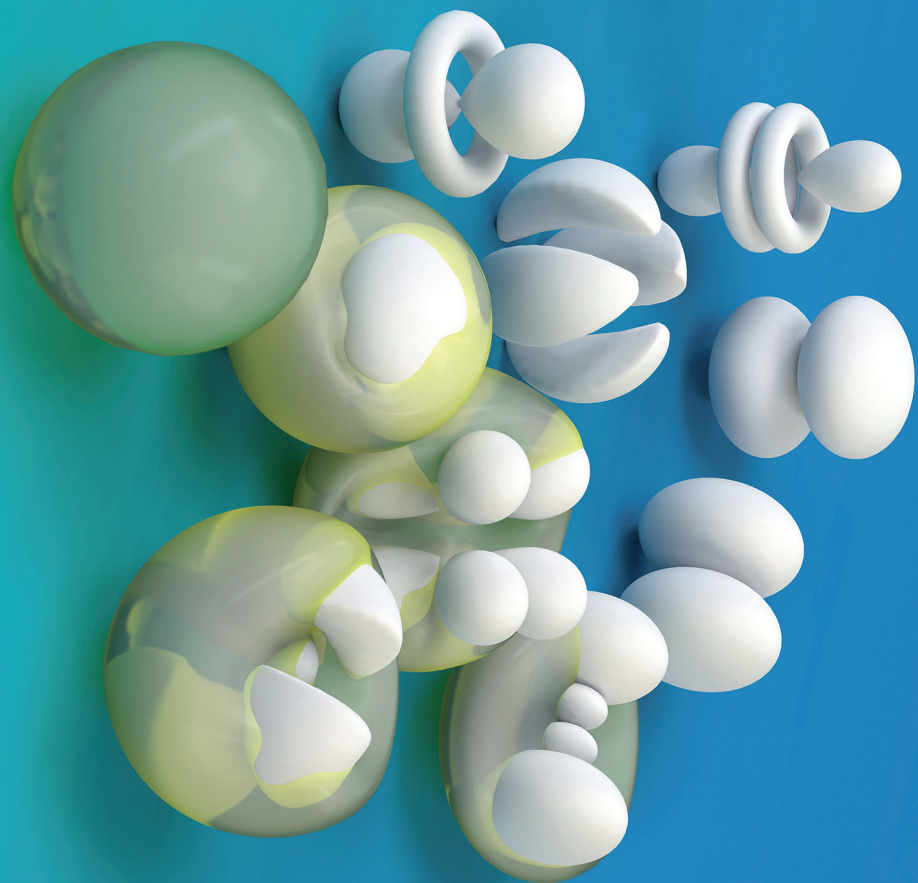


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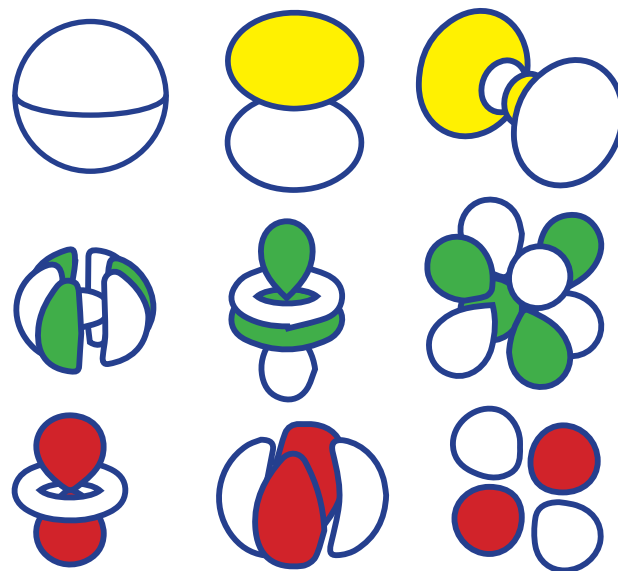
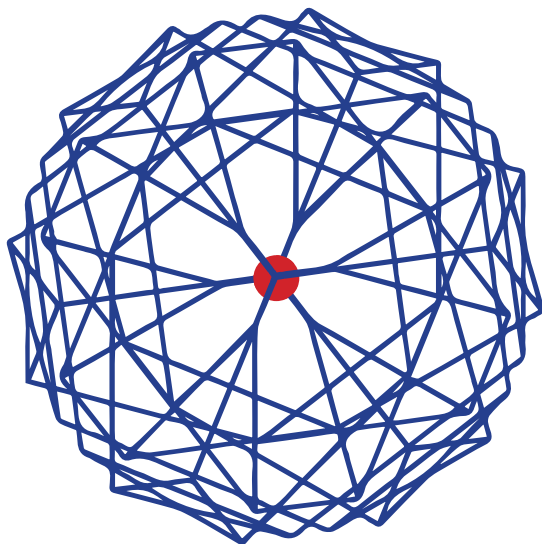


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THE ATOM, A BOX OF ELECTRONS

AN ATOM CONSISTS OF A NUCLEUS THAT
CREATES A SORT OF ELECTRIC BOX AROUND
IT CONTAINING ELECTRONS.



These electrons are quantum particles and can only take a few specific forms, called orbitals, depending on the shape of the 'box'.

When we add electrons to an atom, they pile up, adopting these successive forms. But only up to two electrons can take the same form.

Thus we can construct all the atoms of the periodic classification playing this game of "quantum Lego", adding electrons one after the other around the nucleus.

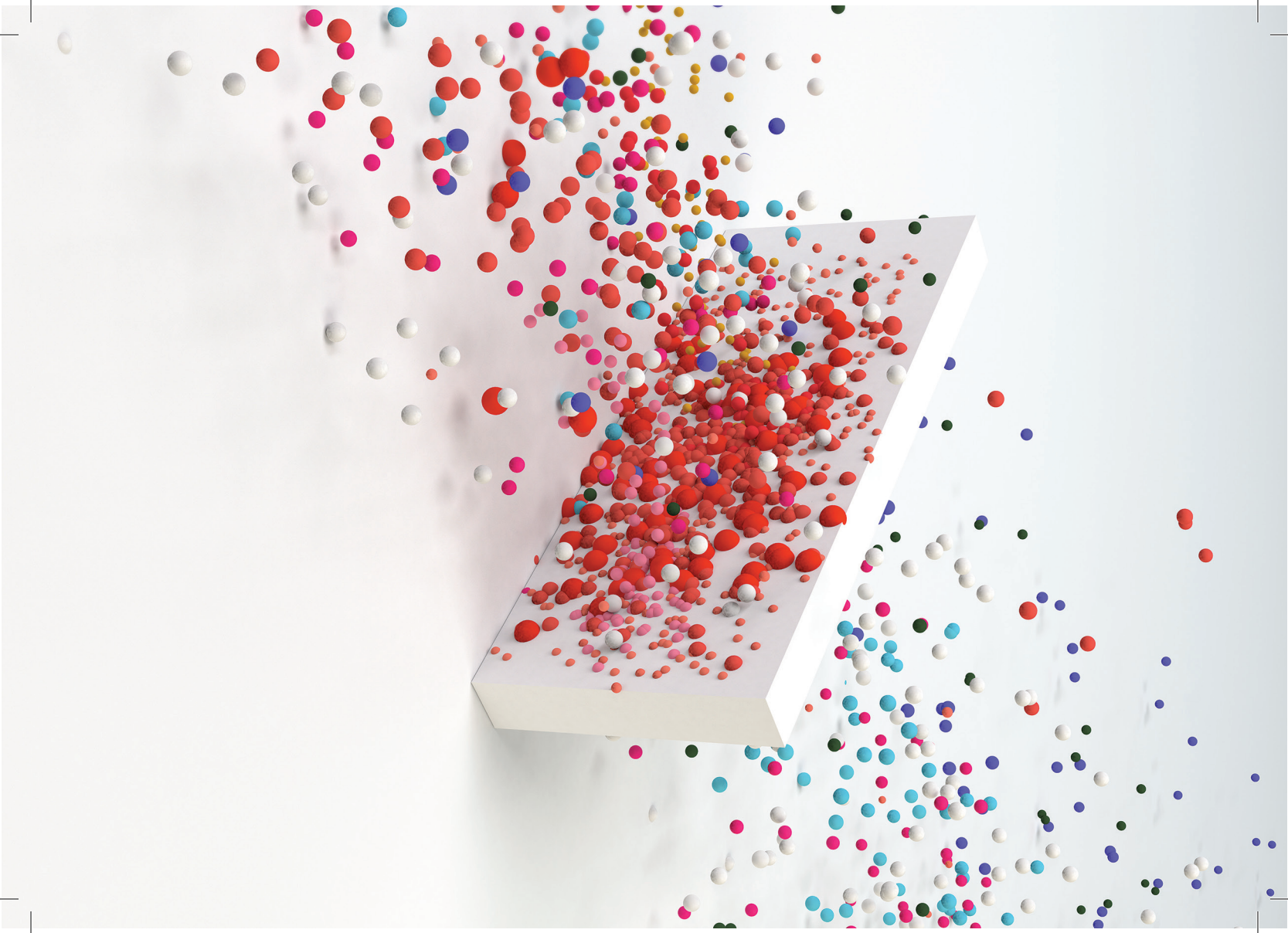


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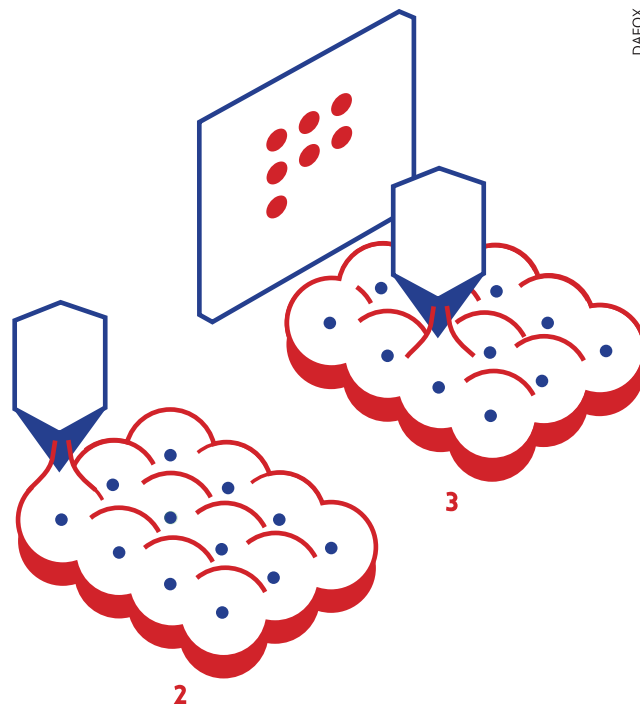
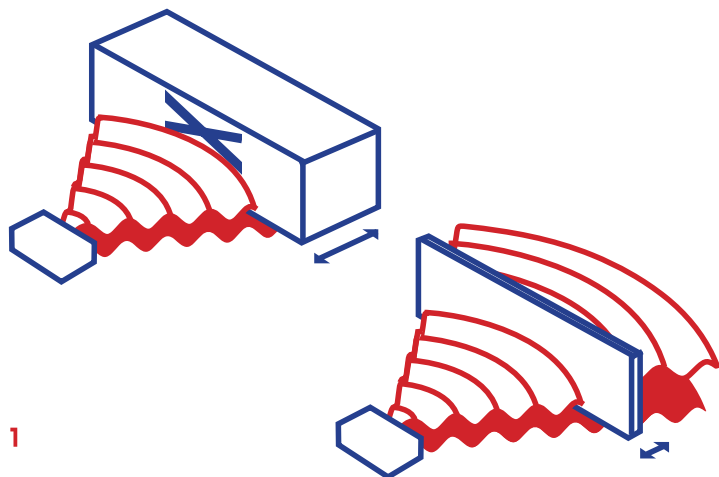
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THE TUNNEL EFFECT

WHEN ATOMS CAN GO THROUGH WALLS.

1. In quantum mechanics, when we send an electron or an atom against a wall, it bounces back. But if the wall is thin enough, it can either bounce or go through! This is the tunnel effect.



2. We bring the tip of a scanning tunneling microscope close to a metal composed of atoms. If we apply an electric voltage to the tip, it can remove the electrons from the metal thanks to the tunnel effect. In this case, the barrier they have gone through is the empty space between the tip and the metal.

3. If we manage to determine where the tip has removed the electrons from the metal, we can find out where the atoms of metal are situated and create a kind of picture of them.

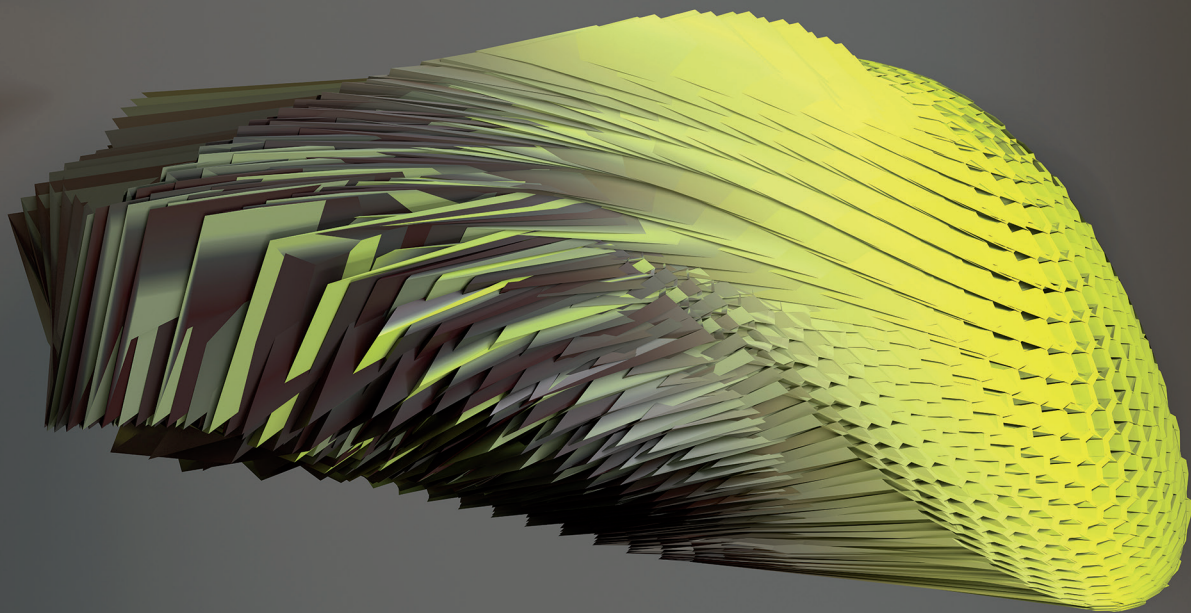


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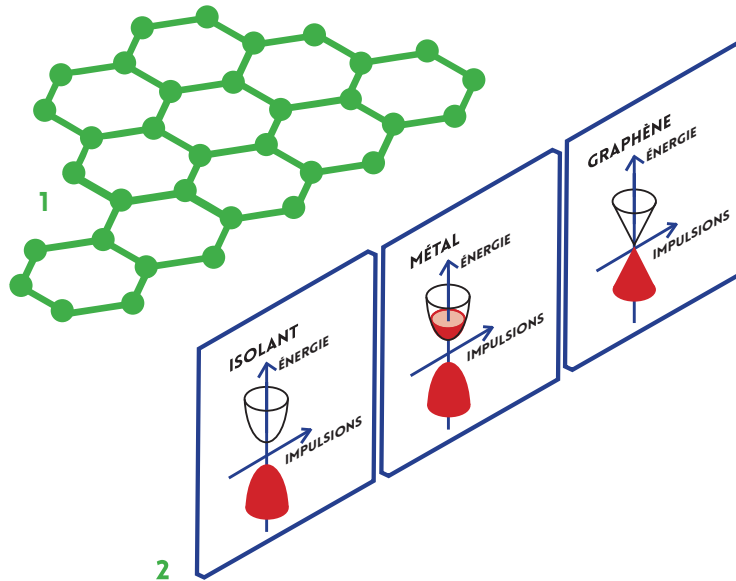
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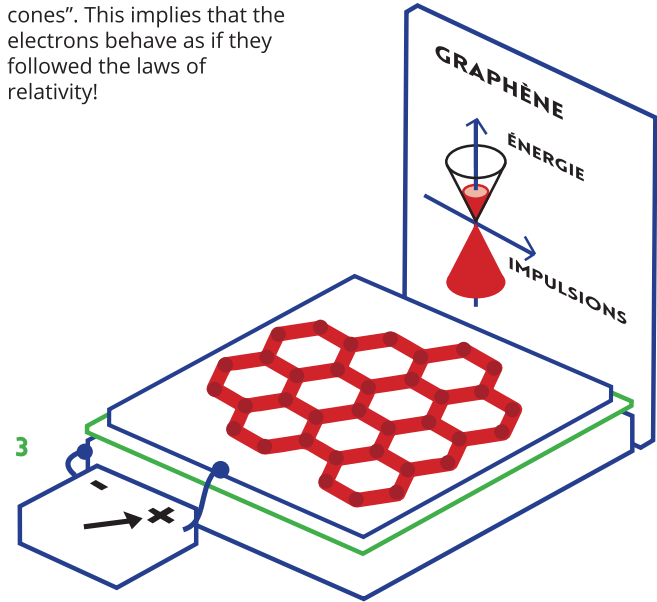
GRAPHENE

WITH ITS ONE-ATOM LAYER, GRAPHENE DISPLAYS UNUSUAL PROPERTIES.

1. Graphene is artificially made in labs. It consists of a single layer of carbon atoms arranged in honeycomb structure. Beyond its extraordinary thinness (one-atom thick), graphene displays a range of unusual properties.



2. When we study the energy of electrons in insulators or in metals according to their momentum, we observe parabolas separated by forbidden gaps. But not only are these gaps absent from graphene, but we observe what we call "Dirac cones". This implies that the electrons behave as if they followed the laws of relativity!



3. By applying an electric voltage to graphene via a metallic grid, we can vary the quantity of conduction electrons and even their nature. This kind of device could be used to create new electronic components.

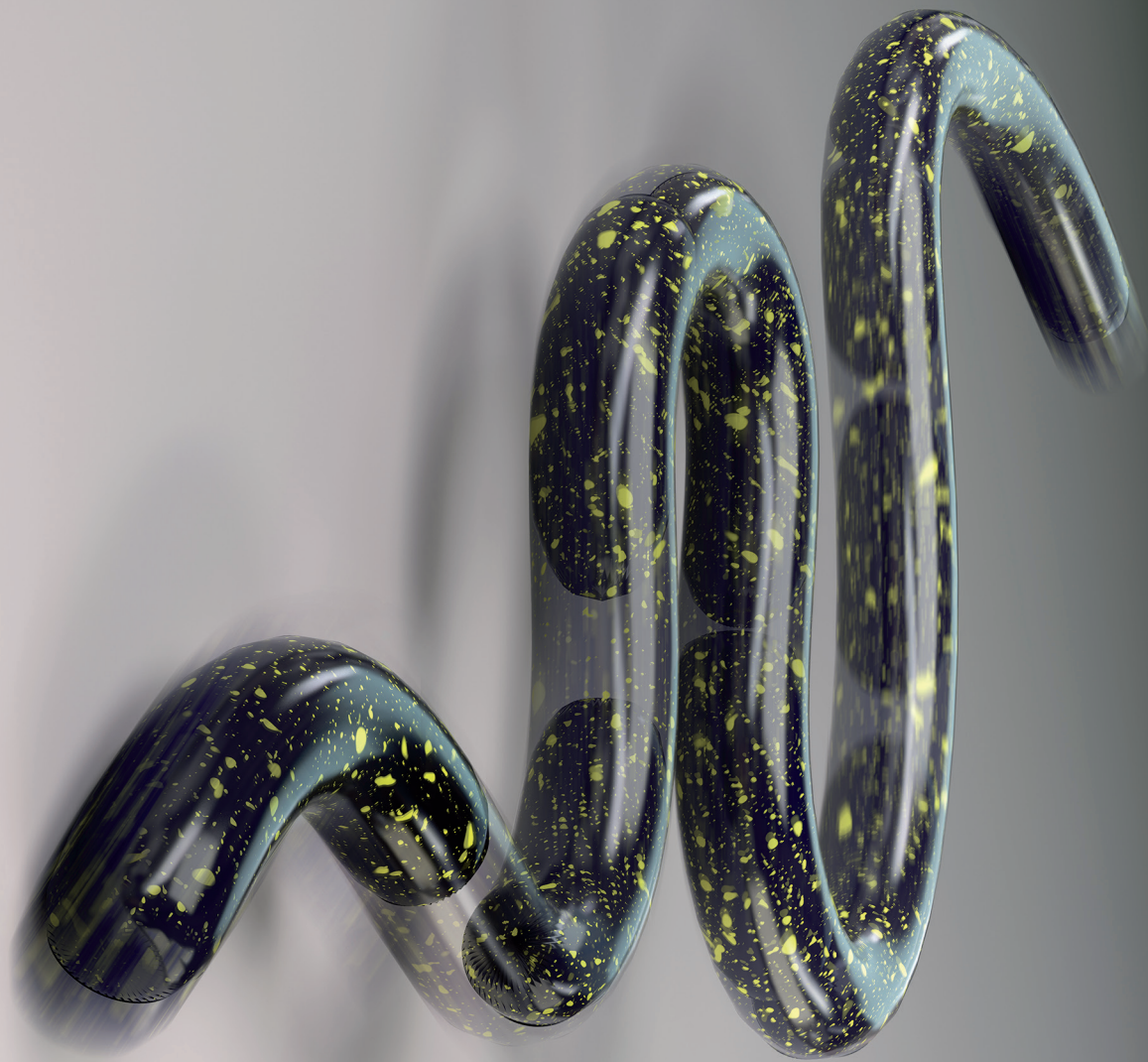


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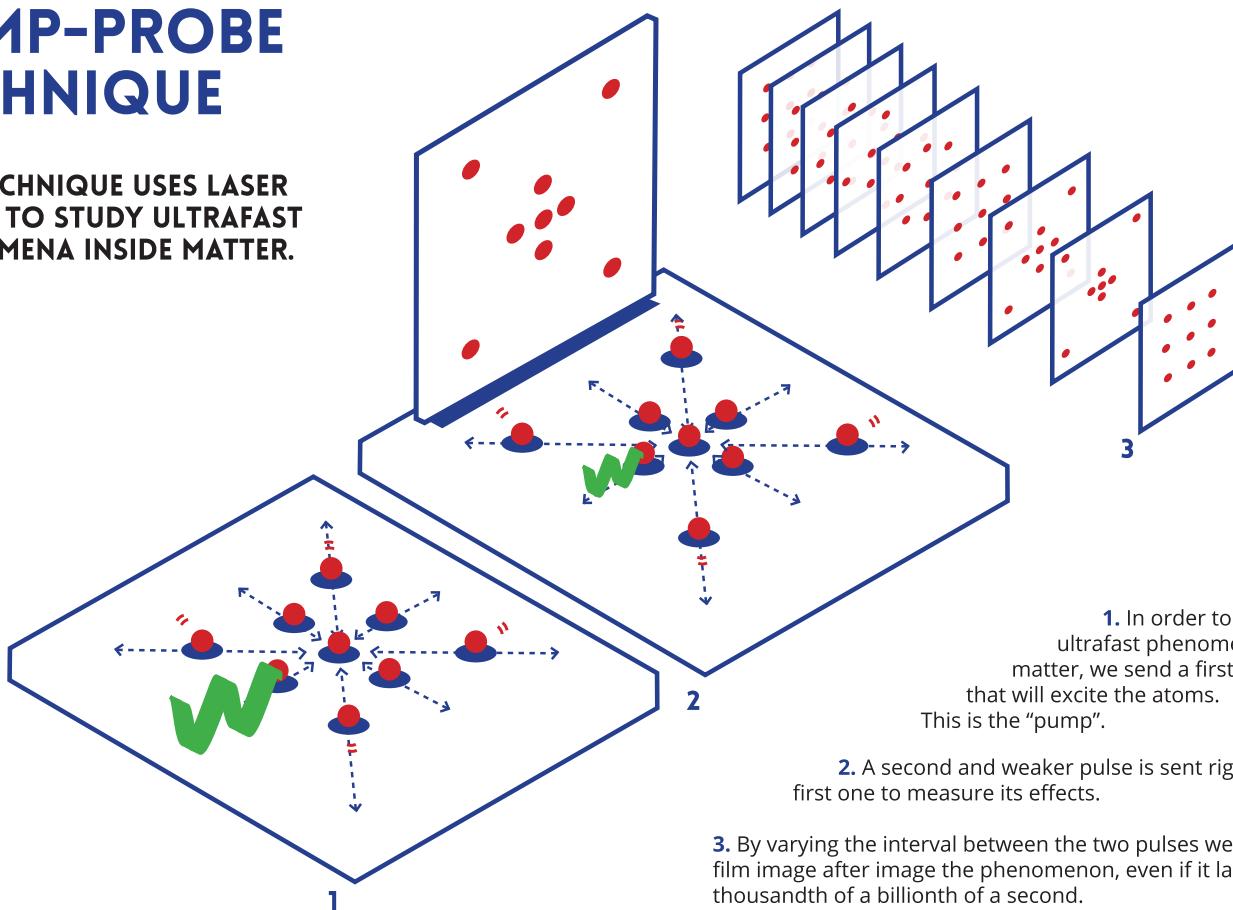


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PUMP-PROBE TECHNIQUE

THIS TECHNIQUE USES LASER PULSES TO STUDY ULTRAFAST PHENOMENA INSIDE MATTER.



1. In order to observe ultrafast phenomena inside matter, we send a first laser pulse that will excite the atoms. This is the "pump".

2. A second and weaker pulse is sent right after the first one to measure its effects.

3. By varying the interval between the two pulses we are able to film image after image the phenomenon, even if it lasts only one thousandth of a billionth of a second.

With this technique we can observe for example atom vibrations, electron excitations, or certain magnetic behaviors inside matter.

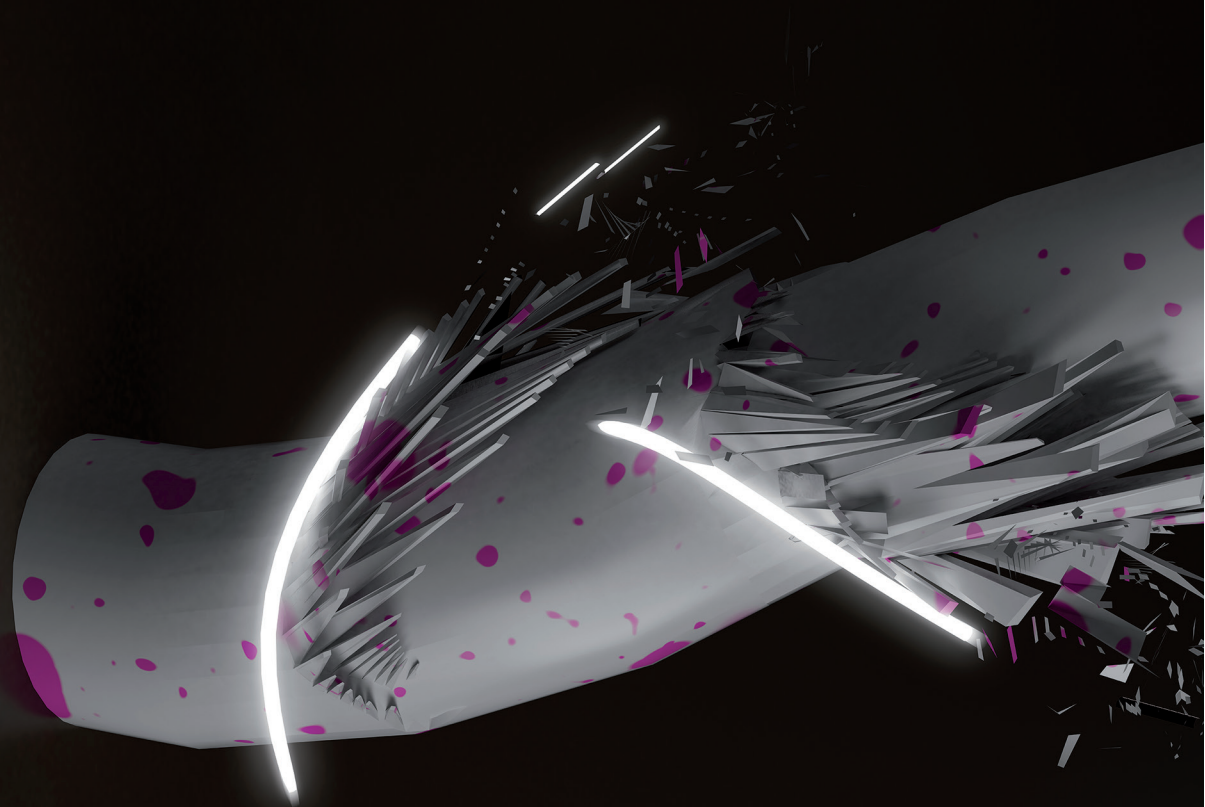


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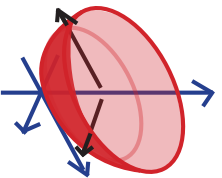
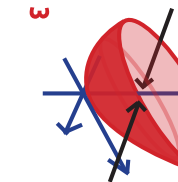
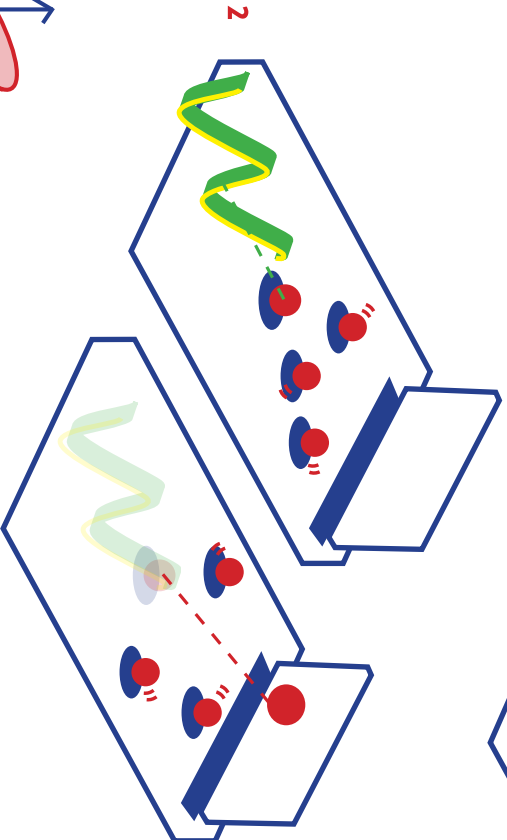
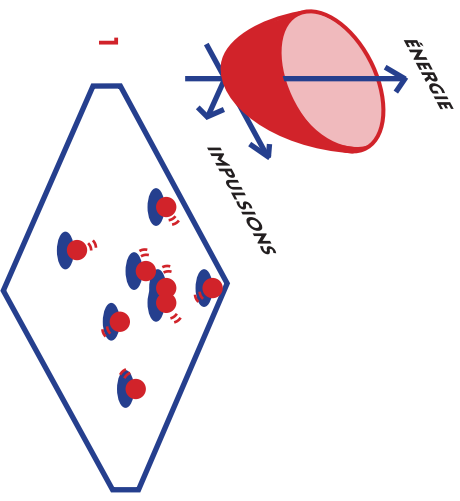
PHOTEMISSION AND METAL

MEASURING THE BEHAVIOR OF ELECTRONS INSIDE METALS.

1. In simple metals, a number of electrons can move freely and their speed will not depend on their direction.
Their energy, which depends on their momentum or on their speed, forms a parabola. This is the conduction band of the metal.

2. Angle-resolved photoemission enables us to measure this band. In order to do so, we send photons (the particles that make up light) on the metal surface. Each photon, if it has enough energy, can eject one electron.
This is the photoelectric effect.

By detecting the direction and the energy of the electron we can reconstruct the form of the band one electron at a time.



3. In some unusual metals, the band can become distorted, as if the electrons were heavier or lighter, sometimes in only a few directions. There can even be several bands for several types of electrons, as in iron-based superconductors.

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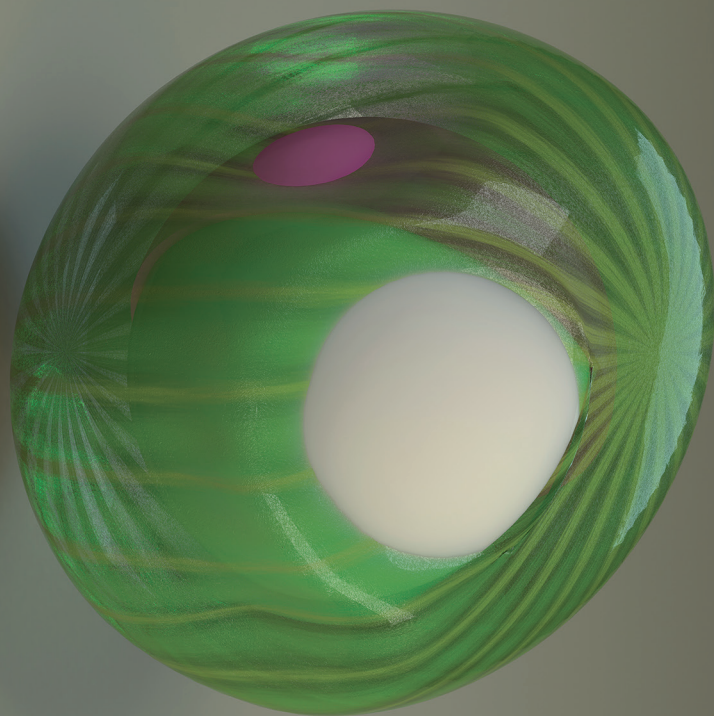


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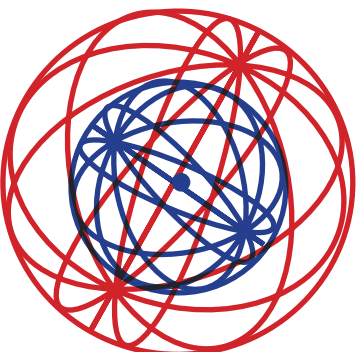
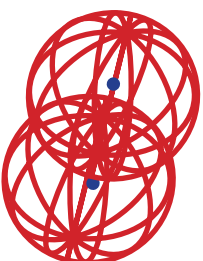
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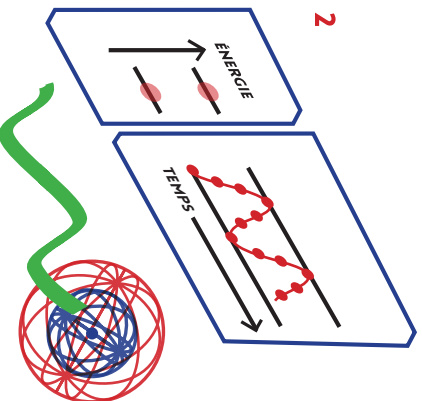
STATE SUPERPOSITION AND DECOHERENCE

A QUANTUM PARTICLE CAN BE IN TWO STATES AT THE SAME TIME! BUT AS SOON AS IT INTERACTS WITH OTHER PARTICLES, THE SUPERPOSITION STOPS.

1. A quantum particle can be in two states at the same time: an atom in two places, or in an excited and not excited state, or having both a high spin and a low spin.

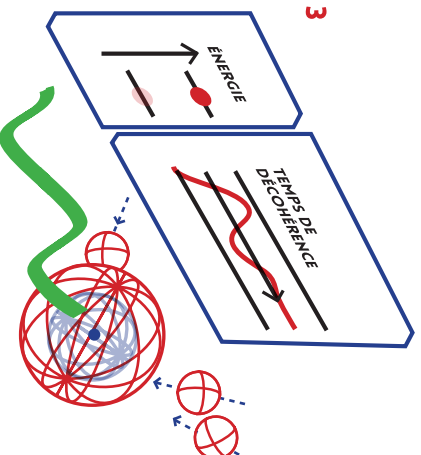


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2. In order to show this superposition we radiate the atom with an electromagnetic wave. At a particular frequency, the wave makes the atom sway between its two states, but progressively. By measuring the probability of an atom to be in his excited state, we observe oscillations, called the "Rabi oscillations".

3



3. If the atom interacts with other atoms or with light, the superposition stops after a period of time that we call decoherence time.

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