

Adventures at Nanoscale: Superconductivity

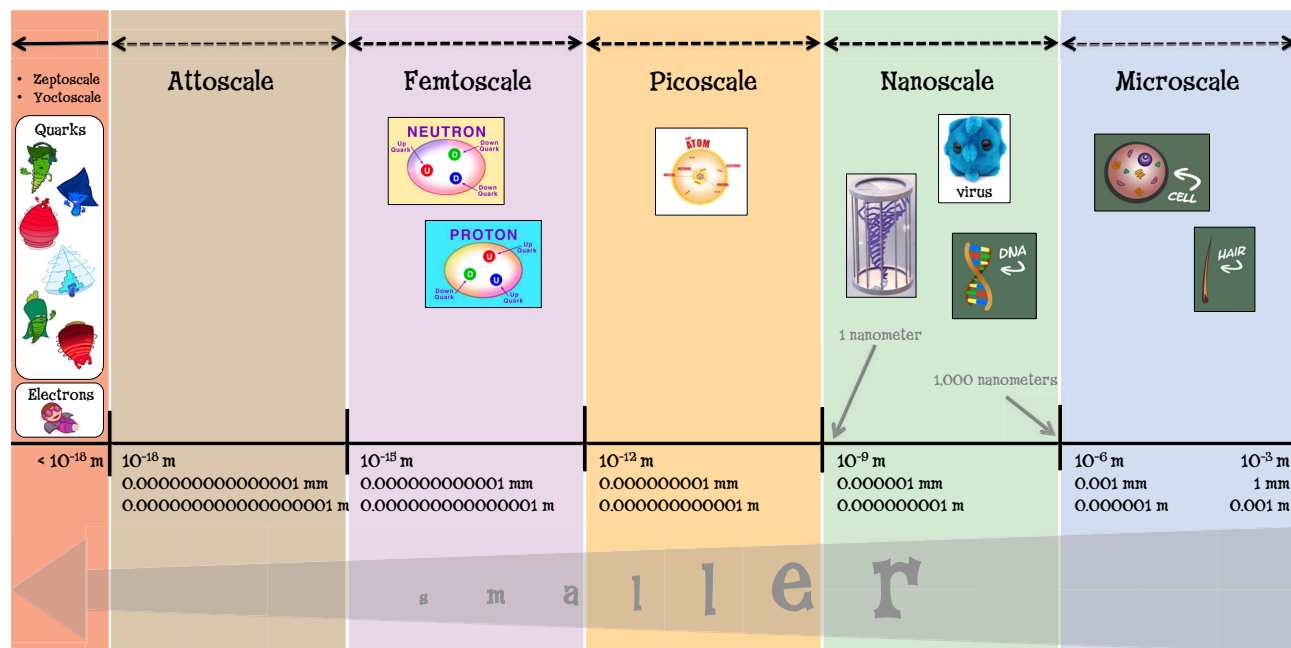
Frequently Asked Science Questions about the Video

1. What is nanoscale?

‘Nano’ is a prefix (goes at the beginning of a word) and refers to a measurement of between 10^{-9} (0.000000001) and 10^{-6} (0.000001). ‘Scale’ in this context means length. The standard measure of length in science is in meters (m). One nanometer (1 nm) is equal to 10^{-9} m or 0.000000001m. A nanometer is 10 times bigger than the size of an atom. Quarks and electrons are really, really, really small—much smaller than nanoscale (many millions times smaller).

2. What in the video represents nanoscale?

When the group of friends first zoom into flashlight, they pass through nanoscale as they get smaller and smaller. The cages and vortices are nanoscale items, typically a few nanometers in size. Their size relative to the atoms and other particles cannot be represented in the video because of the significant differences in size (tens to millions times different). While the cages and vortices are at nanoscale, the copper atoms we see are ten times smaller than nanoscale, and the quarks in the proton SUV and electrons are much smaller. Electron pairing also occurs at nanoscale distances (see question 5), but all of these scales cannot be accurately shown in the video at the same time. The chart below summarizes divisions at the microscale and below.



3. How big are quarks and electrons compared to atoms?

Quarks and electrons are about the same size. They are very, very small (the smallest things scientists know about). Atoms are much bigger and are mostly empty space. The bound electrons (ones that are part of an atom) form a cloud surrounding the nucleus. While the video shows a sort of fuzzy edge to atoms, in reality there is no shell or structure that defines the



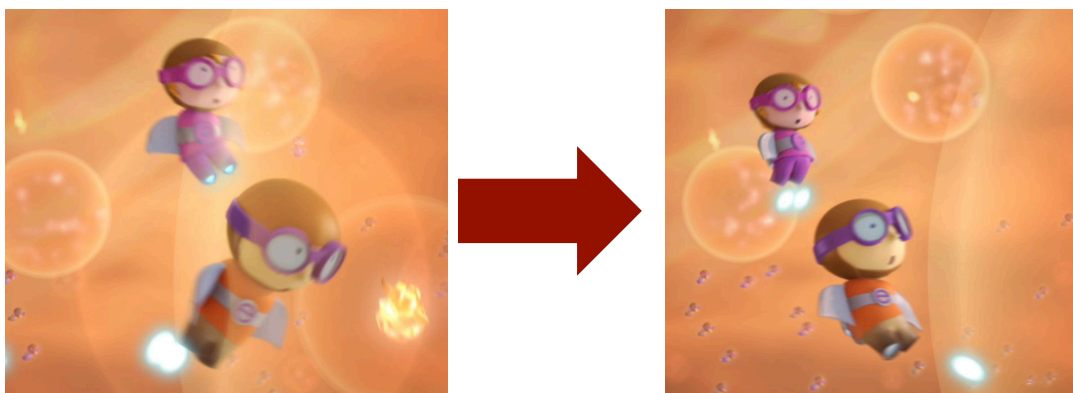
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boundary of an atom. Electrons are actually much smaller (millions of times smaller) compared to the atom than the video shows (see chart in question 2), but the relative size of an atom compared to the actual size of electrons cannot be represented in the video, particularly when we zoom through or past atoms.

4. Why and how do electrons produce photons when the move?

Electrons have the property of electric charge (they are negatively charged) and so they feel or are influenced by the electromagnetic force. The electromagnetic force attracts and repels matter with positive or negative electric charge. Photons are packets of energy. Electrons absorb and emit photons as they travel through a circuit. Photon absorption is not shown in the video, and emission is shown as light being expelled from the electrons.

The electromagnetic force also explains why Eddie and Elly as electrons are repelled by atoms (see image from the video below) and the other free electrons zooming around. Electrons are negatively charged and so when a free electron comes near other electrons—either another free electron that is moving around or the bound electrons moving around an atom—they are repelled, because like electric charges repel each other.



5. How can electrons pair if they are negatively charged?

Since electrons are negatively charged they repel each other, so for electrons to get closer together (to form what is known as *cooper pairs*) there needs to be a positive electric charge that they are attracted to. The positive charge is due to the properties of the superconductor itself. The atoms in superconducting materials have a positive electric charge (called ions), and have an organized pattern or structure known as a lattice. All atoms have kinetic energy and so they move (even in solids); at low temperatures atoms move less. Since superconductors are very, very cold, the atoms of superconducting materials are only wiggling very slightly—and because of lattice structure, the atoms wiggle or vibrate in an organized way.

When an electron moves, it interacts with the atom lattice. This interaction results in a local positive charge on the atom lattice as the electron moves. This positively charged area in the material is sufficient to attract another nearby electron and overcome the repulsive force of the negatively charged electrons. These two electrons become bound to each other, and travel together as a pair as they flow through the material—interacting with the lattice as they move.



The paired electrons are not as close together as they are they shown in the video; the interactions of the electromagnetic force acts over a relatively long range and so the paired electrons can a few to hundreds of nanometers apart (remember, electrons are millions of times smaller than nanoscale). Electrons can travel more easily through superconductors because the low temperature results in the surrounding atoms moving less and so don't get in their way, and individual electrons are more stable and travel a more direct route when they are paired.

6. What are the vortices or tornadoes?

The vortices are very tiny magnetic tornadoes created by moving electrons (imagine the wake left by a boat as it moves through the water or dust kicked up by a runner). Magnetism and electricity are the result of the electromagnetic force. A magnetic field is created by a moving electric charge. Electrons have a negative electric charge and so moving electrons generate a magnetic field, which is manifested as vortices or tiny magnetic tornadoes. The direction of the magnetic field generated is perpendicular or 90 degrees to the direction the electric charge is moving in, so in the video you see the tornadoes moving vertically while the electrons are moving from left to right.

7. How do the vortices trap electrons?

The vortices are very tiny magnetic tornadoes created by moving electrons (see question 6). Magnets like electric charges can attract or repel each other; opposites attract, likes repel. These vortices that form act like positively charged objects attracting negatively charged electrons. In the video, we see that the attractive force of the magnetic vortices is sufficient to pull apart an electron pair in a superconductor, which means the material can no longer act as a superconductor reducing efficiency. As mentioned in the video, scientists are building cages to trap these magnetic tornadoes to prevent them from interfering with electrons to improve energy efficiency.

8. How cages trap vortices?

Cages, also known as pins and wells, are built out of non-superconducting materials. If a magnetic vortex comes across this area as it travels through the superconductor, they fall into these cages or wells and become trapped. Imagine rolling marbles across surface with holes in it—when a marble (vortex) encounters a hole (cage) it falls in. These non-superconducting areas represent areas of electrical resistance, which means they resist the flow of electrons. Electrons follow the path of least resistance, and so while they also travel through the superconductor material, they move around or avoid these areas.

Increases in the temperature or current flow or the density of vortices in the material can make trapping vortices more difficult. Imagine our holey surface with marbles again; fewer marbles would fall into the holes if they were moving very, very fast. Scientists are working on ways to increase the number of cages or wells they can build in an area and new ways to organize them so they can trap as many vortices as possible.

