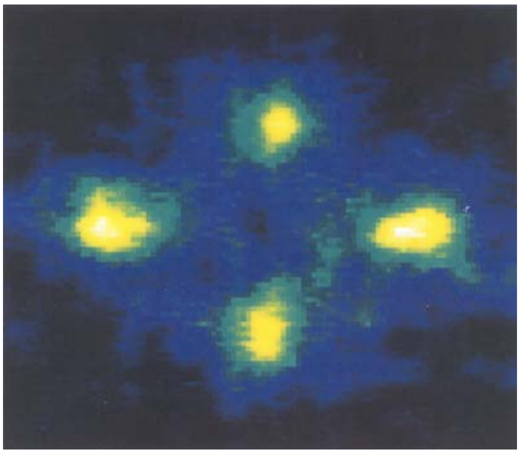
Information sheet 2

Laser cooling of atoms

In 1985, Alain Aspect joined Claude Cohen-Tannoudji, professor at the Collège de France (Chair of atomic and molecular physics), at the Laboratoire Kastler-Brossel (ENS Paris/CNRS/Université Paris VI), and embarked on research into the laser cooling of atoms with Jean Dalibard, and later with Christophe Salomon, physicists at CNRS. The aim is to control the movement of atoms, by using the force of radiation pressure exerted by lasers. It turns out to be possible to reduce the speed of atoms down to extremely low values, in the region of a few centimeters per second. The gas thus obtained has an extraordinarily low temperature: around one microkelvin, which is only a millionth of a degree above absolute zero.



Cooling of atoms to "below photon recoil". This shows the tracks left on a fluorescent screen by several hundred atoms which were cooled and released above the screen. The fact that the tracks have built up into four well-separated peaks shows that the cooling is clearly within the sub-recoil regime. According to the quantum description of the phenomenon, each atom must be considered to be simultaneously present in all four peaks, which are a few centimeters from each other. © Laboratoire Kastler Brossel

Among the many results obtained at ENS and which were rewarded in particular by the 1997 Nobel prize awarded to Claude Cohen-Tannoudji[2], Alain Aspect especially contributed to the development of the first cooling method which made it possible to slow down the speed at which atoms move to below the "photon recoil". This is the speed gained by an atom which emits a photon, rather like a gun recoiling when it is fired. The photon recoil was considered at that time to be an unsurmountable barrier.

Note that the process used to obtain this result (dubbed "velocity-selective black resonance") leads to each atom being placed into a quantum superposition where it is simultaneously present in several areas of space that are a few centimeters distant from each other, which is reminiscent of the state that describes a single particle in an interferometer.

This cooling mechanism has also been analyzed using "Lévy statistics", mathematical methods introduced by the French mathematician Paul Lévy[3] in order to describe how the result of a very large number of random phenomena may sometimes be totally dominated by a single event of low probability. [4]

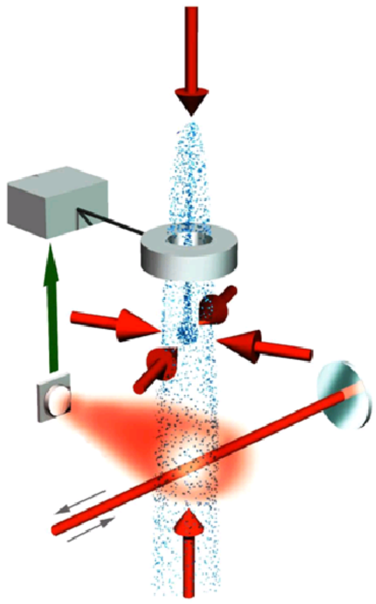
The laser cooling of atoms has paved the way to obtaining even lower temperatures, in the nanokelvin range (a few billionths of a degree above absolute zero), and to the discovery, in the United States in 1995, of gaseous Bose-Einstein condensates (for which Eric Cornell, Carl Wieman and Wolfgang Ketterle were awarded the 2001 Nobel prize for physics).

---

[2] Together with Steven Chu and William Phillips

[3] Professor at the Ecole Polytechnique from1920 to 1959

[4] Francois Bardou, Jean-Philippe Bouchaud, Alain Aspect and Claude Cohen-Tannoudji, « Lévy Statistics and Laser Cooling: How Rare Events Bring Atoms to Rest », Cambridge University Press (2002).



Cold atom fountain atomic clock A cloud of cesium atoms is cooled by six laser beams to a temperature of 1 microkelvin, and propelled upwards at a speed of 4 meters per second. Both when the atoms travel up and then down, they pass through a cavity where there is a microwave field whose frequency is to be compared to the frequency of the atomic transition which defines the second. The more time elapses between the two moments when the atoms pass through the cavity (in this case 0.4 seconds), the greater the accuracy. © SYRTE

Ultra-cold atoms can be observed for a much longer lapse of time than the atoms at room temperature used in the best atomic clocks of the previous generation. They have thus enabled the development of new time standards that are far more accurate, such as the cold atomic clock at the Laboratoire national de métrologie et d'essai - Observatoire de Paris (French national metrology and testing laboratory—Paris observatory), a collaborative venture between the Laboratoire Systèmes de référence Temps-Espace (Space-Time reference systems laboratory) and the Laboratoire Kastler-Brossel. This clock has been the most accurate in the world since 1998. Installed in satellites so as to free them from the influence of gravity, these clocks will be even more accurate, and will enable an ultra-stable time scale to be used throughout the whole world, which will be useful for ultra high-speed telecommunications, as well as for the improvement of satellite positioning systems, such as the American GPS (Global Positioning System) or the future European GALILEO system.

In addition, by making it possible to control the paths of atoms, the methods used to handle atoms by laser have led to the development of a new discipline, atomic optics (see information sheet 3).