

## The Bose-Einstein Condensate

### How Information Technology helps to push on physical achievements

By Susanne La Mura

The Bose-Einstein Condensate has been known in theory for about 70 years but it took until now to make it possible to gather the practical knowledge about it by means of information technology.

The matter that surrounds us consists of atoms that obey the laws of quantum mechanics. At normal temperatures they often conform to classical conceptions, but when the temperature is lowered and the speed of the atoms is therefore reduced, their properties will be increasingly dominated by the principles of quantum mechanics. The atoms rotate round their axes-they have spin- and this movement is described by a spin quantum number, which has to be an integer- a whole number- or a half-integer. Particles that have integer spin are called bosons and those with half-integer spin are called fermions. Bosons strive to gather in one and the same quantum state, namely the one with the lowest energy while fermions on the other hand avoid each other. They can't appear in exactly the same quantum state, so that states of higher energy must also be used.

In 1924 the Indian physicist S.N. Bose carried out a statistical calculation for the kind of particles which have since come to bear his name, bosons, and more specifically light particles later termed photons. Bose presented an alternative derivation for the radiation law earlier found by Planck. He sent his work to A. Einstein, who realized its importance and even extended his theory. His idea was that when a given number of particles approach each other sufficiently closely and move sufficiently slowly they will together convert to the lowest energy state, which is known as the Bose-Einstein condensation (BEC).

Ever since the publication of this pioneering work, physicists have wished to be able to achieve this new fundamental state of matter. By using very advanced methods this was accomplished in 1995 with alkali atom gases, in which the phenomenon can be studied in a very pure manner. While in other systems the condensation phenomenon concerns only a part of the systems and the strong interactions involved tend to hide the BEC phenomenon.

Since a particle sometimes behaves like a wave we can express its wavelength  $\lambda$  in terms of the momentum of the particle  $p$ :

$$\lambda = h/p$$

where  $h$  is Planck's constant. This equation was postulated by de Broglie. The more slowly the particle moves the less its momentum and the longer the de Broglie wavelength. According to the kinetic theory of gases low particle velocities correspond to low temperatures. If a sufficiently dense gas of cold atoms can be produced, the matter wavelengths of the particles will be of the same order of magnitude as the distance between them. It is at that point that the different waves of matter can 'sense' one another and coordinate their state, and this is Bose-Einstein condensation. Sometimes this is compared to a 'superatom', since the whole complex is described by a single wave function exactly as in a single atom.

Using the rubidium with mass number 87 and the sodium with its single stable isotope with both having weak repulsive forces shows that BEC occurs if the density exceeds  $2.6 \times 10^{20} \text{ m}^{-3}$ . It can then be calculated that the atoms for realistic densities must move very slowly, at speeds of the order of a few millimetres per second. This corresponds to temperatures of about 100 nK.

This year's Nobel Laureates achieved this by using in a decisive manner the methods of cooling and trapping neutral atoms.

#### Different starting-points in approaching BEC:

Laser cooling and evaporative cooling:

-Laser cooling:

The basic principle is to exchange momentum between photons and atoms. Cooling is achieved by arranging that the photons can be absorbed only if they collide head-on with the atom in its flight. The speed is then reduced, primarily to a limit set by the randomness of spontaneous emission. The cloud of cooled atoms now also must be held together and this is realized in so-called atom traps. These often work on a combination of laser beams and magnetic fields. The magneto-optical trap (MOT) has become extraordinarily important, since many research groups used this approach. But a further cooling technique was necessary: evaporative cooling.

-Evaporative cooling:

Cooling is achieved by ensuring that the fastest atoms leave the community. The average temperature among the remaining atoms is then reduced. (cooling of a coffee cup!) In an atom trap the atoms are kept in place by magnetic dipole forces. The attractive force can be turned into a repelling force by reversing the atomic magnetic poles. Through the application of a high frequency and then gradually lowering it, it is possible to successively skim off the hot atoms.

The final difficulty to overcome was to avoid atom loss at the centre of the trap, where the magnetic field is zero and spontaneous pole-switching is possible. By rotating a magnetic

field sufficiently rapidly over the sample, it was possible to prevent the atoms from systematically pouring out of the trap.

Due to combining and improving these techniques it has become possible to make spectacular measurements of the properties of the condensate:

It was shown for example, that two separate condensates, if allowed to expand into each other, exhibit very clear interference effects, indicating the coherence of matter waves and long-range correlation. And it was also shown how single parts of the condensate could be switched out in "BEC drops" that obey to the field of gravity. This phenomenon has been described as an atom laser of coherent matter.

### Prospects

BEC in dilute gases offers particularly rich possibilities for studies of fundamental quantum-mechanical processes. But there is even more to it: many interesting aspects can now be simulated with the BEC, for example the supernova ("Bose-nova") or the conditions in white dwarf stars and other fundamental natural phenomena where sharp resonances in essentially motionless atoms or sharp matter-interference fringes are used. Especially in lithography, nanotechnology and holography we might expect some new revolutionary developments.

The importance of computer technology in the area of physics can therefore widely be seen. Without using the possibilities that computers offer in processing data there would be still no proof of Boses and Einsteins theories.

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