Investigating mixtures of fermionic elements at ultracold temperatures

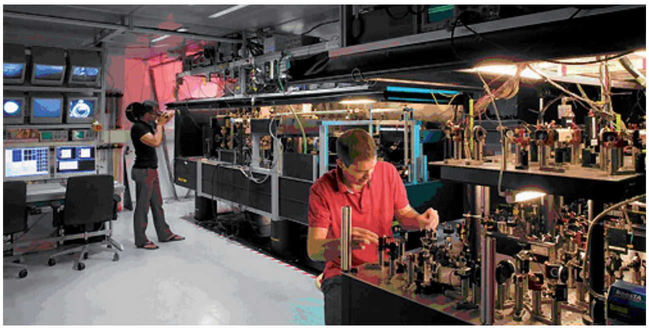
Dr. Florian Schreck

Application Note

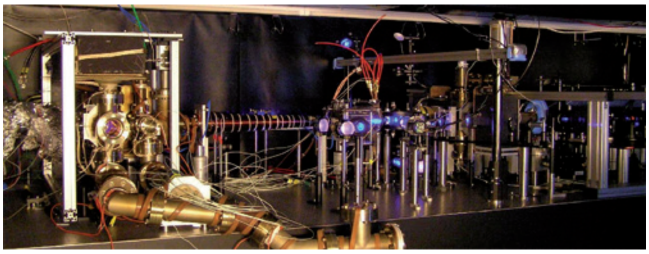
The group of Rudolf Grimm at the institute of quantum optics and quantum information (IQOQI) of the Austrian Academy of Sciences is investigating quantum mechanical behaviour in mixtures of fermionic gases at temperatures in the microkelvin regime.

Experimental setup

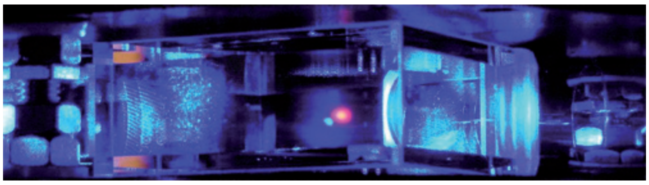
A brief overview of the experiment is given in pictures 1 to 3. An atomic beam of lithium, potassium and strontium is slowed using laser light (in a Zeeman slower).



Picture 1: The laboratory at IQOQI in which the experiments take place. (Photograph: C. Lackner)

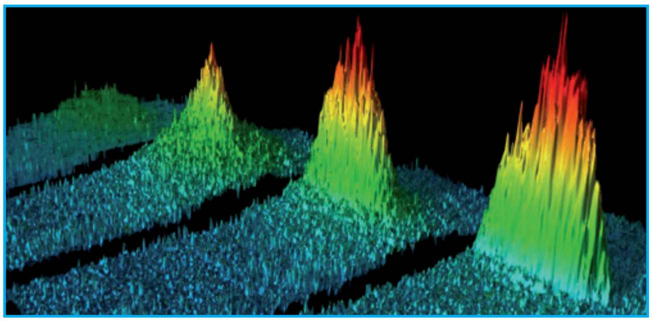


Picture 2: overview of the apparatus. An atomic beam is produced in the oven at the left hand side of the machine. The atoms are slowed down by a laser beam as they travel through the vacuum chamber to the right.



Picture 3: close-up of the central part of the vacuum chamber shown fully in picture 2. The red and blue blobs in the middle are cold lithium and strontium gas clouds, cooled and kept in place by laser beams and magnetic fields.

The atoms are cooled and collected by magnetic fields and another set of laser beams (in a magneto-optical trap). The gas is further cooled by evaporation to reach a temperature and density regime in which the atoms stop acting classically as individual particles, but rather can be described by a single wave. This behaviour, called Bose-Einstein condensation, is a quantum mechanical phenomenon (Picture 4). It is comparable to the behaviour of the particles of light, photons, in a laser beam.



Picture 4: three dimensional renderings of absorption images of the formation of a molecular lithium Bose-Einstein condensate. The four images show the result of four independent experimental runs. The gas cloud was cooled least for the leftmost image and most for the rightmost image. The leftmost image shows a circular density distribution which indicates classical behaviour. The rightmost image shows an elliptical density distribution, a hallmark of quantum behaviour and strong indication that a quantum superfluid has been created. The middle images show the transition from one extreme to the other.

Detection method

The essential data acquisition technique used is absorption imaging. After a sample has been prepared, it is illuminated for 50 μs by a resonant laser beam. Atoms scatter light out of this beam and produce a shadow in the beam intensity profile. The beam intensity profile is magnified by a factor 8 and recorded using an Andor DV437-BV CCD camera. By analyzing the beam intensity profile with and without atoms, the atomic density distribution integrated along the laser propagation direction can be computed. It is beneficial to record the two laser beam profiles (with and without atoms) shortly one after the other so that the beam profile does not change too much due to fluctuations in the setup.

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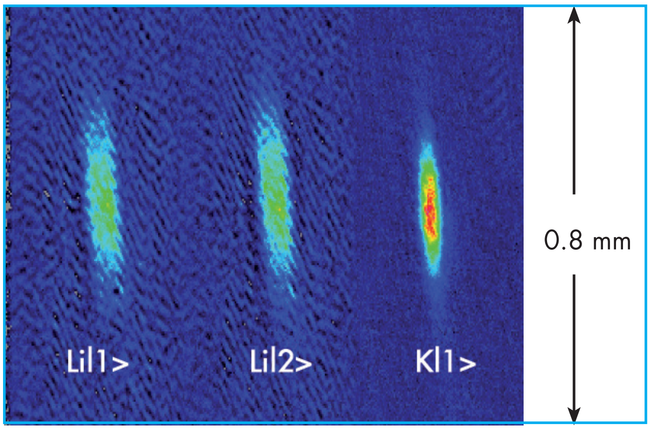
Our experiments require taking consecutive absorption images of two elements, lithium and potassium, as fast as possible. In addition, each element can be prepared in different internal states and we usually have a mixture of two lithium states and one potassium state. Thus, to obtain all information about the sample, three absorption images have to be taken.



Picture 5: false colour absorption images of two different internal states of fermionic lithium and potassium. The atomic clouds are at the same spatial location. The FKS imaging technique was used to image the different components separately. The second (third) image is taken 0.6 ms (1.6 ms) after the first. The imaging system was focused on potassium, leading to chromatic aberrations in the lithium images. Ultimately we plan to use independent cameras for lithium and potassium.

Since each absorption image is created from two raw images (with and without atoms) we have to take six images in a fast sequence. This was possible using Andor's fast kinetics series (FKS) mode. We chose a 512x1024 pixel frame transfer CCD chip which Andor rewired, so that the full area can be used for FKS. The chip area is divided in one exposure area and six storage areas so that our final image size is 146 x 512 pixels. Picture 5 shows example data recorded using the described method.

Andor cameras have been very easy to integrate into our system. They are working as expected and have been in continuous use in our lab since over a year. In this time, we have taken several 10000 pictures.

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