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Quantum mechanic frequency filter for atomic clocks

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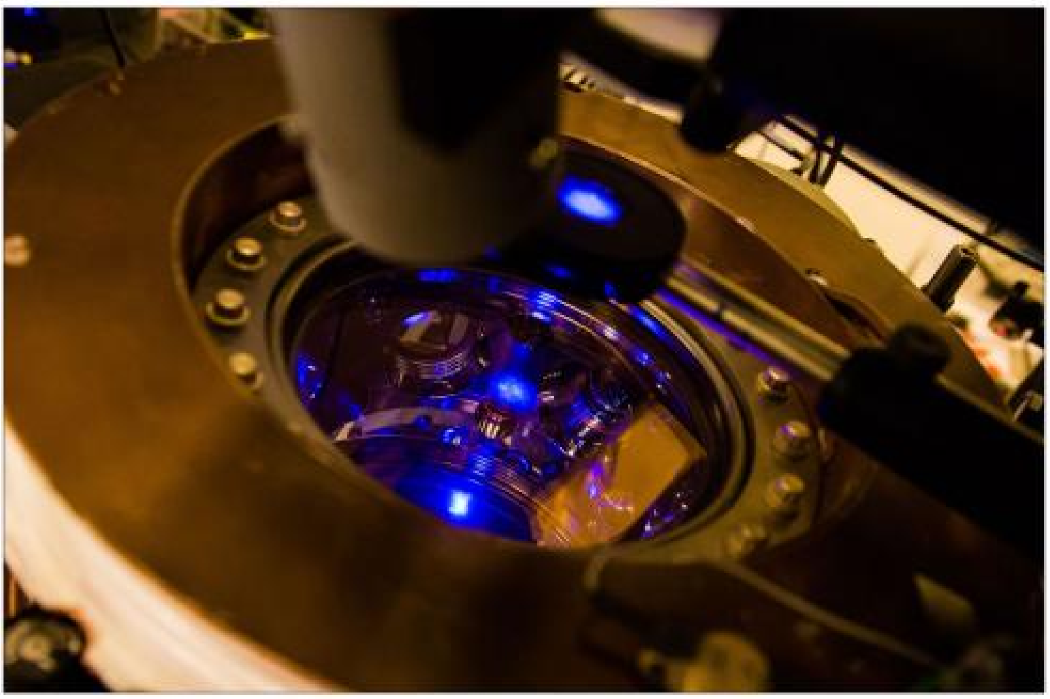


Atoms are cooled down to temperatures near the absolute zero by using laser light (blue light) and magnetic fields.

Atomic clocks are the most accurate clocks in the world. In an atomic clock, electrons jumping from one orbit to another decides the clock's frequency. To get the electrons to jump, researchers shine light on the atoms using stabilised laser light. However, the laser light has to have a very precise frequency to trigger very precise electron jumps. It is however challenging to get the laser light frequency ultra precise – there will always be a little 'noise'. Now researchers from the Niels Bohr Institute have developed a method that reduces the noise so that it is up to 100 times quieter. The results are published in the scientific journal *Physical Review Letters*.

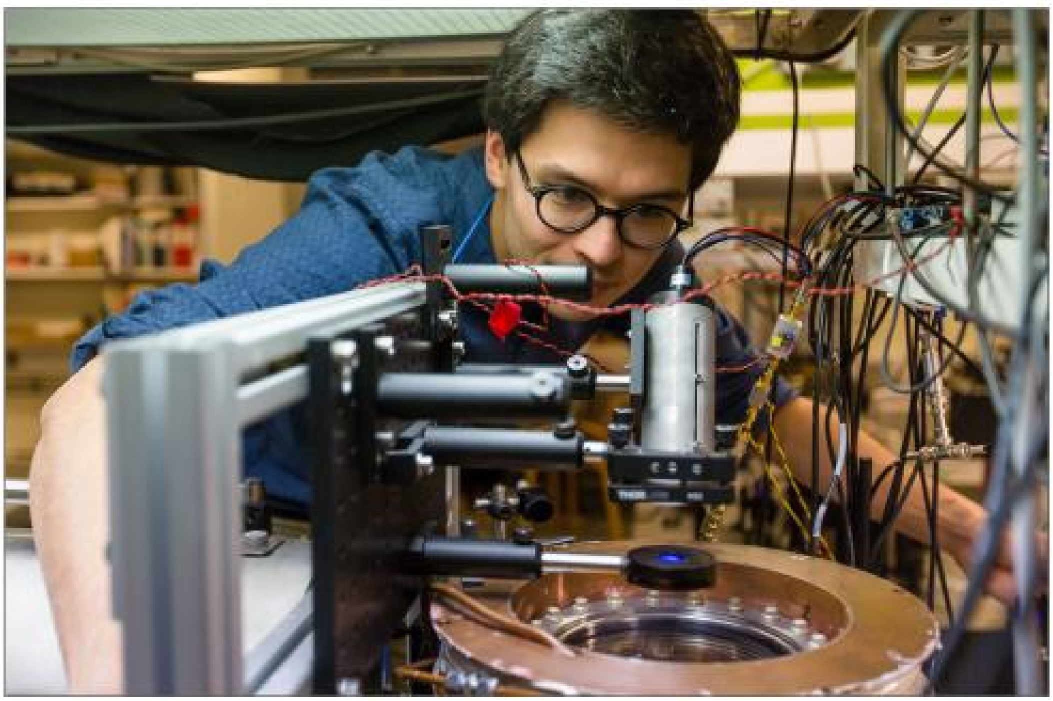
The atoms in the atomic clock are made up of strontium gas, kept in a vacuum chamber. Using magnetic fields and precise beams of laser light (blue light), the atoms are cooled down to near absolute zero, minus 273 degrees Celsius, where it is maintained.

The electrons are located in certain orbits around the nucleus and each orbit has one energy level. By now flashing the strontium atoms with laser light (red light), the electrons get a higher energy level and jump from one orbit to the next, but they immediately jump right back to their normal orbit. When you then shine the light on the strontium atoms, the electrons keep jumping back and forth in a classical sense and this constitutes the pendulum in the atomic clock.

An atomic clock is now so precise that it only loses one second every 300 million years, but we are working to make it even more precise and this has great potential, including for navigation and space based optical technology for exploration of the universe. The problem with making it more precise is controlling the laser light, so that the light has exactly the wavelength that hits the atoms' electrons and gets them to oscillate very precisely and very accurately.

Solves noise problems

"The laser light is stabilised, but it fluctuates a bit and creates 'noise'. Since there are several wavelengths at the same time due to the noise, we send the light via a mirror to a 'resonator', which is two mirrors joined together so that it allows some waves to pass, while the rest disappear. So it is a sorting mechanism so that the laser light wavelengths become more precise. So, everyone should be happy, but the mirrors fluctuate slightly – simply because the atoms in the mirror vibrate and this puts some limitations on the stability that we could not get rid of. So we said – why don't we try to change our mindset and turn the whole thing upside down," explains Jan Thomsen, associate professor and head of the research group, Ultra Cold Atoms at the Niels Bohr Institute at the University of Copenhagen.

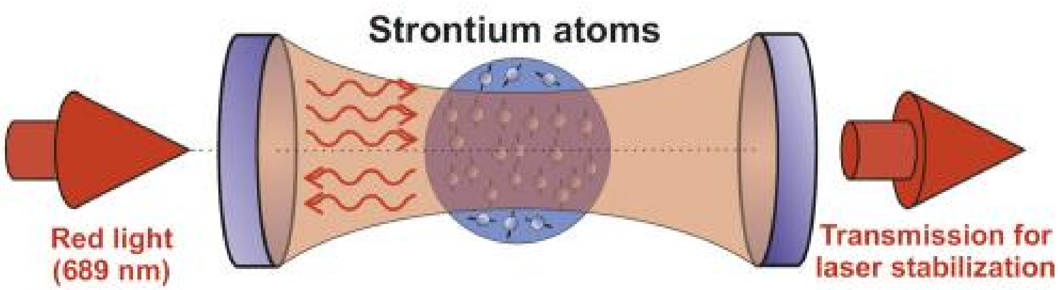


Ph.d.-student Bjarke Takashi Røjle Christensen in the quamtum optics lab at the Niels Bohr Institute.

And so they did – turned it all upside down. Instead of trying to further stabilise the mirrors, they decided to completely ignore the vibrations. They decided to put 'something' between the laser light and the resonator's two mirrors. This 'something' would act as a filter.

The filter consisted of a vacuum chamber with ultra cold strontium atoms between the two mirrors. Strontium is a very 'demanding' atom, which must have a very specific wavelength in order to react with the light. The light is now sent back and forth between the two mirrors and even though the two mirrors vibrate a little due to the temperature in the room, the light does not care, because it is primarily the cold atoms that sort the wavelengths.

"The method is simple, but effective and the result is that the laser beam is much more precise and stable and the noise is reduced by up to 100 times. So we have developed a technique that can create an ultra-precise laser beam using a quantum frequency filter," explains Jan Thomsen, who points out that the technique could be used to make atomic clocks more precise than until now and in a much simpler way than before.



The laser light is sent through a 'resonator', which consists of two mirrors. This resonator selects specific wavelengths. A vacuum chamber containing ultra cold atoms is placed in between the two mirrors and acts as a frequency filter. As a result, the laser can be stabilized much better than with just the empty 'resonator'. Credit: Bjarke Takashi Røjle Christensen, NBI

More information: "Observation of Motion-Dependent Nonlinear Dispersion with Narrow-Linewidth Atoms in an Optical Cavity" *Phys.*

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