Popular science account of

Damping of a classical nano-mechanical oscillator using electromagnetically induced Transparency

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- *What is the aim of this project?*

Put simply, our research is aimed at examining and understanding how an ensemble of very few atoms, or even a single atom, can talk to the motion of a mechanical element (a solid body) of an optomechanical setup. More specifically, we study how the optical response of the atomic ensemble can serve as a means to reduce the motion of a mechanical oscillator and, hence, cool it down.

- *What does optomechanics mean; what is so fascinating about it?*

The branch of physics that studies the behavior and properties of light when it interacts with matter is known as optics. Optomechanics investigates those physical phenomena resulting from the coupling of light waves to the motion of material objects. Nowadays a level of optical control as accurate as the one achieved over atoms or molecules is also becoming possible upon the motion of solid bodies. From a practical point of view, this may allow researchers to engineer highly sensitive displacement sensors intended for gravitational wave detection, or to measure tiny quantities of matter (masses approximately one billion times lighter than the billionth part of a gram, very nearly to that of a single proton or neutron!) and forces at the molecular scale.

On the other hand, optomechanics is enabling a breakthrough in our understanding of the laws of quantum theory. Without these laws we couldn't explain things apparently as obvious as why some materials conduct electricity and why some others don't, why a drinking-glass is transparent, and so forth. Ultimately, any property of matter! Furthermore, some of those properties, which unfortunately are quite technologically demanding in order to be observed at any other than the atomic or subatomic scales, can actually be extremely important for scientific progress (and usually exceedingly challenging for anybody's common sense!). State-of-the-art optomechanical experiments are paving the way to translating these phenomena into a realm that is closer to our perception and common sense.

For instance, it has already been shown that a solid body constituted by as many as several billions of atoms cooled down to its lowest energy state is, paradoxically, still moving, just as the laws of quantum theory dictate! Next, we are going to learn how is this possible.

- *What kind of optomechanical setup we have in mind and how does it work?*

We use light waves to create a mutual coupling between the motion of a mechanical resonator and the optical response of an ensemble of atoms. The atoms and the mechanical resonator are placed far enough away from each other to prevent them from disturbing each other. The mechanical resonator consists of a tiny reflecting plate (mirror) mounted on a cantilever that can swing back and forth at a given frequency. Every light wave that is reflected off the mirror acquires then a power spectrum (light power as a function of frequency) with additional minor peaks, known as sidebands, at a mechanical frequency up or down with respect to the carrier frequency of the original light wave. The strength of these sidebands is directly proportional to the oscillation amplitude of the movable mirror. The upper sideband accounts for light waves having extracted energy from the oscillating mirror, whereas the lower sideband for light waves having transferred energy to it. To cool down the mirror motion we use two atomic resonances, i. e., frequencies describing the process of electrons in an atom being promoted from one orbit to another via light absorption, and two light waves of different frequencies. One light wave is used to probe the absorption of the atoms at one of the atomic resonances as well as to drive the mirror oscillations, the so called 'probe light', whereas the other light wave is used to control the optical response of the atoms and so is called the 'control light'.

By carefully tuning the frequency of the control light to the remaining atomic resonance, one can render transparent the resonant absorbing atomic medium at the frequency of the probe light (this is known as electromagnetically induced transparency). Feeding the control light reflected off the oscillating mirror to the atoms allows us to damp the mirror oscillations. Indeed, the sidebands on the control light alter the transparency of the atoms with respect to the probe light and lead to the generation of probe light sidebands. Consequently, if now the frequency of the probe light is slightly detuned below the original atomic resonance, the process accounted by its upper sideband will be enhanced. This means that the atoms will modulate the probe light wave so that it will oscillate out of phase with the mirror motion and damp the mechanical oscillations.

- *How quiet can the mirror actually be?*

From a description based on classical physics, as the movable mirror approaches a motionless state (or any other equilibrium state), the two sidebands of the driving (probe) light wave, should become totally symmetric and finally vanish once the mirror is completely quiet. However, according to the laws of quantum physics, the state of minimum mechanical energy or (mechanical) ground state of the movable mirror should actually be non zero and, more importantly: one cannot extract energy from it. Accordingly, only the lower sideband could be observed when the movable mirror reaches its ground state. As pointed out above, this fact has already been corroborated in a laboratory!