

On the physical nature of the diffusion laser cooling phenomenon

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Abstract

The physical nature of the phenomenon of diffusion laser cooling is discussed. In particular, the dependence of the cooling efficiency of atoms on the tuning of laser radiation to the "red" or "blue" side on the frequency of the optical transition is discussed. It is again proposed to conduct simple experiments to verify the presented physical explanation.

Laser cooling studies developed rapidly in the 70-90s. Outstanding results were obtained. To cool neutral atoms, the so-called Doppler approach was first successfully developed [1, 2]. The experimenters then discovered that the observed cooling depth of the atoms significantly exceeded the Doppler cooling limit. To explain this phenomenon, some sophisticated physical mechanisms like Sisyphus cooling, Velocity Selective Coherent Population Trapping, Polarization gradient cooling, Resolved sideband cooling, Raman sideband cooling have been proposed.

However, the most popular explanation today for the capture, cooling and holding of atoms and particles by laser radiation is, probably, the idea of an optical dipole trap [3]. The idea was that atoms could be polarized. Due to this polarizability, under conditions of a large gradient of laser radiation intensity, it should be drawn into the laser beam. Such conditions exist in optical tweezers [4]. Moreover, it is assumed that below an atomic resonance ("red" detuning) the dipole potential is negative and the interaction thus attracts atoms into the light field. But above resonance ("blue" detuning) the dipole interaction repels atoms out of the field. According to this distinction, dipole traps can be divided into two main classes, red-detuned traps and blue-detuned traps. Under the conditions of such a dipole trap, atoms can be captured and cooled in a vacuum for a long time.

In the huge stream of publications on laser cooling of atoms, molecules, ions, particles, and mechanical resonators, it is easy to overlook the amazing result of the so-called diffusion laser cooling [5 - 7]. There are no nodes and antinodes, there are no gradients of laser radiation intensity. It turns out that under conditions of completely isotropic irradiation, atoms are cooled no less efficiently than in sophisticated optical trap schemes. The same amazing property is observed here – the effective cooling of atoms occurs when the laser radiation frequency is red-tuned relative to the resonance of the optical transition. The authors do not provide any possible explanation of the physical nature of the phenomenon of diffusion laser cooling.

However, such a physical explanation exists. It was discussed in [8]. We are talking about spatially asymmetric (nonisotropic) scattering of laser radiation. Figure 1 shows a scheme to illustrate the explanation of the physical nature of the diffusion laser cooling phenomenon.

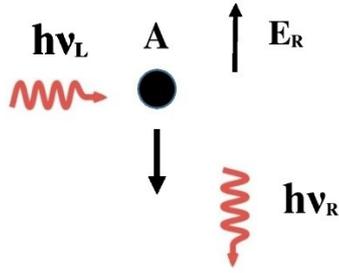


Fig. 1 The scheme of nonisotropic photon scattering.

Here, a cold atom (**A**) falls down in a vacuum under the influence of gravity. A horizontally directed laser photon ($\mathbf{h}\mathbf{v}_L$) is scattered on this atom. It does not scatter isotropically, but downwards in the direction of the atom's motion. The atom receives from the scattered photon a recoil momentum, directed upward (towards the point of space where the atom was previously located). In this case, the energy of the scattered photon ($\mathbf{h}\mathbf{v}_R$) increases by the amount of the recoil energy (\mathbf{E}_R).

$$\mathbf{h}\mathbf{v}_R = \mathbf{h}\mathbf{v} + \mathbf{E}_R \quad (1)$$

The frequency of the scattered photon \mathbf{v}_R increases. If the laser is tuned to the "red" side of the optical transition frequency, the scattered photon will become closer to resonance. And if the laser is tuned to the "blue" side of the optical transition frequency, then the scattered photon moves away from resonance. This, apparently, explains the different efficiency of laser cooling of atoms with "red" and "blue" laser frequency detuning.

This physical explanation can be easily verified experimentally. And similar experiments were carried out many years ago [9, 10]. Unfortunately, this experiments were not brought to their logical conclusion. A vertical resonator formed by two mirrors was used there. Inside the resonator, a cloud of cold atoms freely falls in a vacuum under the influence of gravity. The falling atoms are exposed to horizontally directed laser radiation. In this case, scattered radiation appears in the vertical resonator and the falling atoms slow down.

If the slowing down of atoms is due to the scattering of photons, then it is intuitively clear, that the downward scattering of photons should prevail. However, this information is hidden (erased) by the presence of a vertical resonator. Thus, these experiments should be repeated without vertical cavity mirrors and the preferred direction of photon scattering should be determined at different detuning of laser radiation from the optical transition frequency. It is also interesting to compare the frequency of laser and scattered photons.

There are a large number of experimenters who have all the necessary equipment for such experiments. We once again encourage them to carry out these important, interesting and simple experiments.

Conclusion

Thus, the sub-Doppler cooling of atoms occurs through an increase in the energy of nonisotropically scattered photons. This spatially asymmetric scattering itself is a rather direct manifestation of a fundamental property of quantum physics – the nonequivalence of forward and reversed quantum processes [11]. An even more direct and obvious manifestation of this property is the well-known phenomenon of Bloch oscillations of cold atoms in a vertical optical lattice [8].

We have sufficient direct and indirect experimental evidence of such nonequivalence [11]. It is difficult to understand how long our physicists will persist in ignoring this already quite obvious experimental fact [12].

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