On the experimental study of the physical nature of the trapping and sub-Doppler cooling of atoms and nanoparticles in the field of laser radiation

V.A. Kuz`menko

Troitsk Institute for Innovation and Fusion Research, Moscow, Troitsk, Russian Federation. e-mail: kuzmenko@triniti.ru, kuzmenkovladimir4@gmail.com

Abstract

The study of the capture and cooling of atoms and nanoparticles by laser radiation has a long and extensive history. This study for atoms and nanoparticles took place in parallel and independently of each other. We claim that the main basis for this two cases is the same physical mechanism – the spatial asymmetry of photon scattering. Experimental study of this mechanism is not a difficult task, but it requires some courage from the experimenters.

Keywords: laser cooling, optical tweezers, spatial asymmetry scattering, time reversal non-invariance.

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" or Velocity Selective Coherent Population Trapping have been proposed. The important thing is that these are not proofs of a physical mechanism, but only supposed explanations.

In parallel and independently, work was developed on laser capture and cooling of nanoparticles under the conditions of so-called optical tweezers [3]. The idea was that such nanoparticles could be polarized. Due to this polarizability, under conditions of a large gradient of laser radiation intensity, nanoparticles should be drawn into the laser beam [4]. Under the conditions of such a dipole trap, nanoparticles can be captured and cooled in a vacuum for a long time. It also turned out that optical tweezers can hold cold atoms.

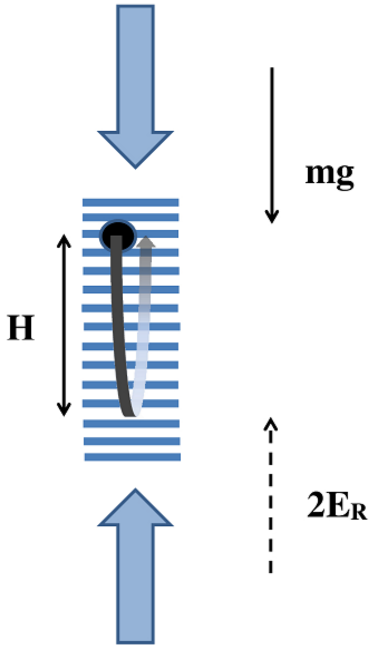
However, there is no reliable experimental evidence that polarizability is responsible for the capture of atoms and nanoparticles in optical tweezers. This is just a supposition. Such evidence is not needed if there is no alternative physical explanation.

However, an alternative physical explanation exists. This is amazing, but its experimental demonstration has long been well known to everyone. We are talking about the so-called Bloch oscillations of cold atoms in a vertical optical lattice [5, 6]. The existing rather vague physical explanation of the nature of these oscillations suggests the existence of some potential barriers for atoms in the optical lattice, from which they are reflected [7 - 9].

This is an erroneous explanation for two reasons:

1) the amplitude of the oscillations is determined by the doubled momentum of the photon recoil,
2) this amplitude has nothing to do with the period of the optical lattice. It is much larger than this period.

The scheme of a typical experiment is shown in Fig. 1. Two laser beams with the same wavelength are directed towards each other and form a so-called standing optical lattice. An initially stationary cold atom falls under the influence of gravity in a vacuum along an optical lattice. The speed of the atom increases (it heats up). At a strictly defined moment in time, a photon is scattered. A photon is absorbed from the upward beam and emitted with downward beam. As a result, the atom receives a doubled photon recoil momentum and returns to its starting point in space (it cools down).



$$\mathbf{H = h^2 /2m^2\lambda^2 g}$$

$$\mathbf{T = 2h/mg\lambda}$$

Fig. 1 Scheme of the Bloch oscillations of cold atoms in a vertical optical lattice.

It is strange that physicists cannot realize the fact that Bloch oscillations of cold atoms in a vertical optical lattice are a direct demonstration of the universal mechanism of cooling of atoms in a laser field due to spatially asymmetric scattering of light. Although in order to realize this fact, it is necessary to additionally recognize another fact (just, a mere trifle) – the non-invariance of time reversal in quantum physics.

We have a sufficient number of direct and indirect experimental proofs of such non-invariance [10]. The Bloch oscillation is one of such evidence. But theorists are not ready to accept this evidence. They would prefer to spend another 100 years cheerfully discussing the collapse of the wave function, the role of the observer, the many-worlds interpretation, the use of complex numbers, and many other mathematical problems known to them. Experimenters in such a situation, apparently, reasonably fear that it will be difficult to publish the results in a prestigious journal. Everyone knows that this is now the main goal of any scientific research. Not to find the truth, but to publish an article.

The same cooling mechanism will work for the horizontal optical lattice. It can also work in optical tweezers. It's just that the spatial asymmetry will be a little different. In this case, the photon is absorbed from the laser beam, and is emitted in the direction of the atom's motion. The atom receives an impulse of recoil in the direction of the initial marked point of space.

Is it possible to experimentally test the concept of cooling through the asymmetry of light scattering? Yes, you can. This type of experiment has already been conducted a long time ago [11, 12]. However, unfortunately, this experiment was not brought to its 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 or even completely come to a stop.

It is intuitively quite obvious that the slowing down of atoms is due to the preferential downward scattering of radiation. But this information is erased by the vertical resonator. Thus, this experiment should be repeated without using vertical cavity mirrors. It is necessary to measure the intensity of scattered radiation upwards, downwards, and sideways. And to determine whether the difference in these intensities is sufficient to compensate for gravity. It would be desirable to conduct similar experiments with nanoparticles in optical tweezers.

In general, the task is to measure the differential cross-sections of forward, reversed and partially reversed quantum processes. This is not a very difficult task for experimenters. In the case of Bloch oscillations of cold atoms, the difference in the differential cross sections of the forward and reverse processes is many orders of magnitude.

Studying the changes in differential cross sections in time and space will provide information about some properties of the nonlocal memory of quantum systems about their initial state [13]. Such a nonlocal memory is obviously the physical equivalent of entropy.

Conclusion

There are a large number of experimenters who have all the necessary equipment for such experiments. We hope that someone will at last carry out these important, interesting and simple experiments

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