Friction force in a field of two elliptically polarized counterpropagating waves

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The dependence of the radiative force on light field parameters is of significant importance for laser cooling and trapping problems. In the theory of sub-Doppler cooling the main attention was addressed to the situation, when a field with polarization gradients is formed by counterpropagating waves, having specific, circular or linear polarizations [1, 2]. In all these cases the light force has the odd dependence on the field detuning δ and, consequently, the direction of kinetic process (cooling or heating) is governed by the sign of δ.

In the present paper we analyse the motion of atoms in monochromatic 1D light field of the most general configuration, which is formed by two running counterpropagating waves with arbitrary elliptical polarizations. In this field all spatial gradients appear (i.e. gradients of the phase, intensity, ellipticity and orientation of polarization ellipse). We find out new peculiarities in the friction force due to the ellipticity of the waves.

For the optical transitions $j_g = 1/2 \to j_e = 1/2$ and $j_g = 1/2 \to j_e = 3/2$ (where j_g, j_e are the total angular momenta of the ground and excited states) we obtain the explicit analytical expressions for the force up to the first order on velocity: $f(v) = f_0 + \xi v$, where the second term is the friction force with the friction coefficient ξ. It was found out that the friction force significantly depends on the polarizations of the waves. For example, if their polarizations are elliptical, then new terms with the even dependence on detuning arise. Note, that this property, thought unexpected, is consistent with the general time-reversal symmetry [3]. The obtained results allow us to distinguish a class of light fields, which is of especial importance for laser cooling. Such a field is formed by the waves, having the same intensity and ellipticity, but opposite rotation, while the semimajor axes of the polarization ellipses make an angle ψ (Fig. 1). For this class of light fields the averaged over the spatial period force $\overline{f}_0 = 0$, and the friction coefficient can have the even dependence on detuning. For example, for optical transition $j_g = 1/2 \to j_e = 3/2$ at $\delta = 0$ the averaged over the field period friction coefficient $\overline{\xi}$ in the zeroth order on the intensity has the form:

$$\overline{\xi} = -\frac{3\hbar k^2}{8} \frac{\sin(4\varepsilon)\cos(2\varepsilon)\sin(2\psi)}{(1-\cos^2(2\varepsilon)\cos^2(\psi))^{3/2}}, \tag{1}$$

where ε defines the ellipticity of the waves ($-\pi/4 < \varepsilon < \pi/4$), i.e. $|\tan(\varepsilon)|$ equals to the ratio of axes of the ellipse. The specific case $\varepsilon = \pm\pi/4$ means circular polarization and $\varepsilon = 0$ means linear polarization. From equation one can see that the sign of friction coefficient and, consequently the direction of kinetic process, is determined by the ellipticity of the waves ε and by the angle ψ between the semimajor axes of their ellipses (Fig. 2). Thus in the case of exact resonance friction is not vanish if $\varepsilon \neq 0, \pm\pi/4$ and $\psi \neq 0, \pm\pi/2$.

Figure 1: The field configuration formed by the two counterpropagating waves with opposite elliptically polarization ε and $-\varepsilon$.

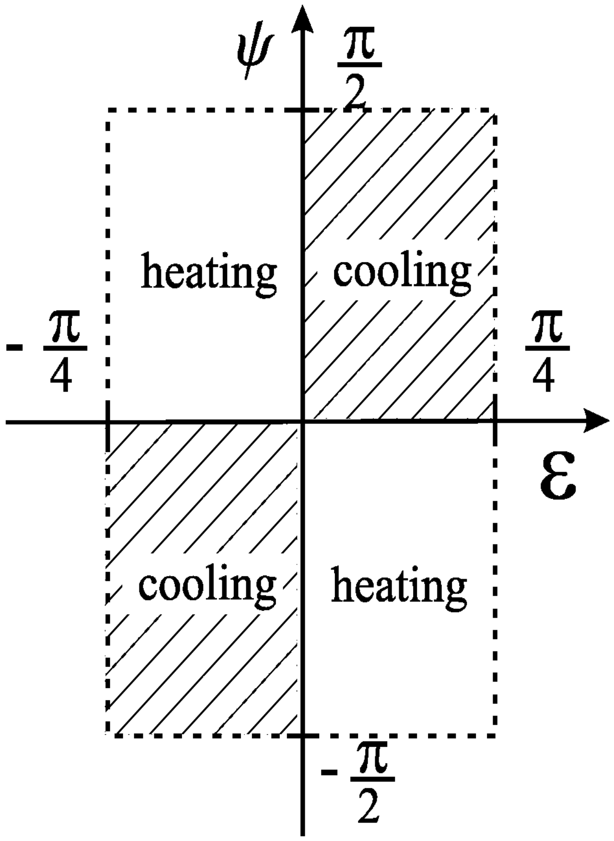

Figure 2: The domains of cooling and heating of atoms with the optical transition $j_g = 1/2 \to j_e = 3/2$ on ε - ψ plane in the case of exact resonance $\delta = 0$.

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[3] G. Nienhuis, P. van der Straten, S-Q.Shang, *Phys. Rev. A* **44**, 462 (1991)