Sisyphus cooling or polarization gradient cooling

Sisyphus cooling or polarization gradient cooling (Dalibard & Cohen-Tannoudji 1985) is a mechanism for cooling of atoms or ions with laser light. It involves a polarization gradient generated by two counter-propagating linearly polarized laser beams in $\text{lin}\perp\text{lin}$ configuration (Fig.1a).

**Figure 1.** a). Polarization of the laser field resulting from the superposition of two laser waves propagating in opposite directions with orthogonal linear polarizations. b). Space variations of the light shifts of the two ground sublevels $g_{\pm 1/2}$.

Most atoms have a Zeeman structure in the ground state. Consider now the simple case where the atomic ground state has an angular momentum $J_g = 1/2$ and two sublevels $g_{+1/2}$ and $g_{-1/2}$. Let us suppose that such an atom is placed in the laser field generated by two counter-propagating linearly polarized laser beams in the $\text{lin}\perp\text{lin}$ configuration (Fig.1a). In this case two Zeeman sublevels, $g_{+1/2}$ and $g_{-1/2}$, undergo different light shifts, depending on the laser polarization. Fig.1b illustrates spatial modulations of the Zeeman splitting between the two sublevels, $g_{+1/2}$ and $g_{-1/2}$, with a period $\lambda/2$. Let us consider an atom moving along z-axis (Fig.1b). Suppose now that the atom is starting from the bottom of a valley of the state $g_{-1/2}$. When the atom climbs a potential hill, it is slowed down because its kinetic energy is turned into potential energy. The laser field excites an atomic transition connecting a ground level $g$, of angular momentum $J_g = 1/2$, with two Zeeman sublevels $g_{+1/2}$ and $g_{-1/2}$, to an excited level $e$, of angular momentum $J_e = 3/2$ (Fig.1b). The rate of this transition is maximal around the tops. This transition decreases the potential energy of the atom by anti-Stokes Raman spontaneous emission, while living its kinetic energy unchanged if the moment of the spontaneously radiated photon has not been taken into account. This process continues till the thermal energy of the atom will be equal to the energy of an atom with a momentum equal to the moment of the laser photon, $k_B T_R = \hbar^2 k^2/(2M)$, (Fig. 2). Here $\hbar$ is the reduced Planck. $k$ is the wave number of the laser photon. $M$ is the mass of the atom. $k_B$ is the Boltzmann’s constant. The temperature, $T_R$, at which this occurs, is known as the recoil limit:
Typical values for the recoil limit of atoms are of the order of 1 μK.

References