Laser cooling of gas atoms by "ac Stark effect"

Wang Yuzhu

(Shanghai Institute of Optics and Fine Mechanics, Academia Sinica)

Laser cooling and trapping of gas atoms is a new subject of great interest in laser spectroscopy. This paper makes a proposal for laser cooling of gas atoms via ac Stark effect. The energy levels can induce atomic shift when the atom is irradiated by light. Experiments show that under the illumination of laser light the amounts of optical frequency shifts are of the order of serveral GHz and the shift of the levels are quasi-transient in nature. We take an atom with three level system as an example to illustrate this process. If an atom is irradiated by an intense laser pulse of frequency ν_{l_2} approximate to the resonance frequency ν_{bc} between the two excited levels of the atom, the laser field will induce the intermediate level shift downward by an amount ΔE_b

$$\Delta E_b = -\frac{E_o^2}{4h}\,\frac{|e\cdot r|^2_{bc}}{\nu_{bc}-\nu_{l_2}}$$

Where $E_o/\sqrt{2}$ is the average intensity of the laser electric field, $|e\cdot r|_{bc}$ is an electric dipole matrix element, h is Planck constant. If at the same time, the atom is irradiated by a less intense cw laser with a frequency $\nu^o_{l_1}$ approximate to the resonance frequency between the ground state and the shifted intermediate level, the atom will transit to the intermediate level after absorbing a photon. And then when the intense laser pulse is removed, the intermediate level will return to its ground state by way of spontaneous emission of a photon. Because the amount of the energy of the photon spontaneously emitted from the atom is larger than that of the photon absorbed, the difference is compensated at some sacrifice of the kinetic energy of the atom during the process of scattering the photons. As a result, velocity will be reduced gradually, and the amount of decrease in velocity of the atom after its scattering one photon can be given by

$$\Delta v = \frac{h\nu^o_{l_1}}{mc} + \frac{E_o^2|e\cdot r|^2_{bc}}{4h(\nu_{bc}-\nu^o_{l_2})m\nu} + \frac{E_o^2|e\cdot r|^2_{bc}}{4h(\nu_{bc}-\nu^o_{l_2})^2}\,\frac{h\nu^o_{l_2}}{mc}$$

where c is light veocity, m is the mass of atom and v is the velocity of atom. In this formula the first term corresponds to the result of Doppler laser cooling proposed by Hansch and Schawlow; the second and third terms represent the results of laser cooling caused by light shift effects. The larger the light shift, the higher the cooling efficiency. It would seem that the method proposed here is a most promising process applicable to the laser cooling and trapping of gas atoms as well as to the acceleration of them.

利用“交流斯塔克效应”实现激光冷却气体原子

王玉珠

（中国科学院上海光学精密机械研究所）

激光冷却和捕陷气体原子是激光光谱学中极为重要的新课题。本文提出利用交流斯塔克效应实现激光冷却气体原子的建议。激光照射原子可引起能级转移，实验证明，光频移可达数千兆赫芝，并且能级移动是准瞬时的。用一个具有三能级系统的原子为例来说明这个建议。用一强脉冲激光照射原子，激光频率 ν_{l_2} 接近两激发态的共振频率 ν_{bc}。由于交流斯塔克效应中间能级向下移动 $\varDelta E_b$；

$$\varDelta E_b=-\frac{E_0^2}{4h}\,\frac{|e\cdot r|^2{}_{bc}}{\nu_{bc}-\nu_{l_2}}$$

式中 $E_0/\sqrt{2}$ 为平均激光电场强度，$|e\cdot r|_{bc}$ 是电耦极矩矩阵元，h 为普朗克常数。同时用一较弱的连续激光器照射原子，激光频率 $\nu^0_{l_1}$ 接近基态与移动后的中间能级的共振频率。原子共振吸收光子后跃迁到中间能级。这时强激光脉冲去除，中间能级恢复至原来位置，原子自发辐射光子回到基态。由于原子自发辐射的光子能量大于它所吸收的光子能量，不足的部分由原子动能中给出。所以原子在散射光子的过程中将不断降低自己的平均动能，速度不断降低。原子每散射一个光子所损失的速度为：

$$\varDelta v=\frac{h\nu^0_{l_1}}{mc}+\frac{E_0^2|e\cdot r|^2{}_{bc}}{4h(\nu_{bc}-\nu^0_{l_2})mv}+\frac{E_0^2|e\cdot r|^2{}_{bc}}{4h(\nu_{bc}-\nu^0_{l_2})^2}\,\frac{h\nu^0_{l_2}}{mc}$$

式中 c 是光速、m 是原子质量、v 是原子速度。上式中第一项即为 Hansch 和 Schawlow 所提出的由于多普勒频移所产生的激光冷却效果，第二和第三项是由于光频移所产生的激光冷却效果，并且随着强激光所产生的“光频移”越大，激光冷却的效率越高。这个方法也可应用于激光捕陷原子和离子。当强激光频率高于共振频率时，这个方法也可用于激光加速气体原子。