



Analytical Analysis Include One by One Anisotropies of an Optical Lattice Potentials

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Abstract: In this paper we focus analytically on optical lattice potentials created with standing light waves. Two laser beams assume to be focus along X-axis and Y-Axis of the working field. The frequency of the laser beam along the X-Axis and Y-Axis assumes to be fixed, in such way that standing waves will be created in XY-plane. This kind of arrangement is usually used in experimental that lead to produced Bose-Einstein condensation BEC in ultra- cold gases. We study the distribution of an optical lattice trapping potential created by the laser beams as a function of anisotropy along Y-Axis. This analysis is mainly subject to know the role which anisotropy play in term of values and profiles of the optical lattice trapping potential OPTP. This unambiguous revision will give us the overall interpretation of the constituency of confinement that the two dimension optical lattice has engaged. The results seem to be in analogous with the experiments facts.

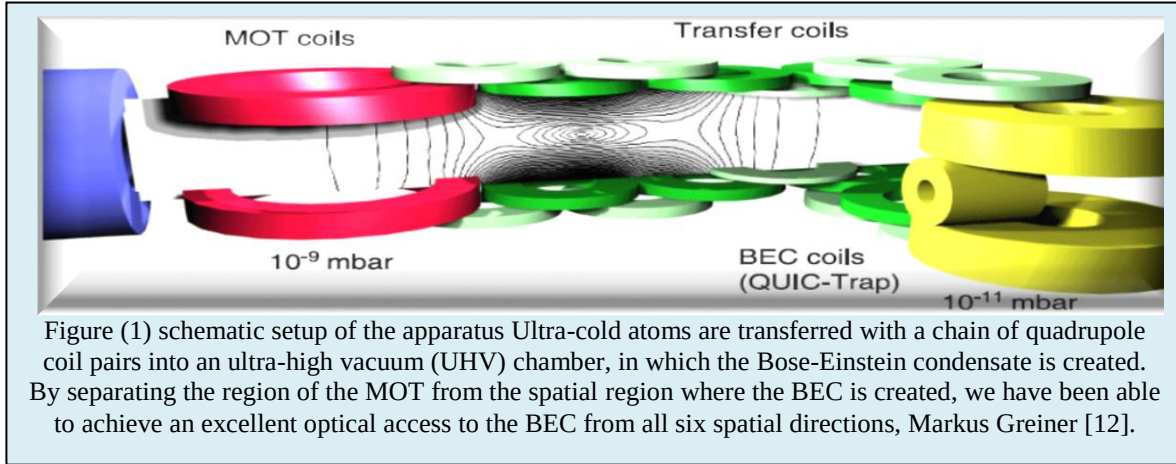
Keywords: Laser cooled atom, BEC atom, Trapping, condensation, Atom Laser

I. Introduction

Over the past 60 years, atomic physicists have developed sophisticated techniques to trap and isolate single neutral atoms and ions. By the early 1980s, physicists had confined single barium and magnesium ions in quadrupole traps. (Simultaneous advances in laser cooling, which slows ions and neutral atoms as they are loaded into a trap, played an essential role in these early trapping experiments.) an optical lattice trap, which is formed by superimposing two counter-propagating laser beams to make a standing wave, can trap atoms a few hundreds of nanometers apart [1-3]. Optical lattices have been broadly utilized as a part of atomic physics science as an approach to cool, trap and control atoms. In the late years ultra-cold atoms in optical lattices have turned into a one of a kind meeting ground for simulating solid state materials [4]. The optical lattice potential emulates the crystal lattice in a solid and the atoms stacked in the lattice emulate the valence electrons. Atoms move in the lattice (actually tunnel quantum mechanically between lattice sites) as valence electrons do in the periodic energy landscape generated by the positively charged ions in a solid crystal. Optical lattices actually are artificial crystals of light, consisting of hundreds of thousands of optical micro-traps, are normally created by interfering optical laser beams. The main differences between artificial crystals of light "optical lattice" and the solid states crystals are summarize in table (1). In recent years Bose-Einstein condensates held in optical lattices has become an active research field, and a review of recent work done with Bose-Einstein condensates in optical lattices can be found in [5]. Optical lattices represent a fast-paced modern and interdisciplinary field of research. An optical lattice is simply a set of standing wave lasers. The electric field of these lasers can interact with atoms - the atoms observe a potential and therefore gather in the potential minima. In the case of a typical one-dimensional setup, the wavelength of the opposing lasers is chosen so that the light shift is negative. This means that the potential minima occur at the intensity maxima of the standing wave. Furthermore, the natural beam width can constrain the system to being one-dimensional. Also neutral atoms can be captured in a magnetic trapping potential due to the interaction of their magnetic moment with an inhomogeneous magnetic field [6]. This method allows an efficient isolation of the atoms from the external environment. In contrast to a magneto optical trap (MOT), a magnetic trap forms a conservative trapping potential. Limitations of the density and temperature due to the light field and spontaneous processes in a MOT can be circumvented. When an atom is placed in an inhomogeneous magnetic field $\mathbf{B}(r)$ the particle is subjected to an external force directed towards the magnetic field minimum or maximum depending on the orientation of the magnetic moment. In a vapor cell magneto optical trap (MOT) atoms are captured from the background gas and cooled to the micro Kelvin regime [7-11]. The basic idea of a MOT is to use dissipative light forces which introduce an effective friction force to slow down and cool an atomic gas. At the same time an inhomogeneous magnetic field is applied which introduces a spatial dependence of the light force leading to a confinement of the atom cloud. The schematic setup for a MOT is shown in figure (1). Six red

detuned laser beams with circular polarization are directed onto the trap center. The magnetic field is created by an anti -Helmholtz coil pair.

artificial crystals of light	solid states crystals
Fully controllable, no defects, no vibrations	Very complex condensed matter environment
Lattice spacing micrometers	Lattice spacing Angstroms
Trapped atom mass ~ 10-100 amu	Electron mass 1/1900 amu
Temperature : T~1 nK	Temperature : T~ 100 K
Table (1) artificial crystals of light vs solid state crystal lattices	



II. Theory

If neutral atoms are placed in an electromagnetic field the atoms develop an induced electric dipole moment μ , where the interaction energy is given by

$$U = -\mu \cdot E,$$

(1)

Where, E is the applied electric field. This dipole moment has two main effects, for near-resonant light the effect is to change the atomic state through the absorption and emission of photons. Using this effect one can coherently manipulate both the internal and external states of the atom. For far off-resonant light, the primary effect is an energy shift to the atomic energy levels through the AC stark shift potential which is given by:

$$U(z, t) = \frac{\hbar\omega_R^2}{\delta} f(t)^2 \sin^2(kz)$$

(2)

Where $k = 2\pi/\lambda$ is the wave vector of the grating light, $f(t)$ is the envelope function for the standing wave and $\omega_R = \mu E_0/\hbar$ is the Rabi frequency, with $\mu = \langle e|\hat{e}|g\rangle$. $\hat{e}$ is the dipole matrix element connecting the ground $|g\rangle$ and excited $|e\rangle$ states of the atom, and δ is the detuning of the beam. Eq. (2) is valid in the limit $\delta^2 \gg \Gamma^2/4$, where Γ is the natural line width of the excited state. The electric field for a standing wave of light is given by:

$$\vec{E}(z, t) = f(t)[E_0 \sin(kz - \omega t)\hat{e} + E_0 \sin(kz + \omega t)\hat{e}]$$

(3)

Since the momentum of the atoms is changed through the stimulated absorption and subsequent emission of photons from the standing wave so, this process can be described as a stimulated Raman process, or one can say as different momentum states. In Bragg and Kapitza-Dirac scattering, near-resonant laser light is used to manipulate the final momentum state of the atoms. For optical lattices if near-resonant light is used the high spontaneous scattering rate leads to short condensate lifetimes. If a condensate is illuminated with a laser beam, the resulting two level atoms potential due to the AC Stark shift can be written as [13]:

$$V(r) = \frac{\hbar\omega_R^2}{\delta} = \frac{3\pi c^2}{2\omega_0^3} \left(\frac{\Gamma}{\omega_0 - \omega} + \frac{\Gamma}{\omega_0 + \omega} \right) I(r) \approx \frac{3\pi c^2}{2\omega_0^3} \frac{\Gamma}{\delta} I(r) \quad (4)$$

Where I is the intensity of the laser beam and the natural line width Γ is given by

$$\Gamma = \frac{\omega_0^3}{3\pi\epsilon_0\hbar c^3} \mu^2 \quad (5)$$

And for multilevel atoms the potential can be generalized to:

$$V(r) = \frac{3\pi c^2}{2\omega_0^3} \frac{\Gamma}{\delta} I(r) \sum_j \frac{c_j}{\delta_j} \quad (6)$$

Where δ_j is the detuning between the ground $|g\rangle$ and the excited state $|e_j\rangle$, and $c_j = \|\mu\|/mu_j$ is the relative coupling strength. Far-detuned laser light can be used to engineer different kinds of potentials with an unprecedented control of the forces exerted on a quantum system. The simplest way to trap atoms using the AC Stark shift potential is by using a focused red-detuned laser beam [14, 15]. The intensity profile of a focused Gaussian laser beam with power P , focused along the z -axis is

$$I(r, z) = \frac{2P}{\pi\omega^2(z)} e^{-2\frac{r^2}{\omega^2(z)}} \quad (7)$$

Where the beam waist along the z -axis is given by $\omega(z) = \omega_0 \sqrt{1 + (z/z_R)^2}$. The minimum beam waist at the focus is ω_0 , and $z_R = \pi\omega_0^2/\lambda_L$ is the Rayleigh length of the focus. If the spatial extent of the condensate is less than the beam waist ($R_{TF} \ll \omega_0, z_R$), then the resulting trapping potential can be approximated as

$$V_{ext}(r, z) \approx V \left[1 - 2 \left(\frac{r}{\omega_0} \right)^2 - \left(\frac{z}{z_R} \right)^2 \right], \quad (8)$$

this potential has cylindrical symmetry with trap frequencies $\omega_r = \sqrt{4V/m\omega_0^2}$ and $\omega_z = \sqrt{4V/mz_R^2}$ in the radial and axial directions. If a second, counter-propagating beam is added where the frequency, polarization, and power of the beam are identical to the initial dipole trap, than a standing wave potential is created with

$$V_{lat}(r, z) = 4V \cos^2(kz) \left[1 - 2 \left(\frac{r}{\omega_0} \right)^2 - \left(\frac{z}{z_R} \right)^2 \right] \quad (9)$$

By ignoring the external trapping potential, the potential due to the lattice can be written as

$$V_{latt}(z) = sE_{rec} \sin^2(kz) = \frac{sE_{rec}}{2} (1 - \cos(2kz)) \quad (10)$$

Where, sE_{rec} gives the lattice depth in terms of the recoil energy. This potential is invariant under translation, i.e $V_{latt}(z + \pi/k) = V_{latt}(z)$. There are two points justify our interest in the experimental study of Bose-Einstein condensates in optical potentials with the aim to investigate fundamental problems often born in the context of solid state physics. The close analogy between the periodic potential seen by an electron moving in a solid crystal and the optical lattice potential seen by a laser cooled atom allows us to apply condensed matter formalism to the atomic physics problem.

Recently more advanced and complicated traps have been applied for studying BECs in laboratories [17-20]. In this paper, we will analysis a typical two dimension optical lattice potential trapping potentials which are widely used in current experiments such as:

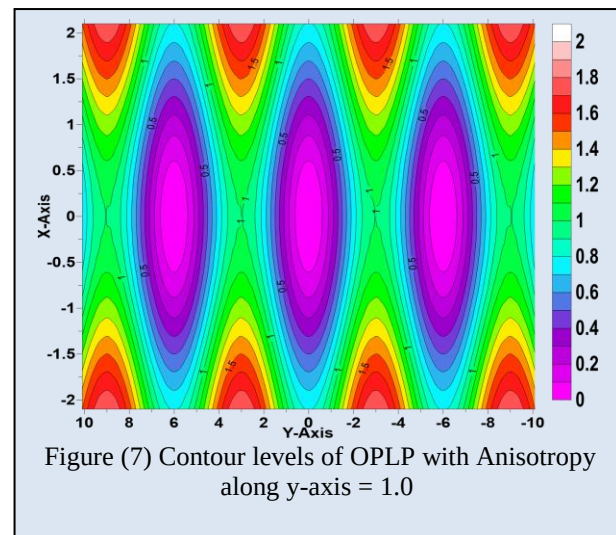
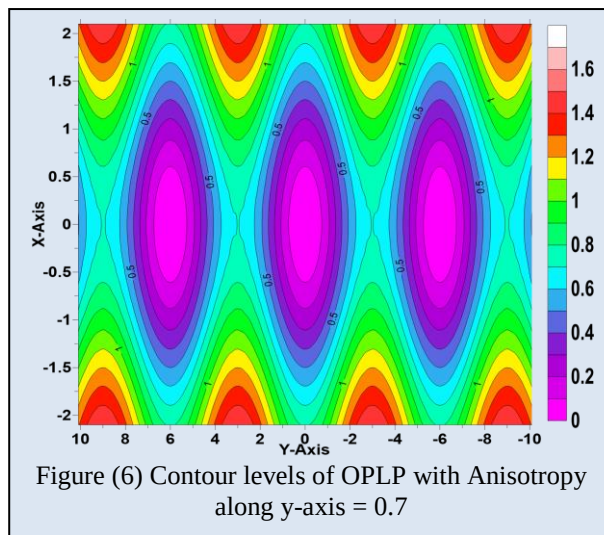
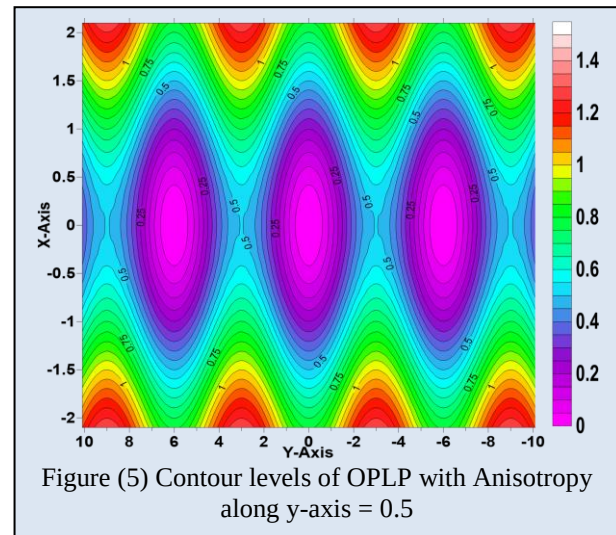
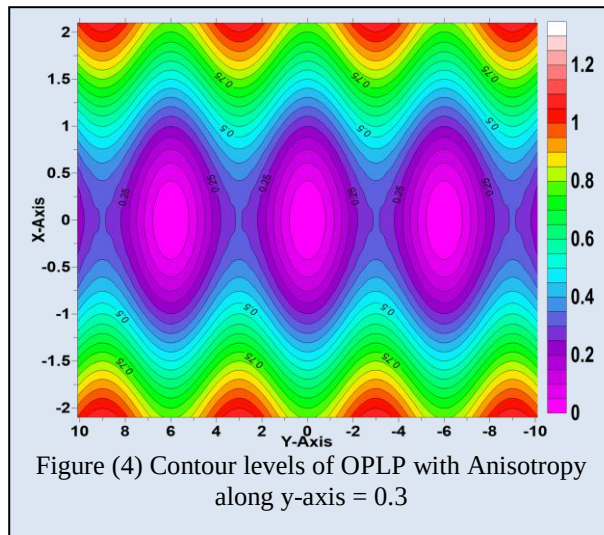
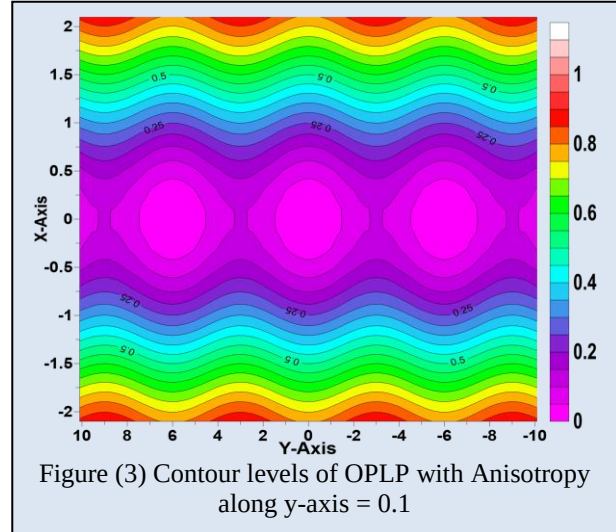
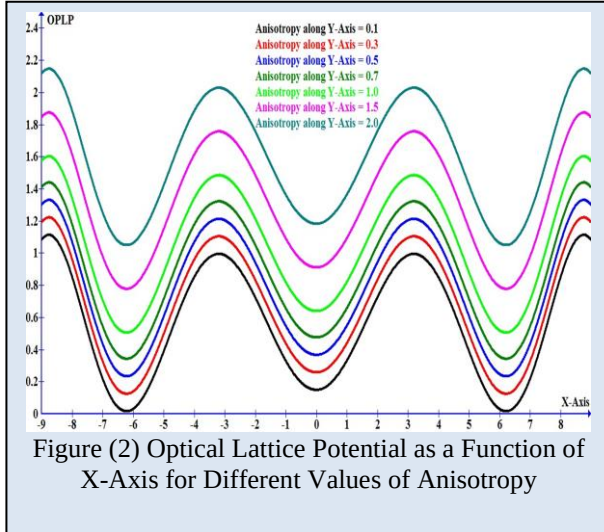
$$V_{opt}(x, y) = sE_{xrec} \sin^2(k_x x) + sE_{yrec} \sin^2(k_y y), \quad (11)$$

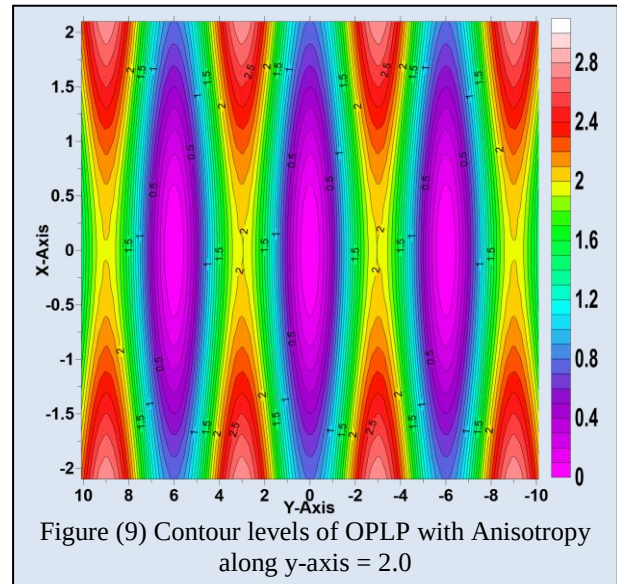
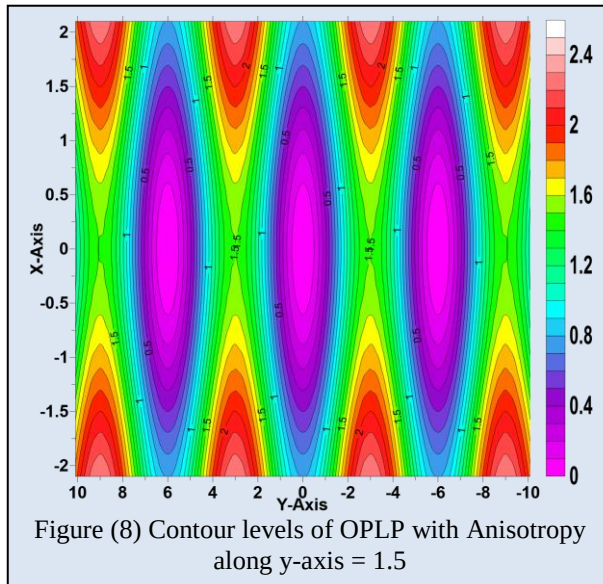
Where $\hat{k}_{x,y} = 2\pi/\lambda$ is the angular frequency of the laser beam, with wavelength λ , that creates the stationary 2D periodic lattice, $E_{x,y} = (\hbar^2 \hat{k}_{x,y}^2)/2m$ is the recoil energy, and s is a dimensionless parameter characterizing the intensity of the laser beam. The optical lattice potential has periodicity $T_{x,y} = \pi/\hat{k}_{x,y} = \lambda/2$. The choices for the scaling parameters t_0 and x_0 , the dimensionless potential $V(x, y)$ with $\gamma_y = t_0\omega_y$ and $\gamma_z = t_0\omega_z$, the energy unit $E_0 = \hbar/t_0 \rightarrow E_0 = \hbar^2/mr_0^2$, and the interaction parameter $\beta = 4\pi a_s N/r_0$ for external optical lattice trapping potentials are reads as follow: $t_0 = 1/\omega_r$, $r_0 = \sqrt{\hbar/m\omega_r}$, $k_r = 2\pi^2 r_0^2 S_\tau/\lambda_\tau^2$, $q_\tau = 2\pi r_0/\lambda_\tau$, $\tau = x, y$.

III. Result and Discussion

A computer programs have written to calculate the distribution of the optical lattice potential generated by the two laser beams along the X-Axis for varies values of anisotropy along the Y-Axis that are (0.1, 0.3, 0.5, 0.7, 1.0, 1.5, and 2.0) the angular frequencies of laser beams assume to be fixed along the X-Axis, and Y-Axis with value equal to $(\pi/6)$ and the anisotropy along the X-Axis also assume to be fixed at value equal to 1.0 as presented in figure (2). One can write several points about this figure that is: The shape of distributions is not change as the value of anisotropy change. The values of OPLP increase as the value of anisotropy increases. The distribution takes almost as a wavy shape but it is neither sine wave nor cosine wave. The distributions along the X-Axis are symmetric. Three minima points can be count along the working field, and the middle one is constructed at higher potentials. The traps of neutral atoms can be take place at these minima points. It is worth to say that the distributions of OPLP generated by the two laser beams along the Y-Axis which is not presented here, is exactly look like that presented in figure (2). Since we assume in this paper that the working field of the optical lattice potentials is the XY-plane, and farther assumption employed in this plane that the optical lattice potential generated by the laser beam along the X-axis is assume to be constant throughout this study, while the OPLP along the Y-Axis assume to be function of the anisotropy. It was found that by using two trapping potential are much patter than one. Figures (3-9) represent contour levels of the distribution of OPLP in XY-plane for different values of anisotropies. One can concludes several points about these figures such as: The maximum forces applied by these potential on neutral atoms are falls at the edges of the working field as seen by red colors of these contour. By changing the values of anisotropy will not change the place of maximum forces applied by trapping potential, but will change its values. Zero forces of the applied OPTP are concentrated around the centre of X-Axis and distribution along Y-Axis. There are dramatic changes in profiles and morals of the OPLP as the anisotropies alteration its value. The zone of the zero-forces appear to be circulated along Y-axis in continues arrangement

from $X = -0.5$ to $X = 0.5$ while the anisotropy has the value equal to 0.1. But as the anisotropy growth the image of the occasion of zero-forces turn out to be more discrete than continues, Really the trapping zone become further contracted and detached. There are other points to be says in next articles about these figures. As a conclusion one can says that the OPLP has great tractability and conceivable for a range of applications for example ideal settings are provided for accurateness measurements because the atoms are restrained in a region of low optical field strength in deficiency of any external field. Moreover, the 2D trap can be straight forward applied as a guide for atoms. We expect the OPLP trap to amplify the atomic phase space density and anxiously to realize Bose Einstein condensation BEC.





VI. References

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