Atom–molecular conversion in regime of self-acquisition

Zingan A.P., Khadzhi P.I.
Dniester State University after T.G. Shevchenko,
3300 Moldova, Tiraspol, the 25th October Str. 128
e-mail: fmfdekan@spsu.ru

***Abstract* — it was studied the dynamic of atom–molecular conversion in condition of bose – einstein condensate with formation of homonuclear molecule in regime of self-acquisition. We received the conditions of appearance of self-acquisition effect in the given system.**

Substantial progress has been achieved in recent years in the experimental and theoretical investigation of the properties of atomic Bose–Einstein condensates. Currently, studies of the dynamics of coupled atomic–molecular condensates under conditions of Feshbach resonance or stimulated photoassociation of two atoms into a molecule are of special interest. It is well – known [1] that the dynamic of wave function BEC can be described by the effective equation of mean-field known in the literature as equation of Gross-Pitaevsky which includes also members of interparticle interaction.

The first experiments in which we can observe BEC of rarefied fallow of alkaline metals [2-4] in ultracold temperatures stimulated further theoretical and experimental investigation of this effect.

In [5, 6] it is studied the process of conversion of two similar atoms into homonuclear molecule in presence of laser emission. It was shown that it takes place as periodical as aperiodical regime of conversion, and peculiarities of temporary evolution of the system is determined by initial density of the particles. Earlier was studied the dynamic of tunneling of bose-condensing atoms between two traps. It occurred that taking into account the inter atomic interaction in this system the effect self-acquisition appeared. It consists in extreme change of mid population in each of the holes in condition of initial atom density change. The question about existence of this effect in conditions of atom – molecular conversion remains open.

The aim of this work is to explore the effect of self-acquisition of system in the process of stimulated Raman atom – molecule conversion with the formation homonuclear molecule as single one-step process. We will study three – level energetic Λ – scheme (fig. 1). One of the levels corresponds to the basic condition of two free atoms with energy $2\hbar\omega_0$, and the other – to basic condition of double atomic with energy $\hbar\Omega_0$. The third level corresponds to activated condition of molecule E_u. The appearance of molecule from two atoms leads to absorption of light quantum with the energy $\hbar\omega_1$ and radiation of light quantum $\hbar\omega_2$. We use Hamiltonian of interaction H_{int}, describing the effect of induced Raman atomic – molecular conversion as single process under the influence of two short pulses of resonance laser radiation [7] taking into account the processes of elastic interparticle interaction

$$H_{\text{int}} = \hbar g\left(\hat{a}\hat{a}\hat{b}^{+}\hat{c}_1\hat{c}_2 + \hat{a}^{+}\hat{a}^{+}\hat{b}\hat{c}_1^{+}\hat{c}_2\right) + \frac{1}{2}\hbar\nu_1\hat{a}^{+}\hat{a}^{+}\hat{a}\hat{a} + \frac{1}{2}\hbar\nu_2\hat{b}^{+}\hat{b}^{+}\hat{b}\hat{b} + \hbar\nu\hat{a}^{+}\hat{a}\hat{b}^{+}\hat{b}, \quad (1)$$

where e $\hat{a}$ and $\hat{b}$ – boson operators of destruction of atom and molecular conditions properly, $\hat{c}_1$ and $\hat{c}_2$ – operators of destruction of photons with frequency ω_1 and ω_2, g – constant of atom – molecule conversion, and ν_1, ν_2, ν – constants of interatomic, intermolecular and atom – molecular interaction properly.

Introducing the particle density $n=|a|^2$, $N=|b|^2$, $f_{1,2}=|c_{1,2}|^2$ and two components of "polarization" $Q=i(aab^*c_1c_2^*-a^*a^*bc_1^*c_2)$ and $R=aab^*c_1c_2^*+a^*a^*bc_1^*c_2$, we have the system of equation

$$\begin{aligned}&\dot{n}=2gQ,\ \dot{N}=-gQ,\ \dot{f}_1=gQ,\ \dot{f}_2=-gQ,\\&\dot{Q}=(\Delta+(2\nu_1-\nu)n+(2\nu-\nu_2)N)R+\\&2gn((4N-n)f_1f_2+Nn(f_2-f_1)),\\&\dot{R}=-(\Delta+(2\nu_1-\nu)n+(2\nu-\nu_2)N)Q,\end{aligned}\qquad(2)$$

where $\Delta=2\omega-\Omega+\omega_1-\omega_2$ – resonance detuning. Solving the system of the equation (2), we have four independent integrals of movement for particle densities

$$n+2N=n_0+2N_0,\ Q^2+R^2=4n^2Nf_1f_2,$$
$$f_1+N=f_{10}+N_0,\ f_2-N=f_{20}-N_0,\qquad(3)$$

where N_0, n_0, f_{10} и f_{20} – the initial density of the particles. Then the main equation, describing the time evolution of molecule densities *N*, it is convenient to present as equation of oscillation of nonlinear oscillator

$$(dN/dt)^2+W(N)=0,\qquad(4)$$

where

$$\begin{aligned}&W(N)=V(N)+U(N),\\&V(N)=16N(1/2-N)^2(N_0-N+f_{10})\times\\&(N_0-N-f_{20}),\\&U(N)=(N-N_0)^2((\Lambda_2/2-\Lambda_1)(N+N_0)+\\&+\Lambda_1+\delta)^2.\end{aligned}\qquad(5)$$

Here $\delta=\Delta/g$, $\Lambda_1=(2\nu_1-\nu)/g$, $\Lambda_2=(2\nu-\nu_2)/2g$ – normalized resonance detuning and coefficients interparticle interaction properly.

There is a special regime of interparticcle interaction, in which we observe the effect of self-acquisition when constants of interatomic, intermolecular and atomic – molecular interaction which does not equal zero (fig. 2).

We study further the dynamic of atom – molecular conversion subject to process of into particle interaction when resonance detuning equals zero. In this case may happen the effect of self-acquisition in the system. When constants of interatomic, intermolecular and atomic – molecular interaction does not equal zero can be observed self-acquisition (fig. 3). When constants of interaction equals zero this effect cannot be observed. It is natural that form "potential" energy includes parameters which determines the presence of self-acquisition.

This normalized molecules' initial concentration which equals zero, the evolution of the system is periodical. If $\frac{N_0}{f_{20}}$ is low, the normalized density of molecules changes periodically in limits from zero to $\frac{n_0}{2}$. Further with the increasing of $\frac{N_0}{f_{20}}$ we can observe the effect of extreme rise of amplitude of oscillation what correspond to demonstration of self-acquisition effect in the system. When with the rising $\frac{N_0}{f_{20}}$ the evolution of the system becomes periodical again but with larger amplitude which increases with the rise of $\frac{N_0}{f_{20}}$.

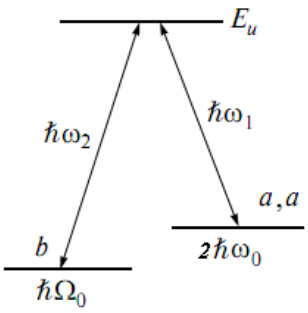

Fig.1 Enegetic scheme and quantum transitions in three-level Λ – scheme

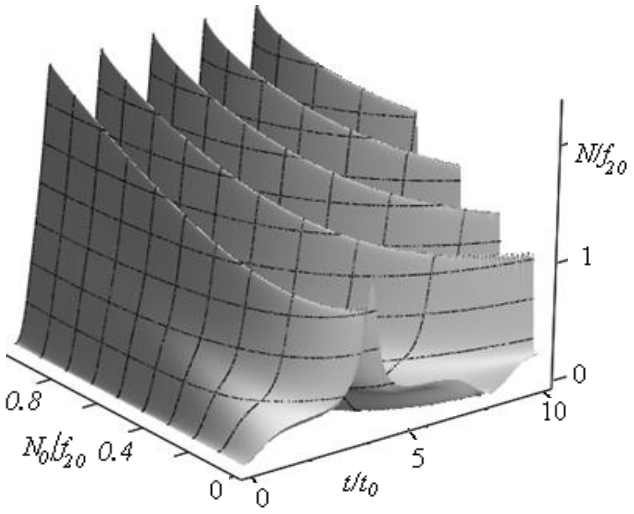

Fig.2 Time evolution of nominolised density of molecules N/N_0 in dependence on value of parameter N_0/f_{20} with $\frac{n_0}{f_{20}} = 0.4, \frac{f_{10}}{f_{20}} = 1, \nu = 1.7, \nu_1 = 1.1, \nu_2 = 1.3$.

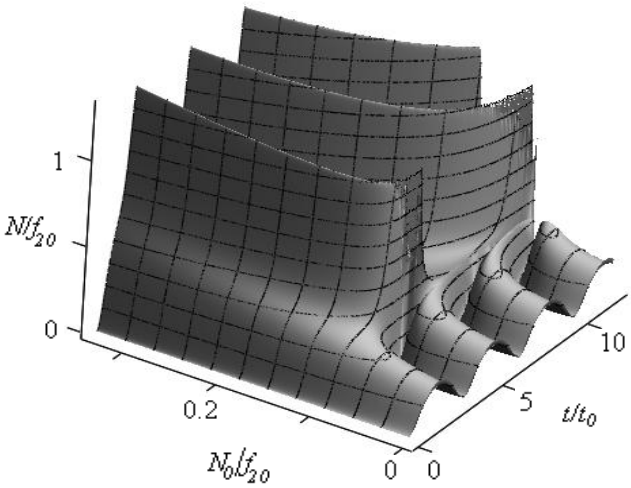

Fig.3 Time evolution of nominolised density of molecules N/N_0 in dependence on value of parameter N_0/f_{20} with $\frac{n_0}{f_{20}} = 0.4, \frac{f_{10}}{f_{20}} = 1, \nu = 0.8, \nu_1 = 1.1, \nu_2 = 1.3$

List of literature

1. Питаевский Л.П, УФН.**168.** p.64. 1998; УФН **176**, p.345. 2006.
2. Anderson H.M., Ensher J.R., Matthews M.R., Wieman C.E., Cornell E.A. Science **269**, p 198, 1995.
3. Корнелл Э.А., Виман К.Э. УФН **173,** p.1320, 2003.
4. Кеттерле В. УФН, **173,** p.1339, 2003.
5. Хаджи П.И, Ткаченко Д.В. Письма в ЖЭТФ **83**, p.120 2006.; ЖЭТФ **131.** p.425, 2007.
6. Khadzhi P.I., Tkachenko D.V. J. of Nanoelectronics and Optoelectronics **4,** p.101, 2009.

[1] Хаджи П.И., Ткаченко Д.В. Письма в ЖТФ **34**, p.87, 2008.