ABOUT THREE MECHANISMS OF TRANSFORMATION OF LOW-FREQUENCY ENERGY OF OSCILLATIONS TO THE ENERGY OF HIGH-FREQUENCY OSCILLATIONS

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The brief review of the most important results which have been gotten at study of the mechanism of the high numbers harmonics excitation by nonrelativistic oscillators, the mechanism of quantum whirligig effect and the mechanism of secondary resonances is given. These mechanisms give opportunity for transforming energy of low frequency oscillations to energy of high frequency oscillations.
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1. EXCITATION OF HIGH NUMBERS HARMONICS BY NONRELATIVISTIC OSCILLATORS

Earlier it was shown [1-5], that nonrelativistic oscillators, which are moving in weak periodic nonuniform medium or potential, can effectively radiate high numbers of harmonics. At that the spectrum of nonrelativistic oscillators radiation is similar to a spectrum of relativistic ones. It means, that the maximum of spectrum is in a vicinity of high numbers harmonics. The mechanism of such radiation was found out. Has appeared, that for radiation is responsible a slow component (virtual wave) complex structure of a field, which exists in periodically non-uniform medium. The considered mechanism of radiation could be described within the framework of classical electrodynamics.

The similar radiation takes place and at movement of the charged particles in periodic potential [6]. However in this case adequate theory should be the quantum theory. Such theory was constructed. The main result of this theory is the proof of high efficiency of harmonic radiation by oscillators in such periodic potential: $U(\vec{r}) = U_0 + g\cdot\cos(\vec{\kappa}\cdot\vec{r})$. And for power of radiation it is possible to get the following expression:

$$\frac{dW}{dt} = \left(g_{eff}\right)^2 \cdot \frac{(e\cdot\omega\cdot V)^2\cdot n}{4c^3}\int_0^{\pi}\sin^3\theta\cdot d\theta ,$$

where $g_{eff} = eg/E_0 < 1$, E_0- energy of particles before radiation.

It is of interest to compare efficiency of the considered radiation to efficiency of known radiation, for example with Cherenkov radiation. The relation of this radiation power to power of Cherenkov radiation can be estimated by the following formula:

$$\left(dW/dt\right)_{Harm} / \left(dW/dt\right)_{Cher} \approx \left(g_{eff}\right)^2\cdot\beta . \qquad (1)$$

At receiving (1) the power Cherenkov radiation we had estimated by the formula: $\left(dW/dt\right)_{Cher} \sim (e^2\cdot\omega^2\cdot V)/c^2$, it means that we took Cherenkov radiation in frequency interval $\Delta\omega\sim\omega$ and $\left(1-c/V\sqrt{\varepsilon\mu}\right)\sim 1$. So, the power harmonic radiation into narrow spectral line $\Delta\omega << \omega \approx \left(\kappa\cdot c\right)/\beta$) close to the power Cherenkov radiation in wide spectral range ($\Delta\omega\sim\omega$). Schematically this relation is represented in Fig. 1

Let's formulate the most essential features of the possible schemes of the X-ray laser, if as undulator to take periodic potential of a crystal grate of an ideal crystal: the period such undulator is the least of what can be realized in a nature ($10^{-13}\,cm.$);density of emitters also is greatest of what can be realized (electron density of a solid state). Such density of emitters allows to realize induce process of radiation in a X-ray range.

Let's explain a small period of undulator. The periodic potential is created by nucleuses of a crystal lattice. Distance between nucleuses is 10^{-8} cm. The sizes of nucleuses about 10^{-13} cm. The number of components in Fourier decomposition of such potential with approximately identical amplitudes will be 10^5. The minimal period of these components is 10^{-13} ($d_{\min} < 10^{-13}\,cm$). Accordingly, such source potentially can excite radiation with wavelength $\lambda_{\min}\sim\left(d_{\min}/\beta\right)\sim d_{\min}$.

Let's briefly describe the possible schema of realization of such X-ray laser. On a crystalline target falls the laser radiation with such parameters: $\lambda_L = 200\,nm$, $E \ge 10^{10}\,V/cm \;\Rightarrow 10^{19}\,W/cm^2$. During a half-cycle of laser radiation all electrons of a target in such a field become free. During the time about 100 periods the instability develops. As a result of this instability the coherent X-ray radiation is excited. During this time structure of undulator (the structure of a crystal lattice) practically does not changed.

2. SECONDARY RESONANCES

To explain the mechanism of the second opportunity of transformation of low-frequency energy into energy high-frequency oscillations easier of all on an example of a children's toy - rotating button on thread (Fig. 2). In this toy the energy of low-frequency movements of our hands is transformed to energy of fast (high-frequency) rotations of a button. The second simple example represents two weakly - connected linear pendulums. It is known, that the presence of the connection between these pendulums results that the energy of oscillation of one pendulum a bit later completely passes in energy of oscillation of the second pendulum. The process of an energy exchange between pendulums is periodic, which frequency is defined (determined) by size of connection.

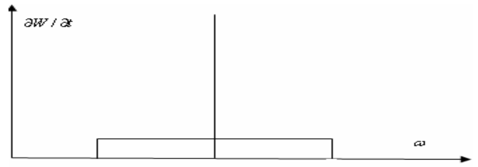

Fig. 1. The relation of our power radiation to power of Cherenkov radiation

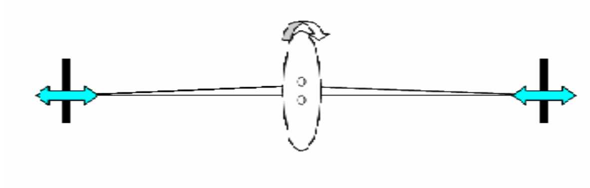

Fig. 2. Children toy. Illustration of secondary resonances

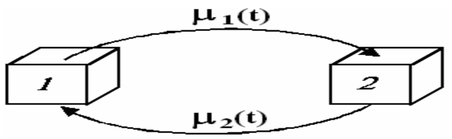

Fig. 3. Two unmutually conjugated resonators

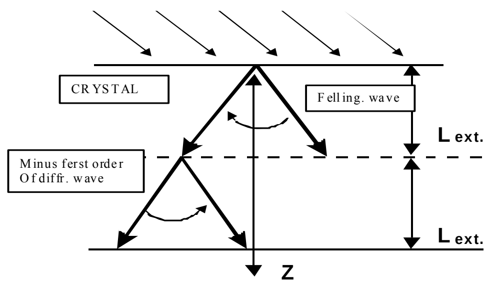

Fig. 4. Interaction of two x-ray waves in crystal

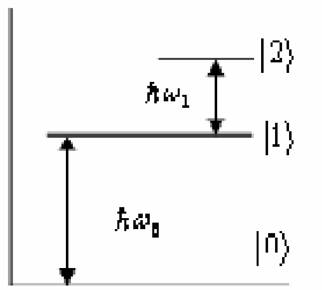

Fig. 5. The scheme of the energetic levels.
ω_1 -the frequency of the stabilized perturbation

The less connection, the less this frequency. Thus, two connected identical pendulums at presence of connection get the low frequency in their dynamics. The presence of this low frequency allows to organize resonant connection of high-frequency pendulums with a low-frequency source of energy. We have considered various variants of such systems [7-10]. Most interesting are two connected resonators (Fig. 3). The low-frequency generator is included in the connection channel. It was shown, that if connection between resonators is not mutual, the energy of the low-frequency external generator can be transformed to energy of high-frequency oscillations of the resonators. Let's note, that the necessity in unmutual connection arises only in systems with two degree of freedom. In systems with the large number of degrees of freedom this requirement is not obligatory. For example, for three identical, one after another connected linear oscillators the presence of unmutuallity is not required. It is explained by that that the central oscillator is connected with two oscillators but others two are connected only with it (only with one). By the second interesting example is an opportunity of X-ray amplification at its distribution in crystals. At that the role of pendulums are play two X-ray waves (falling wave and wave a minus of the first order of diffraction), the connection between which is carried out through a crystal (Fig. 4).

3. THE MECHANISM OF SUPPRESSION OF QUANTUM TRANSITIONS (QUANTUM WHIRLIGIG)

Let's consider quantum system, which is described by Hamiltonian:

$$\hat{H} = \hat{H}_0 + \hat{H}_1(t) \ . \qquad (2)$$

Second summand in the right part describes perturbation. The wave function of system (2) satisfies Schrödinger equation which solution we shall search as a row of own functions of the not perturbed system:

$$\psi(t) = \sum_n A_n(t) \cdot \varphi_n \cdot \exp(i\omega_n t) \, , \qquad (3)$$

where $\omega_n = E_n / \hbar$; $\quad i\hbar \cdot \partial\varphi_n / \partial t = \hat{H}_0 \varphi_n = E_n \cdot \varphi_n$.

In simplest case it's enough to study three-level quantum system with two periodic perturbations: $\hat{H}_1(t) = \hat{U}_0 \exp(i\omega_0 t) + \hat{U}_1 \exp(i\omega_1 t)$ (Fig.5). In this case the system equations for determination of the amplitudes A_i takes the form:

$$i \cdot \hbar \cdot \dot{A}_0 = V_{01} A_1 \, ; i \cdot \hbar \cdot \dot{A}_1 = V_{10} A_0 + V_{12} A_2 \, ; \; i \cdot \hbar \cdot \dot{A}_2 = V_{21} A_1 \quad (4)$$

Besides we shall consider the case when the matrix elements of direct and return transitions are equal ($V_{12} = V_{21}, V_{10} = V_{01}$). Let's consider also, that the matrix elements of transitions between the first and second levels are much more, than matrix elements of transitions between zero and first levels ($V_{12} / V_{10} \equiv \mu >> 1$). Let at the initial moment of time ($t = 0$) the considered quantum system is on first, excited level. Then, as it is easy to see, the solution of system (4) will be functions:

$$A_0 = \frac{1}{i \cdot \mu} \sin(\mu \cdot t) \, ; A_1 = \cos(\mu \cdot t) \, ; A_2 = -i \sin(\mu \cdot t). \quad (5)$$

From the solution (5) follows, that the large parameter μ, the less will be probability that the system from the excited state will pass in nonexcited, stationary state [11, 12]. Similarly it is possible to s how, that occur stabilize and initially not exited states, i.e. the zero level is stabilized too. It is necessary to say some words about parameter μ. Physically this parameter defines the ratio of number of quanta of low-frequency perturbation which is responsible for transitions between the first and second levels to number of quanta of high-frequency perturbation, which determines transitions between the first and zero levels.

The mechanism of quantum whirligig allows to create the dense ensemble of high excited quantum systems, i.e. allows to increase essentially the lifetime of the excited, inverted states.

CONCLUSION

Thus, the considered three mechanisms allow to use the low-frequency perturbations for excitation of high-frequency radiation.

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О ТРЕХ МЕХАНИЗМАХ ПРЕОБРАЗОВАНИЯ ЭНЕРГИИ НИЗКОЧАСТОТНЫХ КОЛЕБАНИЙ В ЭНЕРГИЮ ВЫСОКОЧАСТОТНЫХ КОЛЕБАНИЙ

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Кратко описаны три физических механизма, позволяющие использовать низкочастотные колебания для возбуждения высокочастотных волн. Этими тремя механизмами являются: механизм возбуждения гармоник высоких номеров нерелятивистскими осцилляторами, механизм квантовой юлы и механизм вторичных резонансов.

ПРО ТРИ МЕХАНІЗМИ ПЕРЕТВОРЕННЯ ЕНЕРГІЇ НИЗЬКОЧАСТОТНИХ КОЛИВАНЬ В ЕНЕРГІЮ ВИСОКОЧАСТОТНИХ КОЛИВАНЬ

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Коротко описано три фізичних механізми, що дозволяють використати низькочастотні коливання для збудження високочастотних хвиль. Цими трьома механізмами є: механізм збудження гармонік високих номерів нерелятивістськими осцилляторами, механізм квантової дзиґи й механізм вторинних резонансів.