

Lecture 14. Nonequilibrium radiation. Spontaneous and stimulated emissions. Characteristics of certain types of lasers (ruby, helium-neon laser)

spontaneous and stimulated (induced) emissions – спонтанное и вынужденное излучения

optical pumping – оптическая накачка

pumping by electron impact –накачка электронным ударом

Inverse population of energy levels - инверсная заселенность энергетических уровней

Goal. To describe nonequilibrium radiation, spontaneous and stimulated emissions, characteristics of certain types of lasers (ruby, helium-neon laser)

If the system is in thermodynamic equilibrium the radiation of this system is equilibrium. On the basis of this radiation one can do a comprehensive analysis of the system properties. If the system is not in equilibrium, then, correspondingly, the radiation is nonequilibrium. There are differences between the equilibrium and nonequilibrium emission spectra of the same working system in the intensity of spectral lines, and in the presence of spectral lines of forbidden transitions. As it was already mentioned, any isolated system sooner or later goes into a state of equilibrium, therefore, in order to have the steady nonequilibrium radiation the external influence is needed. Radiation from outside can be used for providing such influence. Such radiation under certain conditions can cause forced (induced) transitions. For the first time the idea of forced transitions was said by Einstein in 1916.

Spontaneous and stimulated emissions

Spontaneous emission rise from spontaneous transition. Atom is in an excited state on average $\tau \approx 10^{-7} - 10^{-8}$ sec, then emits a photon and goes into a lower state. The spontaneous emission forms the characteristic spectrum of element.

Characteristics of spontaneous emission:

1. There are different frequencies (not monochromatic)
2. Radiation in any direction
3. Phases of the emitted photons are different (no coherence)

Stimulated emission occurs when an excited atom (molecule) collides with a photon with energy equal to the difference between the excited level and some underlying level. In this case, the atom immediately reacts and emits a photon with a frequency and phase, exactly coinciding with the frequency and phase of the incident photon, and in the same direction with it. In this case, it does not matter whether the transition was disabled by the selection rules. The emitted photon is totally the same as incident photon.

Characteristics of stimulated emission:

1. Radiation is monochromatic
2. Radiation is in one direction
3. Coherency
4. The possibility of strengthening the external radiation source

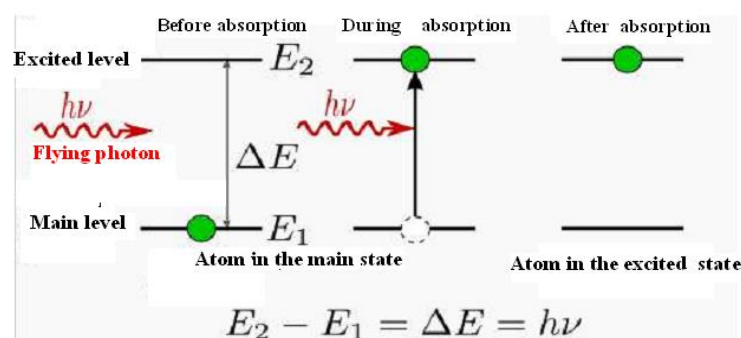


Fig. 14.1 - Stimulated absorption

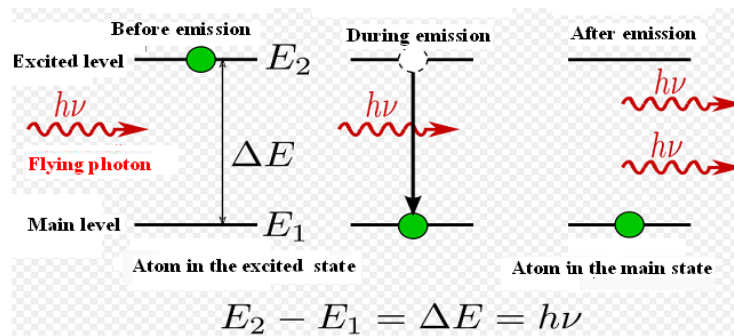


Fig. 14.2 - Stimulated emission

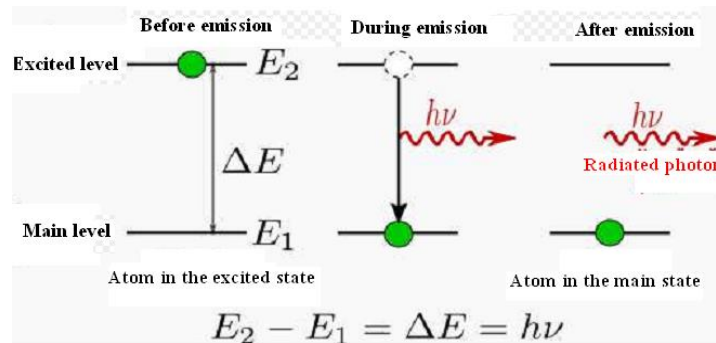


Fig. 14.3 - Spontaneous emission

Einstein proposed to characterize the process of absorption or emission by mean of the coefficients which are the probabilities of determining how many transitions occur on average per unit of time with each of the atoms. Quantum mechanics offers the possibility based on the structure of the electron shell to calculate these coefficients, called Einstein coefficients.

Inverse population of energy levels

Quantum generators (lasers and masers) are designed for amplification and generation of electromagnetic radiation on the basis of induced transitions in quantum systems. The principal feature of lasers is the coherence of the radiation. Through many years of research in the field of quantum electronics in the USSR (Prokhorov, Basov) and USA (Townes, Schawlow) in the early 60's first quantum generators of IR (masers) and optical (laser) ranges were created. As already noted, in a nonequilibrium environment under the influence of external radiation a strengthening of the radiation may take place, at

$$h\nu = E_n - E_m \quad (14.1)$$

where ν is the frequency of incident radiation, E_n and E_m are upper and lower energy levels of bound states under following condition: there is inversion in the distribution of atoms number on different levels. The difference from the Boltzmann distribution is that the upper working level is more populated than the lower. In this case, the bulk of the incident radiation will cause stimulated emission from the upper level, and will not be absorbed by the bottom. Methods of creating an inversion in the system: optical pumping and pumping by electron impact. Consider the solid-state lasers with optical pumping. It should be noted that optical pumping is not possible for a system with two operating levels.

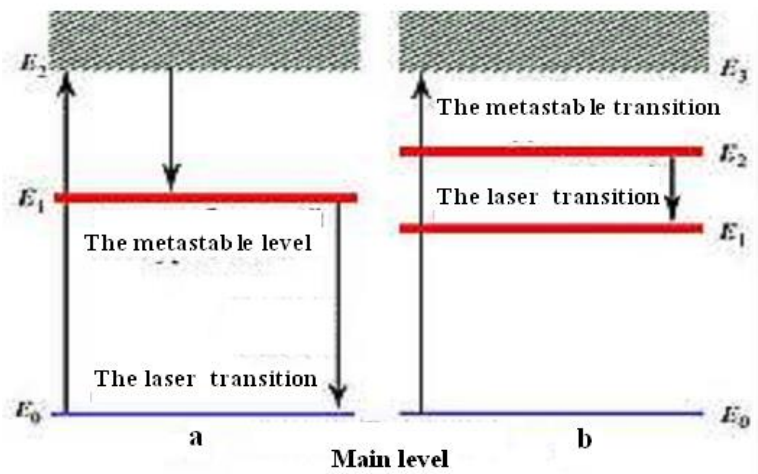


Figure 14.3 - a) 3-levels optical pumping (ruby laser), b) 4-level optical pumping (neodymium laser)

Photons of the external radiation with a frequency that satisfies $h\nu = E_2 - E_0$ falls on an equilibrium atomic system. Since the system at the beginning is in equilibrium this radiation is mostly absorbed by the atoms of the ground state. After it these atoms lifted to state E_2 . Of course, atoms on this level always undergo spontaneous transitions to lower levels. Thus, accumulation of electrons on the level E_2 does not happen. If between levels E_2 and E_0 there is the metastable level E_1 , then E_1 may become more populated than E_0 , in other words, the inverse population can be created. If at this moment one submits the external radiation of frequency $h\nu = E_1 - E_0$, it is possible to obtain the output amplification of this radiation, and it will be coherent, monochromatic and expands in one direction. The ruby laser works according to this principle of **3-levels optical pumping**.

The principle of **4-levels optical pumping** is similar to the 3-levels pumping, the difference is that between the upper and lower levels there are two levels, metastable E_2 and usual E_1 . After accumulation of electrons on E_2 the external radiation with frequency $h\nu = E_2 - E_1$ is given. The induced transitions caused by this radiation in 4-level working system would have a greater effect of the gain.

In gas lasers pumping is realized by electron impacts of 1 order (pure gas Ar, Ne, Kr, Xe) or 2-order (a mixture of gases, for instant He Ne).

Literatures

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