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Quantum electronics

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One may assume as generally accepted that quantum electronics started to exist at the end of 1954 - beginning of 1955[1,2]. Just by that time theoretical grounds had been created, and the first device, - a molecular oscillator - had been designed, and constructed. A basis for quantum electronics as a whole is the phenomenon of an induced radiation, predicted by A. Einstein in 1917. However, quantum electronics was developed considerably later. And it is quite natural to ask the questions: why did it happen so? What reasons put obstacles for the creation of quantum devices considerably earlier, for instance, in the period of 1930-1940?

In order to try to answer these questions I should like to say some words about the bases on which quantum electronics is founded.

As I have already noted, the phenomenon of an induced radiation was predicted by Einstein. It is well-known that an atom being in an excited state may give off its energy in the form of emission of radiation (quantum) in two ways. The first way is a spontaneous emission of radiation, *i.e.* when an atom emits energy without any external causation. All usual light sources (filament lamps, gas-discharge tubes, etc.) produce light by way of such spontaneous radiation. It means that scientist engaged in the field of optical spectroscopy were well acquainted with that type of emission many years ago.

The second way for an atom to give off its energy is through stimulated emission of radiation. That phenomenon was noted by Einstein to be necessary in order to describe thermodynamic equilibrium between an electromagnetic field and atoms. The phenomenon of stimulated emission occurs when an excited atom emits due to interaction with an external field (quantum). Then two quanta are involved: one is the external one, the other is emitted by the atom itself. Those two quanta are indistinguishable, *i.e.* their frequency and directivity coincide. This very significant characteristic of an induced radiation (which was, apparently, first pointed at by Dirac in **1927)** made it possible to build quantum electronic devices.

In order to observe a stimulated emission, it is necessary, firstly, to have excited atoms and, secondly, that the probability of an induced radiation must

$$a = \frac{1}{v} hv\; n_1 B_{12} \tag{3}$$

Therefore, for the optical range the absorption coefficient depends only on the population of the lower level. For as in the radio range, as a rule, $hv << kT$. In that case

$$n_2 = n_1 e^{-\frac{hv}{kT}} \approx n_1\left(1 - \frac{hv}{kT}\right)$$

Then the value of a will be

$$a = \frac{1}{v} hv\; n_1 B_{12} \frac{hv}{kT} \tag{4}$$

As is seen from Eqn. 4, due to stimulated emission, the value of the absorption coefficient becomes reduced by a factor kT/hv compared to what it would be without the presence of induced emission. Therefore, all scientists engaged in radiospectroscopy have to take into account the effect of induced radiation. Moreover, for increasing an absorption coefficient one has to lower the temperature in order to decrease the population of the upper level and to weaken, in this way, the influence of stimulated radiation. It follows from Eqn. 2 that for systems that are not in thermal equilibrium, but have $n_2 > n_1$, the net absorption coefficient becomes negative, *i.e.* such a system will amplify radiation. In principle, such systems were known to physicists long time ago for the radio range. If we pass molecular or atomic beams through inhomogeneous magnetic or electric fields, we can separate out molecules in definite state. In particular, one may obtain molecular beams containing molecules in the upper state only. Actually physicists engaged in the field of a micro-wave radiospectroscopy started to think about application of molecular beams for increasing the resolving power of radio spectroscopes. In order to gain a maximum absorption in such beams, one must have molecules either in the lower state only or in the upper states only, *i.e.* one must separate them using inhomogeneous electric or magnetic fields. If molecules are in the upper state, they will amplify a radiation.

As is well-known from radio engineering, any system able to amplify can be made to oscillate. For this purpose a feedback coupling is necessary. A theory for ordinary tube oscillators is well developed in the radio range. For description of those oscillators, the idea of a negative resistance or conductance is introduced, *i.* e. an element in which so-called negative losses take place. In