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THE 1964 NOBEL PRIZE IN PHYSICS

N. V. KARLOV and O. N. KROKHIN

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THE Swedish Academy of Sciences awarded on 29 October, 1964 the 1964 Nobel Prize in Physics to the corresponding members of the USSR Academy of Sciences **Nikolaĭ Gennadievich Basov** and **Aleksander Mikhaĭlovich Prokhorov** for fundamental investigations in the field of radio physics which led to the construction of quantum generators and amplifiers of electromagnetic radiation—masers and lasers. The prize was awarded to them together with the eminent American scientist, the vice-president of the Massachusetts Institute of Technology Professor **Charles Townes**.

This is the second Nobel Prize awarded for work at the P. N. Lebedev Physics Institute of the USSR Academy of Sciences. Five Nobel Prize laureates are now working in this institute: the names of N. G. Basov and A. M. Prokhorov have now been added to those of I. E. Tamm, I. M. Frank, and P. A. Cerenkov.

Quantum radio physics was born scarcely more than ten years ago, and occupies at present a firm place in the framework of physics and radio technology. A series of problems which contemporary radio technology is able to solve successfully is very closely connected with the methods and achievements of quantum radio physics.

Quantum radio physics appeared as a natural continuation of work in radio spectroscopy which was developed at the end of the Forties and the beginning of the Fifties. At that particular time it became possible in connection with the development of generation and receiving techniques of high-frequency electromagnetic radiation to apply radio-physics methods to the investigation of the long-wave part of the absorption line spectrum of molecules due mainly to their rotational transitions. In the USSR work on radio spectroscopy was started by A. M. Prokhorov in 1949. The results of work on molecular spectroscopy in the radio region yielded valuable data on the structure of the molecules and the character of their bonds.

In their work in the field of radio spectroscopy Basov and Prokhorov strove to extend the capabilities of this method, to increase the sensitivity and resolution of the radio spectrometers, and to make accessible to observation weak transitions and the fine structure of the molecular spectra. The idea was thus conceived of using in place of a homogeneous gas molecular beams moving perpendicular to the direction of propagation of a wave; on account of the Doppler effect this led to a substantial decrease in the line width. Another more fundamental idea was to use instead of the absorption the stimulated emission of the molecules which are somehow excited (or "sorted") to a given energy level. In this case, instead of resonance attenuation there occurs resonance amplification of the electromagnetic wave. If such a molecular beam is directed into a cavity, i.e., a system in which there exist weakly damped standing electromagnetic waves with a frequency coinciding with the frequency radiated by the molecules, then for very small attenuation the intensity of the stimulated emission will exceed the attenuation and coherent electromagnetic oscillations will appear in the cavity spontaneously, without oscillations from the outside. Generation of electromagnetic waves will thus occur.

For a radio physicist, however, generation or amplification does not mean a simple increase of the energy of the electromagnetic field. Indeed, it is well known that heated bodies radiate electromagnetic waves. An increase in the temperature of the body increases the intensity of the radiated waves. However, in this radiation the electrical field does not vary as a sine or cosine function, this being the result of the fact that such radiation constitutes the sum of different waves emitted by different, independent, i.e., incoherent sources. Filtering does not lead to coherence of the radiation selected from the total spectrum of the thermal radiation. At the same time classical methods of coherent amplification have long been well known in radio physics, and consequently also generation of monochromatic oscillations with the aid of electronic instruments in which the kinetic energy of electron currents is transformed into microwave energy.

The question arises then whether a system consisting of an aggregate of excited molecules and a cavity will ensure the conditions for coherent radiation, and whether there will occur as a result of the induced radiation extreme narrowing of the initial spectral line such that the electromagnetic oscillations in the cavity will vary harmonically. The theoretical conclusions and subsequent experiments answered this question in the affirmative.

Thus there appeared a new type of generator (and later also amplifier) of electromagnetic radiation in which the energy source are not electron currents which do not vary periodically with time, but an aggregate of excited molecules, i.e., the "active" medium. These generators and amplifiers came to be known as quantum generators and amplifiers, and the scientific field dealing with them—quantum radio physics.

Work in this field started at the beginning of the Fifties and the first lecture of Basov and Prokhorov, which included all the basic ideas of the quantum generator, was presented at the All-union conference on nuclear magnetic moments which took place on 22-23 January 1953. After this, starting in 1954, Basov and Prokhorov published in the Journal of Experimental and Theoretical Physics and in the Transactions (Doklady) of the USSR Academy of Sciences a series of important articles on this subject; the first report of a successful experiment was presented by Townes and co-workers in May 1954 and published a little later in the Physical Review.

Why then were these new generators and amplifiers called quantum generators and amplifiers? Because to generate or amplify use is made of radiation corresponding to transitions between quantum states of molecules.

Actually stimulated emission occurs also in nonquantum physics. It is well known that for a definite phase relationship of the oscillations of the electric field and of an excited classical oscillator, the oscillator can transfer its energy to the field increasing its amplitude. However, this analogy cannot be carried too far. The active medium—the atoms and molecules—obeys the laws of quantum mechanics, and a correct theory of quantum generators can only be constructed on the basis of the equations of quantum mechanics.

Stimulated emission was postulated in 1917 in the work of A. Einstein. He considered problems connected with the transfer of momentum and energy to atoms and molecules in absorption and radiation of photons ensuring thermodynamic equilibrium between the radiation and the matter. Later, in connection with developments of quantum theory, P.A.M. Dirac considered certain properties of stimulated emission, in particular problems related to coherence.

The introduction of new principles of generation and amplification into radio physics made it possible to solve a series of fundamental problems. As was noted in a lecture of Basov and Prokhorov at the annual meeting of the USSR Academy of Sciences in 1960 it was possible even then to construct with the aid of the methods of quantum radio physics efficient generators with a high frequency stability and amplifiers of great sensitivity. The stability of quantum generators is due to the fact that the frequency of the radiation is determined essentially by the frequency of the quantum transition, and depends thus little on the parameters of the cavity and other external conditions. The high sensitivity of quantum amplifiers is due to their low intrinsic noise level, quantum amplifiers being able, unlike the usual amplifiers, to operate at low temperatures and do not have superfluous shot noise characteristic of ordinary amplifiers. Quantum generators and microwave amplifiers were of great importance in the setting up of frequency and time standards, in navigation, geodesy, radio astronomy, investigations of cosmic space, in solving the problem of communication of large volumes of information over very large distances, etc. It is hard to overestimate their value.

One of the important achievements of quantum radio physics has been the construction of generators and amplifiers of optical radiation—lasers. With the aid of those, it has been found possible to obtain powerful coherent light waves unattainable until recently. Coherent optical radiation offers enormous possibilities: like radio waves, it is capable of carrying information, but of incomparably greater volume, or focused into a small volume it allows one to obtain enormous densities of light energy and to evaporate any material. With the appearance of coherent generators and amplifiers optics has become similar to radio physics. It has become possible to construct nonlinear optics which holds great possibilities.

At present, a large number of different optical quantum generators is available which differ from each other not only in details of construction, but also in operating principles; however, the common mark that unites them is their utilization of stimulated emission of nonequilibrium quantum systems.

Soviet scientists have contributed greatly not only to the pioneering investigations which laid the foundations of quantum radio physics. The development of quantum radio physics has been enriched by the method of obtaining active particles by using an auxiliary pumping radiation in a system of particles with numerous energy levels, a method which has found very wide application. This method was proposed by N. G. Basov and A. M. Prokhorov in 1955. In 1958 Prokhorov proposed the use of a plane open resonator which came to play an important part in the development of lasers. During the same year, Basov proposed the use of semiconductors, and the following years saw the development and construction by him and his co-workers of various forms of semiconductor lasers.

N. G. Basov and A. M. Prokhorov have established and headed large scientific groups, fruitfully developing the ideas and methods of quantum radio physics.

The investigations carried out independently by Basov and Prokhorov on the one hand, and by Townes on the other, led to a fundamental discovery of great scientific and practical value. They undoubtedly merit high recognition and for this reason their being awarded the Nobel prize has met with the approval of the scientific community.

Translated by Z. Barnea