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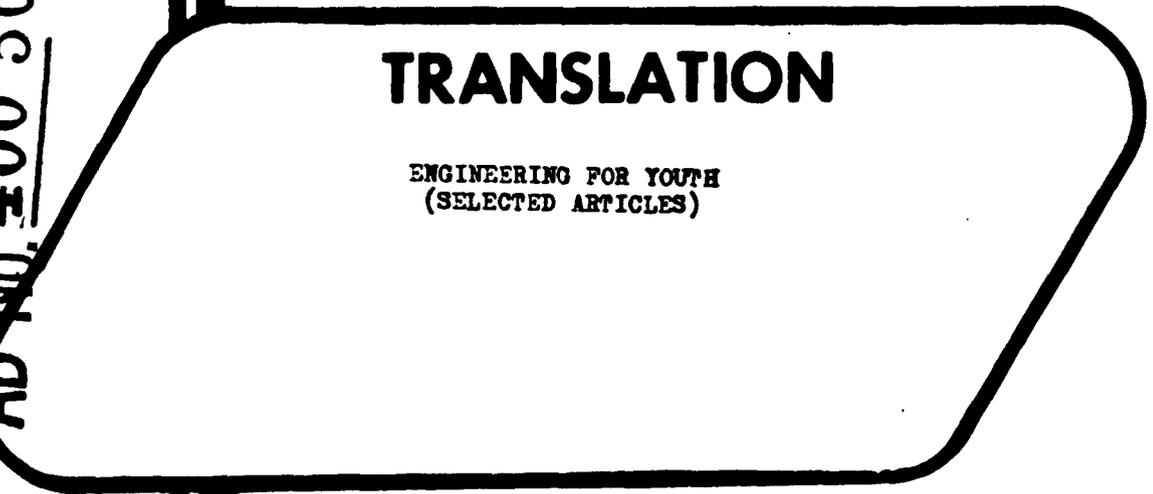
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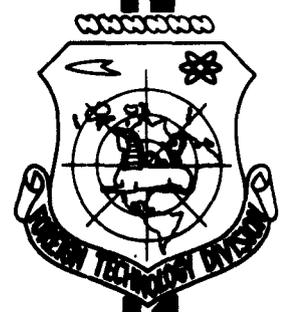
ENGINEERING FOR YOUTH
(SELECTED ARTICLES)

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

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ENGINEERING FOR YOUTH (SELECTED ARTICLES)

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Still Another Secret of Nature has been Uncovered

Theory of Superconductivity

by

N. Bogolyubov, Academician

About fifty year ago the Dutch (Holland) scientist Kamerlingh Onnes discovered a remarkable phenomenon, for the explanation of which numerous investigations have been conducted so far. The phenomenon detected by him - superconductivity - lies in the fact, that certain metallic conductors, being cooled to very low temperatures, cease showing any resistance to the electric current passing through them. They transform as physicists say into the state of superconductivity.

Later on, thanks to investigations by German Researcher Meissner, it was possible to explain the highly favorable magnetic properties of super-conductors.

The definite successes in explaining this phenomenon have been attained abroad by scientists- F and G.London. They reduced the great number of phenomena of superconductivity to several axioms. But even after that the problem remained unsolved.

What kind of a problem is it and why is it so important to solve it ?

Before answering to this question, it is advisable to mention the mechanism of ordinary conductivity of metals.

As is well known, in a metallic conductor the atoms are situated not orderlessly, but in proper rows. They form, as physicists say, a crystalline lattice of the metal. The electric current flowing through the conductor represents a flow of electrons. Passing through the crystal lattice of the metal, the electrons collide with the atoms of this lattice thus causing its fluctuations, i.e. sound fluctuations. In this way the energy of the electrons, roughly speaking, is consumed for the excitation of

lattice oscillations. The stream of electrons experiences a definite resistance.

According to modern ideas, the crystal lattice of the metal can receive an energy from the electrons, only in definite portions - sound quanta (phonons).

A considerable contribution into the explanation of the superconductivity phenomena was made in 1950 by the English scientist Froelich.

What is Conductivity and Superconductivity ?

On the color insert and in the caricature drawings our artists have tried to depict the physical processes, taking place in insulators, semiconductors, as well as in conductors (in normal state and during superconductivity).

In an ideal insulator, e.g. in a diamond, atoms of the substance are situated in the crystalline lattice in such a way, that each carbon atom is firmly bound with four adjoining carbon atoms. The free electrons are totally absent in such a crystal or exist in very small number (on account of foreign admixtures), that electric current does not practically pass through it. Electric conductivity in the insulator can be produced, only by heating same to a very high temperature.

The atoms of the semiconductors, e.g. germanium or silicon, are less firmly bound with their neighbors. These bonds, as the temperature rises weaken on account on an increase in oscillations of crystal lattice atoms of these substances. Fluctuating germanium or silicon atoms with a rise in temperature begin losing more and more of their electrons, as if shaking them off from themselves. Having lost its electron, the germanium or silicon atom tries to capture the electron, lost in the very same manner by one of its neighbors. This in turn, tends to acquire the electron, separated from much farther atoms and so on. Such free electrons, jumping from atom to atom, when an outer electric voltage is applied to the crystal for a very weak electric current, rising with temperature.

At normal temperature in the conductors there is always a great number of free electrons, it is therefore sufficient to apply a low outer electric voltage, and a

considerable current will start flowing through the conductors.

At very deep cooling of conductor the fluctuations of atoms of the crystalline lattice, hindering the movement of the electron stream, decrease. In consequence the electrons encounter no obstacles. The substance becomes a superconductor. Substance, field, space, time...

Illustration: Academician N.N. Bogolyubov

He proposed that this is the action of the electrons with phonones, which under normal conditions produces resistance of conductors, and it can serve as a basis for explaining the phenomenon of superconductivity.

Soon the prediction by Froelich was gradually confirmed by experiments. It became clear, that the basic equation, written by him for studying the reaction of electrons with phonones, rightfully reflects the truth. But neither Froelich nor the researchers after him succeeded in solving this equation in view of greater purely mathematical difficulties.

A new important physical idea was introduced by English scientists Shafrot, Butler and Blatt. They have introduced an idea about the importance of the so-called correlation-reaction between pairs of electrons - to explain superconductivity.

American scientists Barden, Cooper and Shiffer to explain the phenomenon of superconductivity also based themselves on the importance of electrons reacting with phonones. But neither have they succeeded in solving the corresponding equation.

Drawing...When the substance transforms into state of superconductivity the movements of the atoms of the crystalline lattice and free electrons are coordinated, just as the movements of ballet dancers, which are subject to one melody, produced by the orchestra.

They have confined themselves to a certain simplified model, in which a direct, resembling attraction, reaction of electrons with each other, figures. By introducing an additional hypothesis, that electrons group in pairs, these researchers obtained a series of important formulae, as we know now, correctly describing the relationship between the major values, characterizing the state of superconductivity.

In spite of the fact that in the Barden, Cooper, Shiffer report there is a whole series of insufficiently explained physical and mathematical assumptions, it should be considered as an important contribution into the theory, keeping in mind the extreme complexity of the problem.

In the report entitled "On a New Method in the Theory of Superconductivity" we have succeeded in developing a new method, which allows perfectly strictly to solve the problem not only in the initial state by Froelich, but also with additional complications of same, caused for example, by subsequent consideration of electrostatic repulsion of electrons. This new method, in the development of which have actively participated my coworkers D.N. Zubarev, V.V. Tolmachev, S.V. Tyablikov, Yu.A. Tserkovnikov, is based on the development of an idea concerning the microscopic theory of superfluidity, published already ten years ago.

The phenomenon of superfluidity was discovered in 1938 by academician P L.

Kapitsa. Investigating liquid helium, he detected, that its viscosity disappears, when helium is cooled to a temperature, approaching absolute zero, i.e. to minus 273 °C. An important role in explaining this phenomenon was played by the theory of academician L.D. Landau, based on a number of ingenious hypotheses about the microscopic nature of the Phenomenon, which have been used in role of axioms. The author of these lines succeeded in developing a subsequent microscopic theory of superfluidity and to develop special mathematical methods, which were used as basic for the new method, allowing to fully solve the problem of superconductivity.

This brought an explanation to the following picture of movement of a superfluid liquid; in contrast to the movement of an ordinary liquid or gas, in which individual particles move orderlessly, the movement of the superfluid liquid demonstrates a high degree of orderliness. This is due to the fact that particles of superfluid liquid react intensively with each other. This reaction is particularly intensive for particles with oppositely directed velocities. Proper consideration of this reaction has constituted the basic difficulty in formulating the theory of superfluidity. An analogous difficulty was hidden also in the theory of superconductivity. Solving of same with practically the same mathematical methods, which have been developed for the theory of superfluidity, led to decisive results.

In this was established a deep analogy of the phenomenon of superconductivity with the phenomenon of superfluidity and it was proven that superconductivity is nothing other than superfluidity of electrons in metal.

The establishment of this analogy is highly essential. Up until now in physics existed a common idea, that a deep analogy in the behavior of the system, consisting of helium atoms, and the system formed by electrons is hardly possible. The fact is that the statistical properties of these particles, which determine the behavior of systems made up of same, are highly variegated. It should be said, that helium nuclei are subject to statistics, which bears the name of the Hindu scientist Bose, and

electrons are subject to statistics, bearing the name of the Italian physicist Fermi.

A general picture of electron behavior in superconductive state can be made in the following manner. Free metal electrons form in this state a bound "collective", similar by its properties to the one, which in the theory of superfluidity is called condensate. In order to select an electron from this "collective" it is necessary to apply work of the order of thermal energy, corresponding to a transition temperature from superconductive to normal state. Thanks to such a bond the movement of the "collective" as a whole appears to be stable. Upon additional stabilization under the effect of the magnetic field this movement, i.e. electric current, encounters no resistance in the metal.

We want to mention, that electrostatic repulsion of electrons counteracts the formation of such a "condensate". But this repulsion, as we now know, has a considerably lesser effect than as assumed in the Barden, Cooper, Shiffer theory. Furthermore, our method enabled to calculate oscillations of a "collective" of electrons and to establish the existence of a special form of excitation - electron waves, the energy of which is inversely proportional to maximum velocity of electrons.

It would be improper to think, that with the creation of a theory of superconductivity the interest of scientists in this problem will fade away. On the contrary, right now when the basic mechanism of this phenomenon has just become perceptible, there is immediate origination of practically important new problems. It is necessary,

for example, to know how to determine the dependence of transition temperature upon the structure of the metal. The fact is, the extreme smallness of temperature very much hinders practical utilization of superconductors.

Consequently the solution of the problem of effectively raising this temperature represents a difficulty but favorable problem for researchers.

I do hope, that the new method will obtain broad application in other branches of statistical physics, first of all in the theory of metals.

New Discoveries in the Field of Theoretical Physics
(Descriptive Title)

By: A. Sokolov

In 1957 have been made two fundamental discoveries in the field of theoretical physics, revealing the laws of motion and reaction of electrons.

The first discovery was made by the Chinese physicists theoreticians Li Chzhen-Dao and Yan Chzhan-nin, who have shown that during beta-decomposition of nuclei the number of electrons departed in direction of nuclear spin is smaller than in opposite direction (See Journal Tekhnika Molodozhi • No.1,1958).

The second fundamental discovery was made by the known Soviet physicists theoretician academician Nikilay Nikolayevich Bogolyubov. He together with his coworkers succeeded, finally, to formulate the theory of superconductivity.

The phenomenon of superconductivity was developed experimentally in 1911. It consists in the fact that in some metals, cooled to very low temperatures resistance to electric current is completely eliminated.

After this discovery physicists-theoreticians have unsuccessfully tried for over 40 years to explain this unusually interesting phenomenon. F. and G. London succeeded in obtaining a series of equations to study certain properties of superconductors. But these equations bore a normal nature and have not entirely revealed the physical nature of superconductivity.

A known contribution into solving the physical nature of superconductivity was made in 1950 by the English scientist Froelich. He tried to explain this phenomenon as the result of reaction of free electrons with fluctuations of atoms of crystalline lattice of the metal.

His theory bore a qualitative nature, because Froelich has not succeeded in solving the equations obtained by him, and not to mention, that the reaction between electrons has not been considered in his theory.

On the other hand, American physicists Bardin, Cooper and Shriver in their recent report (1957) plainly do not discuss the reaction of electrons with fluctuations of lattice atoms, and confine themselves to the reaction of electrons with each other. Nonetheless in view of the extremely complex problem their experiments should be considered a great achievement.

Finally a strict and complete theory of superconductivity was presented by N.N. Bogolyubov and his students in 1957 (actually N.N. Bogolyubov, worked parallel with Bardin, but independent from him). He considered not only the reactions of electrons at low temperatures, but also the reaction of electrons with lattice fluctuations. The idea of this experiment was to establish the deep physical and mathematical analogy between phenomena of superconductivity and superfluidity, i.e. in establishing a bond between the behavior of particles at low temperatures, subject to Bose statistics (helium atoms) and Fermi statistics (electrons). At this point we would like to mention, that the strict theory of superfluidity, i.e. loss in viscosity by the liquid helium at low temperatures, was finally formulated also by N.N. Bogolyubov approximately a decade ago. According to the Bogolyubov theory at low temperatures the free metal electrons form a strongly bound "collective", which during the movement in the metal encounters no resistance. Upon a rise in temperature the electrons begin getting away farther and farther from this "collective" and the metal begins losing its superconductive properties.

The scientific society has highly esteemed the theoretical solving of the problem of superconductivity and the Scientific Council of the Moscow University has synonymously awarded to N.N. Bogolyubov the Lomonosov premium of first class for 1957.

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