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AN ANTHOLOGY OF THE DISTINGUISHED ACHIEVEMENTS IN SCIENCE AND TECHNIQUE. PART 38: NOBEL PRIZE LAUREATES IN PHYSICS FOR 2005-2010

Purpose. Implementation of brief analytical review of the distinguished scientific achievements of the world scientists-physicists, awarded the Nobel Prize in physics for period 2005-2010 yy. Methodology. Scientific methods of collection, analysis and analytical treatment of scientific and technical information of world level in area of modern theoretical and experimental physics. Results. The brief analytical review of the scientific openings and distinguished achievements of scientists-physicists is resulted in area of modern physical and technical problems which were marked by the Nobel Prizes in physics for the period 2005-2010. Originality. Systematization is executed with exposition in the short concentrated form of the known scientific and technical materials, devoted creation of quantum theory of optical coherentness by scientists-physicists, development of laser exact spectroscopy, opening form of spectrum for a black body and anisotropy of space microwave base-line radiation, opening of effect of giant magnetoresistance, opening of mechanism of spontaneous violation of symmetry in subatomic physics, development of new technology of transmission of light in optical fibres, invention of a semiconductor circuit for registration of images and results of innovative experiments on research of 2D material of graphen. Practical value. Popularization and deepening of scientific and technical knowledges for students, engineers and technical specialists and research workers in area of modern theoretical and experimental physics, extending their scientific range of interests and collaboration in further development of scientific and technical progress in human society. References 31, figures 25.

Key words: **modern physics, achievements, quantum theory of optical coherentness, laser overexact spectroscopy, space microwave base-line radiation, effect of giant magnetoresistance, spontaneous violation of symmetry, transmission of light in optical fibres, semiconductor circuit for registration of images, 2D material of graphen.**

Приведен краткий аналитический обзор выдающихся научных достижений ученых мира, отмеченных Нобелевской премией по физике за период 2005-2010 гг. В число таких достижений вошли создание квантовой теории оптической когерентности, развитие лазерной точной спектроскопии, открытие чёрнотельной формы спектра и анизотропии космического микроволнового фонового излучения, открытие эффекта гигантского магнетосопротивления, открытие механизма спонтанного нарушения симметрии в субатомной физике, разработка новой технологии передачи света в оптических волокнах, изобретение полупроводниковой схемы для регистрации изображений и результаты новаторских экспериментов по исследованию двумерного материала графена. Библ. 31, рис. 25.

Ключевые слова: **современная физика, достижения, квантовая теория оптической когерентности, лазерная сверхточная спектроскопия, космическое микроволновое фоновое излучение, эффект гигантского магнетосопротивления, спонтанное нарушение симметрии в субатомной физике, передача света в оптических волокнах, полупроводниковая схема для регистрации изображений, двумерный материал графен.**

Introduction. As is well known, in 1900 the prominent German theoretical physicist Max Planck (1858-1947) developed the quantum theory of the thermal radiation of an absolutely black body (ABB), according to which the heat flux from the ABB contained separate discrete portions (*«quanta»*) of energy [1, 2]. Precisely for the discovery of discrete quanta of «action» (energy) M. Planck in 1918 was awarded the Nobel Prize in physics [1]. In 1905 the quantum theory of thermal radiation of M. Planck was significantly supplemented and developed by another prominent German theoretical physicist Albert Einstein (1879-1955), who extended it to light radiation and introduced the concept of the flux of *«quanta of electromagnetic radiation»* for sunlight or *«photons»* – peculiar quasiparticles without a rest mass [1, 2]. So in physics, the concept of dualism (duality) for light, which was simultaneously a flux of quasiparticles (photons) and a set of electromagnetic waves of various lengths, was introduced. The light radiation having a quantum-wave nature is of a stochastic nature. In this connection, the state of the light field is determined only statistically [3]. Light quanta are characterized by different wavelengths that are not moving in phase. The microstructure of the light field is determined by a huge number of parameters, an exact description of which can not be given. Therefore, previously, it was possible to investigate only certain particular characteristics of the light field (for example, its spectrum and average intensity [3]).

1. Quantum optics and high-precision laser spectroscopy. The Nobel Prize in physics for 2005 was awarded to an outstanding scientist working in the field of modern optics and laser technology [3]: American theoretical physicist Roy Glauber (Fig. 1) – *«for his contribution to the quantum theory of optical coherence,»* to the American experimental physicist John Hall (Fig. 2) and the German experimental physicist Theodor Hansch (Fig. 3) – *«for the development of precision laser spectroscopy, in particular, for the methods of Raman spectroscopy in the optical range.»* In 1963, R. Glauber published in print the method he developed for quantizing the electromagnetic field to calculate the structure of a light field with coherent waves. It should be recalled that the term *«coherence»* comes from the Latin word *«cohaerentia»* – *«cohesion»* and physically *means «the consistent flow of several oscillatory or wave processes in time, the phase difference of which is constant»* [4]. Waves of light radiation satisfy these requirements. That's why it is considered coherent. It is the coherence of the waves of light radiation that determines the phenomenon of their *«interference» – «amplification of waves at certain points of space and their attenuation in others, depending on the phase difference of the waves»* [4]. To describe the complex picture of the light field and determine the spatial-temporal distribution of its intensity, he introduced the so-called *«correlation functions»*, which form the basis of the new division of optics – *«quantum optics»* created by R. Glauber [3]. The methods of quantum optics developed by him make it possible to investigate the subtle details of intermolecular interactions in various physical bodies from the change in the indications of several photoreceivers that record the flux of light photons and fluctuations in the light field (the deviation of its intensity from a certain average value) when light is scattered in the medium under consideration.

At present, such a physical device from the field of quantum electronics as a laser [5] has become an indispensable tool for accurate measurements. As is well known, high stability of laser radiation and its monochromaticity contribute to this.

Fig. 1. Prominent American theoretical physicist Roy J. Glauber, born in 1925, Nobel Prize Laureate in physics for 2005

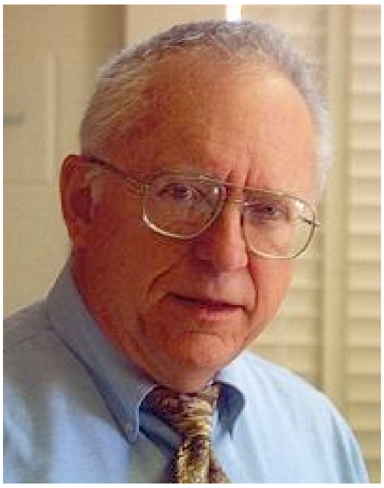

Fig. 2. Prominent American experimental physicist John L. Hall, born in 1934, Nobel Prize Laureate in physics for 2005

Fig. 3. Prominent German experimental physicist Theodor W. Hansch, born in 1941, Nobel Prize Laureate in physics for 2005

Any conventional laser operates in a very narrow frequency band of electromagnetic radiation and is always characterized by a certain frequency. J. Hall and T. Hansch in their scientific studies have shown that to achieve ultra-high accuracy of measurements requires a laser emitting a huge number of light waves with coherent frequencies (modes) [3]. When they are added, a light pulse is formed, the duration of which is shorter the more frequencies participate in its formation. According to their estimates, to obtain, for example, a light pulse with a duration of 5 femtoseconds ($5 \cdot 10^{-15}$ s), it is necessary to add a million frequencies that cover most of the visible light range [3]. Their frequency spectrum form a kind of *«comb»* with *«teeth»*, corresponding to individual frequencies. As a result of such a superposition of electromagnetic waves between the mirrors of the laser cavity [5], short light pulses will appear. Outgoing laser through the semitransparent mirror of its resonator, light will form a sort of «ruler» with fissions in the form of ultrashort light pulses [3]. Such a mode of operation of one of the lasers was obtained by T. Hansh in the 1970s. However, a real scientific breakthrough in increasing the accuracy of measurements occurred in 1999, when lasers with superfine pulses were required to measure the optical frequencies of atomic clocks operating on cesium atoms.

In the case when the measured frequency of the radiation of a microobject (for example, an atom) coincides with one of the frequency *«teeth»* for the considered *«spectral comb»* from this laser, then it is uniquely determined. The physical approach developed by the learned laureates in the field of new applications of laser spectroscopy makes it possible to measure the frequencies of radiation emitted by the atoms of a substance with unprecedented accuracy [3]. Thus, the *«frequency comb»*, formed by a new type of quantum oscillator of stimulated emission of the optical band (laser), has become an effective standard in ultra-precise measurements of atomic radiations.

2. Discovery of the black body spectral shape and the anisotropy of cosmic background microwave radiation. In 2006, one of the most notable scientific events in world physics was the Nobel Prize to two American radiophysicists George F. Smoot (Fig. 4) and John C. Mather (Fig. 5) *«for the discovery of the equilibrium form of the cosmic background Microwave radiation and its anisotropy»* [6]. In radio astronomy this radiation is also called «cosmic relic radiation» [7]. Relic (this term comes from the Latin word *«relictum»* – *«remnant»* [4]) radiation is a microwave electromagnetic radiation, preserved in space from the early stages of the development of the universe. Note that «cosmic relic radiation» with a wavelength of about 7 cm and a temperature of about 3 K was discovered in 1965 by American experimental physicists Arn Penzias and Robert Wilson (Nobel Prize in physics for 1978 [1]). Then A. Penzias and R. Wilson observed this short-wave electromagnetic background radiation propagating in the cosmic space of the boundless universe, as «electromagnetic noise» in radio telescopes fixed on the surface of our planet, which is unavoidable for these cosmic researchers [1, 7].

Fig. 4. Prominent American radiophysicist George Fitzgerald Smoot, born in 1945, Nobel Prize Laureate in physics for 2006

Their discovery confirmed the «hot» model of the universe [1, 7]. As we know, the era of quantum physics for earthlings was discovered by the prominent German theoretical physicist Max Planck (1858-1947), who in 1900 formulated his famous quantum law of equilibrium thermal radiation for an artificially or naturally heated «absolutely black body» (ABB) [2, 8]. Let us remind the reader that the quantum theory of M. Planck, developed by him for thermal radiation of the ABB, based on the concept of the «quantum of action», which was fundamentally new in physics and appeared in the scientific world, in fact, as a revolutionary event, was awarded the Nobel Prize In physics for 1918 [1]. In the quantum theory of M. Planck, the AKT (substance) and thermal (electromagnetic) radiation from it are in an equilibrium state [8]. In astrophysics it is believed that in the early stages of the development of the universe its matter and radiation from it were also in equilibrium [7]. This assumption allows us to determine the possible spectral composition of the relic electromagnetic radiation, which in shape must correspond to the spectrum of radiation from the ABB. This spectrum of thermal radiation for the ABB (an idealized computational model) by physicists has been thoroughly studied long ago. Therefore, according to this hypothesis, in the background (relic) radiation of the Universe, the number of its electromagnetic quanta with a particular wavelength will depend only on the temperature of the matter of the Universe at an early stage of its development [7]. At a later stage of the evolution of the Universe, in the opinion of astrophysicists, its electromagnetic radiation, while maintaining its frequency spectrum, «breaks away» from its matter and adiabatically cools, uniformly penetrating the entire Universe [7].

Fig. 5. Prominent American radiophysicist John Cromwell Mather, born in 1946, Nobel Prize Laureate in physics for 2006

For greater clarity, it is necessary to indicate that this cosmic electromagnetic radiation is concentrated mainly in the microwave range (in the frequency range typical for modern domestic microwave ovens) [7]. The first measurements of the cosmic microwave background radiation were carried out by radiophysicists at high-altitude radiophysical stations. With the help of such measurements, the long-wavelength part of the relict radiation spectrum was investigated. The results of these studies made it possible to estimate the temperature T_R of a given background radiation, which amounted to about 2.7 K [7]. Conducting more accurate and large-scale measurements of the cosmic microwave background of the Universe required the use of a sophisticated instrument placed outside the Earth's atmosphere. In 1989, the US aerospace agency NASA for this purpose created and launched into the outer space satellite «COBE» (COsmic Background Explorer), whose external view is shown in Fig. 6.

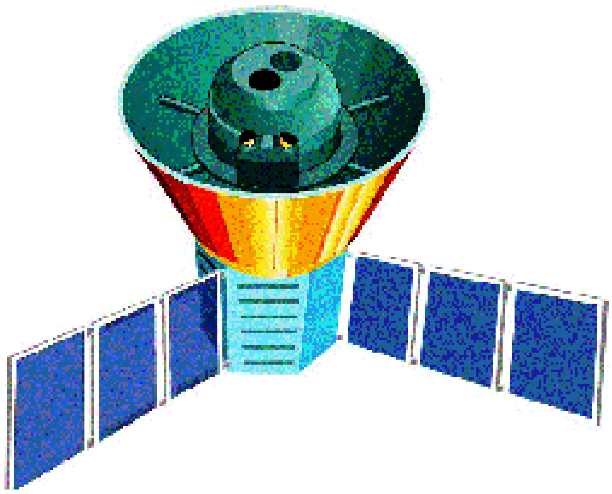

Fig. 6. External view of the American satellite «COBE» comprehensively investigated in the 1990s relic (background) radiation of our Universe [7]

On the satellite «COBE», a microwave relic radiation spectrometer with a high resolving power was installed, which makes it possible to estimate the degree of isotropy of this radiation [7]. Already the first measurements with the help of the satellite equipment «COBE» of cosmic microwave background radiation have shown that it completely corresponds to the spectrum of the equilibrium radiation of the ABB (the «spontaneous» spectrum of electromagnetic radiation). During numerous measurements on this satellite, it was established that the temperature T_R of the cosmic microwave background of the universe is (2.725±0.002) K [7]. In addition, a program of similar radiophysical studies using the satellite «COBE» contained a study of the anisotropy of this radiation – the detection of small deviations in the intensity and, correspondingly, of the temperature of cosmic relic radiation in various directions of the universe. Note that the possible deviation of this radiation from the mean temperature in different parts of the universe can testify to the places where galaxies and stars originate in it, and also indicate the regions of concentration of matter in the universe. In this part, the results of such studies are particularly interesting with respect to «dark» matter or «black holes» of the Universe [9], which can significantly change the temperature of the background radiation. As you know, such a matter can not be directly seen, but can be detected by its super-strong influence on the physical processes taking place in outer space [7]. In astrophysics it was established that in the Universe thanks to gravity there is a continuous process of formation of clumps of matter – proto-types of future planets, stars and galaxies. In the regions of matter thickening, the temperature rises locally [7]. The SOBE spectrometer made it possible to measure the temperature fluctuations T_R of background radiation at the level of $10^{-5}\cdot T_R$ in three frequency ranges corresponding to the maximum intensity of the relict radiation [7]. At the same time, its angular resolution was about 7 angular degrees for outer space. The results of the measurements carried out on the «COBE» satellite for four years showed the contribution of the «Milky Way» galaxy, which includes our solar system, to the dipole component of cosmic background radiation at the level of $\Delta T_R/T_R=10^{-3}$ [7]. Experiments on «COBE» confirmed the Gaussian character of the distribution at large angles of resolution of temperature fluctuations ΔT_R in the background radiation of the Universe. They allowed to give a rigorous justification of the cosmological model of the «Big Bang», which occurred about 12 billion years ago in the Universe.

3. Discovering the effect of giant magnetoresistance. About 150 years ago it was established experimentally that when the conductor is placed with an electric current in an external magnetic field, its reactance R_e slightly changes [10]. This phenomenon was called the magnetoresistive effect – the «magnetoresistance» of the conductor R_{em} [4, 8]. The nature of the established dependence for R_e on the level of the intensity H_m of the external magnetic field was then unknown. For more than a half-century history of the evolution of world electrical engineering, no one paid serious attention to this phenomenon for chains made of traditional conductor materials (copper, aluminum, iron, etc.). After all, changes in the resistance R_e of the conductors for them, depending on the level of the magnetic field intensity H_m, did not exceed a few percent [10]. Only after in the leading scientific laboratories of the world of materials scientists learned to artificially create special laminates with new physical properties, this dependence of R_e on H_m began to be studied more closely. In the second half of the 20th century, talented physicists – the Frenchman Albert Fert (Fig. 7) and the German Peter Grünberg (Fig. 8) experimentally recorded the appearance of the «giant magnetoresistance» R_{em} in new laminates [10]. The discovery by these physicists of the phenomenon of «giant magnetoresistance» was noted by the Nobel Prize in physics for 2007 [6, 10].

Fig. 7. Prominent French physicist Albert Fert, born in 1946, Nobel Prize Laureate in physics for 2007

The «roots» of the new physical phenomenon under consideration deeply «enter» the quantum nature of the electric current in the conducting material, according to which this current is determined by the drifting free electrons, which have in it an energy close to their maximum energy – the Fermi energyW_F [10, 11].

Fig. 8. Prominent German physicist Peter Grünberg, born in 1939, Nobel Prize Laureate in physics for 2007

The electric current in a metal conductor of a high-current circuit at room temperature (about T_0=293 K [8]) of surrounding its air medium is a superposition of a rapid (with an average thermal velocity v_{eT} of the order of 10^5 m/s [11, 12]) of random motion in interatomic or interionic space of free electrons (elementary particles-fermions [8]) and slow (with an average velocity v_{eD} of the order of 10^{-2} m/s [11, 12]) of the directed displacement (drift) of the «electron gas» in the internal crystal structure of the conductor. It is known that electrons as quantum objects possess wave properties. For an electron moving with velocity v_e, the length of the electron wave λ_e is determined by the fundamental quantum-mechanical relation introduced by the eminent French theoretical physicist Louis de Broglie (1892-1987), of the form [8]: $\lambda_e=h/(m_e v_e)$, where $h=6.626\cdot10^{-34}$ J·s is the Planck constant; $m_e=9.109\cdot10^{-31}$ kg is the rest mass of an electron. Then, at $v_{eT}=10^5$ m/s, we find that for a chaotic motion of carriers of an elementary electric charge of the «electronic gas» of a conductor having a density n_e of the order of 10^{29} m^{-3} [11], at this temperature it will correspond to the average electron wavelength $\lambda_{eT}\approx7.3\cdot10^{-9}$ m. According to [8], the considered Fermi gas of a conductor is considered to be «degenerate» when an inequality of the form $n_e\lambda_e^3>>1$ is satisfied. Substituting in this inequality the given numerical values for $n_e=10^{29}$ m^{-3} and $\lambda_{eT}\approx7.3\cdot10^{-9}$ m, we are convinced that the randomly moving free electrons of our conductor will be a purely «degenerate» Fermi gas. In the case of a drift (directional displacement) of the «electronic gas» of the conductor ($n_e=10^{29}$ m^{-3}), the parameters sought for it will have the following numerical values: $v_{eD}=10^{-2}$ m/s; $\lambda_{eD}\approx7.3\cdot10^{-2}$ m. After substituting the values of these parameters into the above inequality, we come to the conclusion that the drifting «electronic cloud» of the conductor, in comparison with its randomly moving free electrons, will even more satisfy the requirements of the «degeneracy» of the Fermi-gas. And if so, the quantum properties of the drifting «electron cloud» of the conductor under consideration will be significant and must be taken into account when studying the electrophysical processes in it.

The active resistance R_e of the conductor is determined by the scattering of drifting free electrons (electron de Broglie waves [11]) on the inhomogeneities of the conductor material (for example, on the defects of its crystal lattice, impurity atoms or quasiparticles, phonons, quanta of elastic thermal vibrations of atoms of this Lattice) [8]. Among other things, electrons also have such an important quantum-physical characteristic as the «spin» S_e (this term derives from the English word *«spin»* – *«to rotate»* and in atomic physics it denotes the intrinsic mechanical moment of the momentum of an elementary particle or atomic nucleus [4]). Quantitatively, the spin S_e of an electron is expressed in special units with respect to a constant value $h/(2\pi)$ [8, 11]. Therefore, the electron spin will be numerically equal to $2\pi S_e/h=1/2$ [8]. It is this value of the spin S_e that determines for an electron capable of rotating about its axis in two directions (for example, in the direction of the vector of intensity H_m of the acting magnetic field or against it), its spin quantum number in the form $m_S=\pm1/2$ [8]. A distinctive feature of the electron spin S_e is that it not only causes the electron to respond to the action of an external magnetic field, but also generates a similar field. For ordinary conductors (especially nonmagnetic – copper or aluminum), the spin S_e of an electron does not have a serious effect on the conductivity flow in it. Therefore, practically no one remembers this characteristic of the main carriers of negative charge in metal conductors in traditional electrical engineering. But for new layered materials, in which the phenomenon of the «giant magnetoresistance» was discovered, it turned out that it is the electron spin that plays the key role [10]. What is the role of this quantum-physical characteristic? For a more reasoned answer to this simple but complex question, let us first consider the behavior of free electrons inside a ferromagnetic material of a planar conductor (conductive bus) of a rectangular configuration with a longitudinal current. Let the magnetic induction of its pre-magnetized material also be directed along the longitudinal axis of such a conductor. In this case, the internal magnetic field of the conductor will differently affect its longitudinally drifting free electrons, the spins S_e of which differ by their orientation with respect to the indicated direction of the field vector H_m of this field (over the field or against the field). The electric current of the conductor under consideration in this case will consist of two carefully interleaved electron fluxes, one of which has electron spins S_e oriented in the direction of magnetization of its material and the other with their orientation against the direction of the internal magnetic field of the conductor [10]. The electrons of these two flows will experience a different resistance from the crystal structure of the conductor metal in this case. It turns out that electrons with spins S_e oriented *opposite to the magnetic field* will move *more freely* along the conductor (without delay), and electrons with their spins S_e oriented *along the magnetic field – more difficult* (with a delay) [10]. In the first case (for a sort of electrons with spins S_e *opposite to the field*), the resistance R_e of the conductor will be relatively *small*, and in the second case (for a sort of electrons with spins S_e *along the field*) – *large*. We note that similar features in the flow of the conduction current for us will for the time being be characteristic only of a ferromagnetic material (diamagnetic materials such as copper and other metals do not exhibit such singularities at T_0=293 K) [10]. Similar features of the free electron drift in conductors were established relatively recently – in 1968 by a group of French physicists, which included also the future Nobel Prize winner in physics in 2007, A. Fert [10]. It was then before the researchers and the question arose about the feasibility of practical use of the revealed features of the electron drift for a sharp change in the values of the resistivity R_e of the conducting structures. Now, on the basis of the data of [10], we can briefly answer the question posed earlier by us about the role of the spin S_e of the electron. The answer can be reduced to the fact that the concentration of free electrons with the considered S_e (*along the field* or *opposite to the field*) near the level of the Fermi energy W_F depends essentially on the orientation of the spins of H_m electrons for a number of conductors relative to the direction of the intensity vector H_m of the internal (external) magnetic field, characteristic for conduction bands and determining the drift current of the conductor [10]. If there are a lot of free electrons in the material of a conductor with Fermi energy W_F, then a relatively large conduction current with *small* electric resistance R_e to it (current) can flow in it. If there are a little of free electrons in the material of the conductor with Fermi energy W_F, then comparatively weak conduction current with *large resistance* R_e to current can occur in it [10].

Having created in the 1980s artificially new ultrathin layered conductive materials (*superlattices* (Fig. 9), in which strictly alternating magnetic and nonmagnetic layers of two types of metals have a thickness of several atoms [10]), physicists learned to control not only by the magnitude of the magnetization of their layers, but also by the character of their magnetic ordering. And then through the nature of the magnetic ordering of the layers – the electrical resistance R_e of a similar conductive «puff».

In 1986, P. Grünberg's research group in the «puff» made of ultrathin layers of magnetic iron Fe and nonmagnetic Cr chromium (Fig. 10) revealed the effect of alternating magnetization orientations of such Fe iron layers in the absence of an external magnetic field H_m [10, 13]

$$H_m = 0.$$

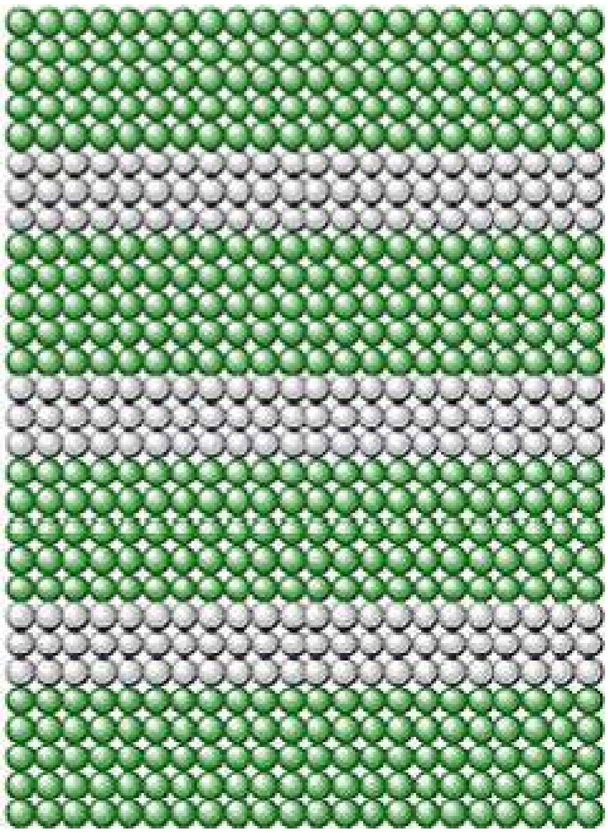

Fig. 9. Schematic view of the modern *superlattice* – strictly alternating layers of atomic thickness of two materials (for example, from 4 layers of magnetic iron Fe and 3 layers of nonmagnetic chromium Cr) with similar crystal structures [10]

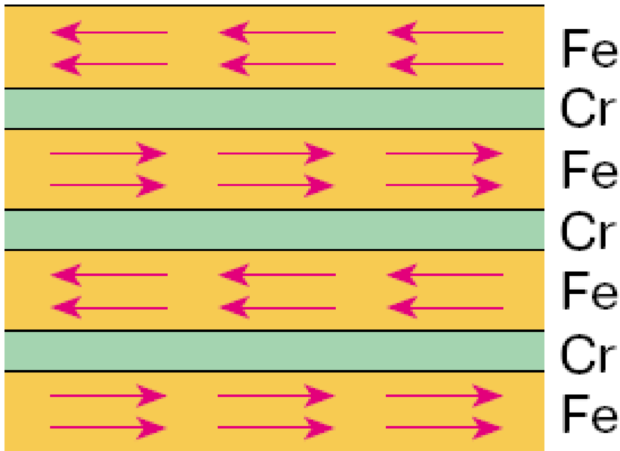

Fig. 10. Schematic representation of the order of alternation of the magnetization of hyperfine layers of iron Fe in a «puff» of iron Fe and non-magnetic chromium Cr in the absence of external constant magnetic field [10]

In the case of an external high constant magnetic field with strength H_m on the one shown in Fig. 10 the «slab» – the *superlattice* Fe-Cr, the magnetization of the layers of iron Fe was acquired due to the magnetization reversal by the field of these layers of the same spatial orientation (Fig. 11) [10, 13]

$$H = H_m.$$

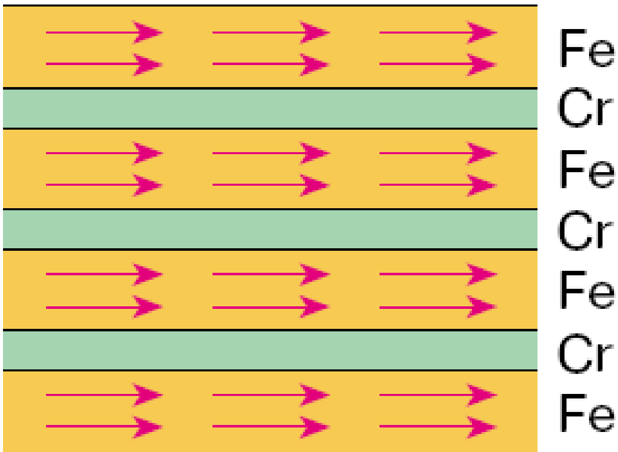

Fig. 11. Schematic representation of the magnetization of ultrathin iron Fe layers in a «puff» of iron Fe and non-magnetic chromium Cr under the action of external high constant magnetic field [10]

It is interesting to note that when the action of an external strong magnetic field with the strength H_m on the *superlattice* under consideration ceases Fe-Cr magnetization of its atomic Fe layers returned to the initial state, shown in Fig. 10. Thus, thanks to superlattices, the physicists-experimenters have a real possibility of rapidly changing the nature of the magnetic ordering of their hyperfine layers [10, 14]. And, finally, they have a real way to control the change within the noticeable limits of the electrical resistance R_e of the conductive «puff». A. Fert and P. Grünberg with their colleagues during 1988-1989, studying the passage of a constant electric current across the layers of «puff» from iron Fe and chromium Cr in the absence and impact modes of an external strong permanent magnetic field, and discovered the effect of «giant magnetoresistance» [13, 14]. In the first experiments of A. Fert, in which an experimental sample of this «puff» of Fe-Cr was placed in a cryostat with a temperature of about 4.2 K, a decrease in the value of its active resistance R_{em} for the cases H_m=0 and H=H_m from the range of high constant magnetic fields (H_m is more than 10 kOe [12]) was approximately twice [10, 14]. Initially, in analogous experiments of P. Grünberg, carried out with this «puff» only at room temperature T_0=293 K, the changes in R_{em} were only 1.5 % [10, 13]. P. Grünberg took several years of careful scientific research to bring his results to room temperature T_0=293 K to the level of reducing the values of R_{em} by two times [10, 15]. An analysis of the experimental results obtained for such a change in the values of the active resistance of the R_{em} «puff» from Fe-Cr showed that they are due to the influence of the orientation of the free electrons of the S_e considered by us above (*along the field* or *opposite to the field*) in the hyperfine layers of iron Fe. The concentration of the corresponding two types of drifting electrons (with a magnetic quantum number m_S=+1/2 or m_S=−1/2) near the Fermi energy level W_F [13-15].

Practical use of the «giant magnetoresistance» effect in computer technology immediately led to a sharp increase in the density of magnetic data recording on hard disks. «Puff» with Fe-Cr and such active resistance R_{em} appeared to be a compact, fast, sensitive and simple by design magnetic field sensor [10]. Being located above the rapidly rotating plate of the hard drive of the computer, such a «puff» tracked the magnetic fields of the information bit streams flying under it in the binary system (the term *«bit»* is derived from the English words *«binary»* and *«digit»* [4]) and immediately transferred them to the corresponding pulses of the electric current.

4. **Discovery of the mechanism of spontaneous breaking of symmetry in subatomic physics.** Nobel laureates in physics in 2008 were scientists from Japan (Makoto Kobayashi, Fig. 12; Toshihide Maskawa, Fig. 13) and the United States (Yoichiro Nambu, Fig. 14) for discoveries in elementary particle physics that explained the causes The fact that the universe we observe consists of matter, and not of antimatter and matter equally, and also the mechanism of the appearance of matter in matter [16]. The studies of these theoretical physicists concern the breaking of symmetry in the world of elementary particles. Their works are related to different time periods, and the symmetries they are considering are related to different interactions of elementary particles [16]. In 1973, M. Kobayashi and T. Maskawa in their joint article suggested that the reason that led to the predominance of matter over antimatter in the universe may be that they participate in different ways in weak interactions (the so-called violation of CP-symmetry) [16-18].


Fig. 12. Prominent Japanese theoretical physicist Makoto Kobayashi, born in 1944, Nobel Prize Laureate in physics for 2008

The first experimental observations in the world of the Kobayashi-Maskawa asymmetry were made by physicists only in 2002 with the help of accelerators KEKB (Japan) and Stanford Linear Accelerator (USA) [16, 19].

Fig. 13. Prominent Japanese theoretical physicist Toshihide Maskawa, born in 1940, Nobel Prize Laureate in physics for 2008

The hypothesis stated in the above-mentioned paper by M. Kobayashi and T. Maskawa, «*The CP Violation in the Renormalizable Theory of Weak Interaction»* (1973), [16] postulated the existence of the third generation of «quarks», which was indirectly confirmed by experiment in four years (in 1977) with the discovery of the *b*-quark [19]. It should be recalled that a quark in the physics of elementary particles and high-energy physics is called a hypothetical particle with a fractional charge of the electron electric charge e_0=1.602·10^{-19} C [8, 11]. In this regard, M. Kobayashi and T. Maskawa in 2008 were awarded the Nobel Prize in physics *«for the discovery of a source of symmetry breaking, which allowed to predict the existence in nature of at least three generations of quarks»* [16-19].

Prior to the work of these theoretical physicists, hadron physics was a real impotent dark «mess» [16]. By 1960, in the experiments on proton synchrotrons by nuclear physicists, dozens of various strongly interacting hadron particles had already been discovered [8]. These hadron particles were with a wide variety of masses, charges, lifetimes and «channels» of decay [16]. Physicists at that time did not understand the «purpose» of these particles, nor their relationship with each other. At that time, there was not even a reasonable scheme for classifying these hadrons. The search for intelligent hadron systematics led scientists to the idea of quarks [16]. In the proposed Y. Nambu, together with the Italian physicist G. Jona-Lazinho, the models of the interaction of hadrons of physics saw a spontaneous breaking of the «chiral» symmetry. Owing to this violation with particles, metamorphoses took place in the developed model: mesons appeared (as bound states of fermion particles, which were analogous to «Cooper pairs» of electrons in superconductors [5]), and the fermion particles themselves became much heavier and can be was identified with protons and neutrons [16]. This led to a rethinking of the physical essence of hadrons [8].

The main investigations of Y. Nambu, who emigrated from Japan to the USA in 1952, was devoted to the development of the idea of spontaneous breaking of symmetry in subatomic physics, expressed by him in 1960 [20]. In 1965, together with M. Khan, he succeeded in creating a scheme of strong hadron-particle interactions, based on three triplets of quarks with integer charges (the well-known Hahn-Nambu model [20]).

Fig. 14. Prominent Japanese-American theoretical physicist Yoichiro Nambu, born in 1921, Nobel Prize Laureate in physics for 2008

Y. Nambu based on this model introduced the «color» interaction of elementary particles [16, 20]. By this theoretical development he laid the foundations of quantum chromodynamics. He essentially developed the quark model of hadron structure [19]. The idea of spontaneous symmetry breaking in the world of elementary particles was actively developed by theoretical physicists, and subsequently the Higgs mechanism of violation of electroweak symmetry also grew out of it. It was *«for the discovery of the mechanism of spontaneous breaking of symmetry in the physics of elementary particles»* that he won the Nobel Prize in physics in 2008 [16].

5. **Development of a new technology for the transmission of light in optical fibers.** In 2009, the first half of the Nobel Prize in Physics was awarded to the Chinese Charles Kao (Fig. 15) *«for the revolutionary achievements concerning the transmission of light in fibers for optical communications»* [21]. Historically, it happened that Ch. Kao in the field of information technology was at the source of fiber-optic data transfer. Because of the rapid development in the world of telecommunications, it has turned out that the traditional technologies for the transmission of information over long distances (with the help of coupled electromagnetic waves in metallic wires and free radio waves) have a fundamental disadvantage – the relatively low speed of the processes taking place in the transmission channels. In order to increase in them (channels) the speed of information transfer by increasing the modulation

frequency, an increase in the carrier frequency of the electromagnetic signal is required. That is why physicists turned their eyes to light pulses (signals), whose frequency is of the order of 10^{15} Hz [8, 11].

Fig. 15. Prominent Chinese experimental physicist Charles K. Kao, born in 1933, Nobel Prize Laureate in physics for 2009

At first glance, an optical fiber with thin glass filaments placed in a protective envelope had to satisfy the rigid requirements for the transmission of light pulses over large distances. However, experimental data testified that in the first half of the 20th century, in the purest glass fibers, the attenuation of the light signal was about 1000 dB/km [21]. Physicists have found that for the effective use of optical fiber as a communication information carrier, the attenuation factor of the light pulse in it should be 20 dB/km or less [21]. In the 1960s, after the graduation from the University of Greenwich (England), with a degree in electrical engineering and the subsequent defense of his doctoral dissertation, he began research at the Standard Telephones and Cables (Harlow) on fiber technology [22]. Here he made his innovative physical and technical discovery, explaining the strong attenuation of light pulses in ordinary glass fibers. He in 1966 found that the reason for this are the impurities present in the glass fibers. In this regard, Ch. Kao, for the efficient use of fiberglass in the transmission of information, proposed carrying it out of thin quartz filaments (Fig. 16) [22]. It was in quartz glass lenses that the lowest level of attenuation of the transmitted light pulse was observed.

Ch. Kao was the first in the world to use fiber-optic cables to transmit telecommunication information over long distances. Technical difficulties in obtaining high-purity quartz glass for these purposes were overcome only in 1972 when researchers from Corning Glass Works (R. Maurer, D. Keck and P. Schulz), using the technology of chemical precipitation from the gas phase, glass fibers were obtained with an attenuation factor of up to 4 dB/km [21, 22].

Fig. 16. External view of a fragment of a bundle of optical fibers with quartz filaments in a protective shell, effectively transmitting light pulses for long distances [22]

Fig. 17 shows the dependence of the attenuation factor of the light signal in a quartz fiber-optic fiber on the length of the waves propagating along it [21].

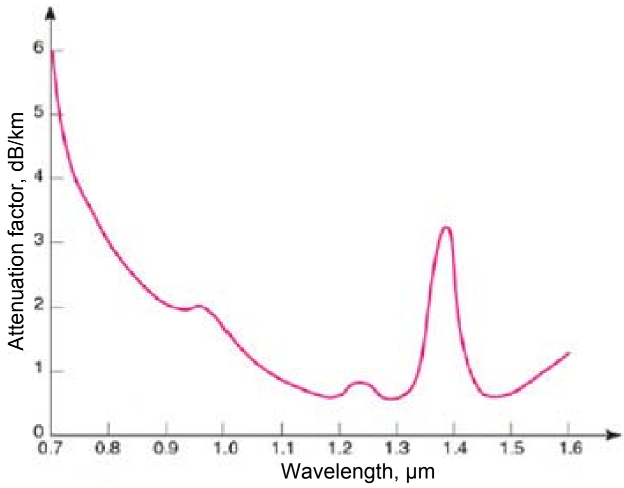

Fig. 17. Attenuation of the light pulse in quartz filaments as a function of the length of its electromagnetic waves [21]

From Fig. 17 that the loss of light intensity is least of all not in the optical but in the infrared (IR) region of the light signal spectrum [21]. This is why the minimal absorption (scattering) of light energy in quartz optical fibers occurs in separate «transparency windows» (at wavelengths of 1.3 μm and 1.45 μm) in the near infrared range of the light pulse. It is at these wavelengths (frequencies) of electromagnetic waves that modern fiber-optic communication operates [21]. Note that, according to Fig. 17 with decreasing wavelength of the light wave, the damping coefficient increases sharply due to the scattering of light by the inhomogeneities of the refractive index of the medium under consideration (the case of «Rayleigh scattering» [8]). In the region of wavelengths of light waves of more than 1.45 μm, strong lines of absorption of the hydroxyl group OH begin to appear in quartz filaments [21]. As is known, because of Rayleigh scattering of light waves in the atmosphere, the sky on the Earth looks blue-bluish, and the sunset or sunrise is orange-reddish [8, 23]. In 1988, the first transatlantic fiber-optic communication cable was laid [21]. At present, the technology of production of such cables is constantly being improved. Now, in the prototypes of the latest developments in fiber optic cables, the decay factor of the light pulse is characterized by a level of up to 0.2 dB/km [21].

6. The invention of a semiconductor circuit for images recording. In 2009, the second half of the Nobel Prize in physics was awarded to Americans Willard Boyle (Fig. 18) and George Smith (Fig. 19) *«for the invention of a semiconductor circuit for images recording»* [21]. W. Boyle and G. Smith invented a semiconductor device that allows you to obtain digital photographs without photographic film. This semiconductor sensor device, which allows to take photographs in digital format, has been called a «Charged-Coupled Device» or a CCD-matrix [21]. In the CCD-matrix, which is part of a modern camera or digital video camera, the light stream is immediately transferred to a digital file with a color image of the object being photographed.

Before considering the operation of the CCD-matrix as a whole in this semiconductor sensory scheme for recording a color image, we need to start with its one of the main components – a semiconductor cell of digital memory, schematically depicted below in Fig. 20. In 1969, W. Boyle [24] and G. Smith [25], as employees of the famous American laboratory «Bell Labs», began to develop a new highly efficient semiconductor device for recording and reading information in which the information would be stored in the form of microscopic «charge clouds» [21].

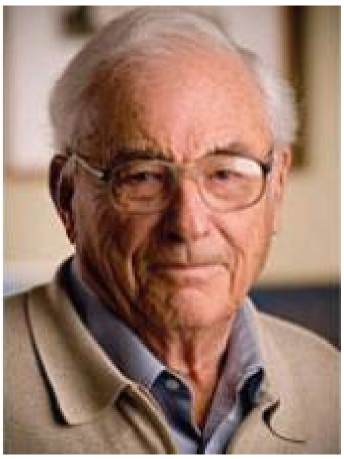

Fig. 18. Prominent American experimental physicist Willard Boyle (1924-2011), Nobel Prize Laureate in physics for 2009

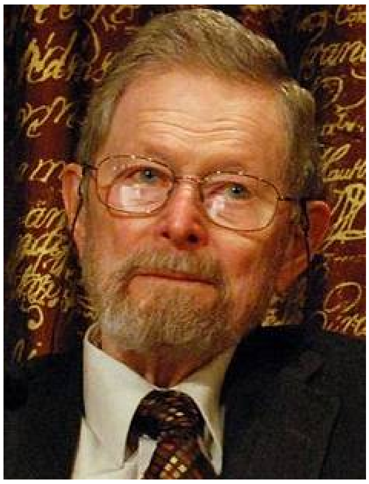

Fig. 19. Prominent American experimental physicist George Elwood Smith, born in 1930, Nobel Prize Laureate in physics for 2009

As a result of research by them in 1969, a semiconductor digital memory cell was proposed, consisting according to Fig. 20 from a plane metal electrode separated by a layer of insulator (silicon dioxide SiO_2) from *p*-type semiconductor (Si silicon) [21]. The role of a bit of information in such a device was played by the «cloud» of electrons that appears in the semiconductor when it is excited.

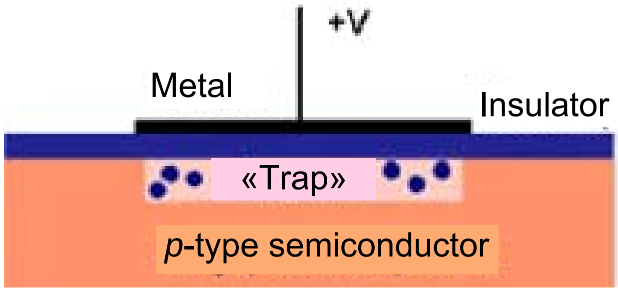

Fig. 20. Schematic representation of the elementary semiconductor cell of digital memory proposed by American physicists W. Boyle and G. Smith [21]

Recall that a semiconductor also possesses such a property as photosensitivity [8, 21]. Light photons (quanta of the electromagnetic field), falling into a semiconductor, generate in it pairs of electrons and holes. In order for such electrons not to be absorbed by holes and stored in a certain region of the semiconductor, W. Boyle and G. Smith proposed to apply an electrical potential of positive polarity to the metal electrode of this cell. Because of their positive charge, the emerging holes «left» out of the small area under this positively charged electrode, and the electrons that appeared to «sit» in it and appeared to be in this local «trap» [21]. It was this «trap» that played the role of a «custodian» of information in a semiconductor cell of digital memory. If there was a small «cloud» of electrons in this «trap», then «1» is written in the cell, if not, «0» [21]. Then, in front of W. Boyle and G. Smith, a serious question arose about reading out information from similar memory cells. For this purpose, they came up with a new method of data transmission – «charge communication» [21]. It was this method that was realized by them in the created CCD-matrix, presented in a simplified form in Fig. 21.

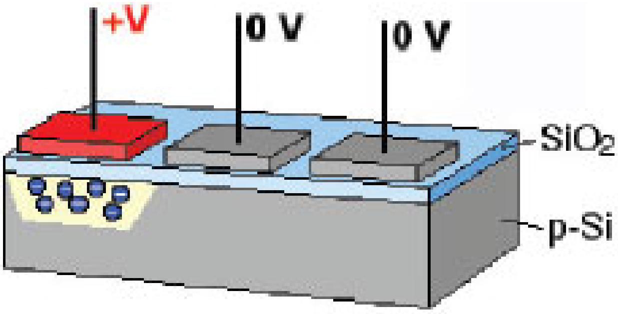

Fig. 21. Schematic representation of a one-dimensional CCD-matrix with three cells of digital memory in a row [21]

By supplying certain voltage *V* to the metal electrodes of the digital memory (with potential $+V$ and the presence of a small «cloud» of electrons) in the digital information memory cells adjacent to the active information cells (for initial voltage V=0 and the absence of a small «cloud» of electrons in their «traps») and then removing the electric voltage from the active cells, it was possible synchronously in a finite number of cycles to shift information in the CCD-matrix to the reader, at the edge of this matrix [21]. The reader will perceive the electric charge coming from the active cell of the digital memory and give the corresponding electrical signal. In the case that the reader will not simply detect the absence or presence of an electric charge in the «trap» of the next memory cell, but also measure the charge accumulated in it, then the output of such a semiconductor circuit produces a real optical image recorded immediately in digital form. It should be noted that some electromagnetic waves that are part of the light signal cells influencing the semiconductor and determining the colors of light emanating from the object of observation will cause the emergence of memory cells of the electrons «caught» by them in the «traps» of memory cells. The name of the «charged-coupled device» (CCD-matrix) reflects the way the electric charge is read in it by shifting from one matrix element to another, gradually filling the camera's buffer register [26]. Further, the voltage from the reader is amplified and fed to the analog-to-digital converter, after which the signal is digitally received for subsequent processing in the camera processor [26]. This matrix, the general view of which is shown in Fig. 22, in fact, is a microchip consisting of millions of photocells that react to light. CCD-matrices made a scientific and technological revolution in photography (they quickly entered our everyday life in the form of compact digital photo and video cameras) [26, 27]. They are widely used in low-dose digital X-ray units and installed on all modern telescopes [27].

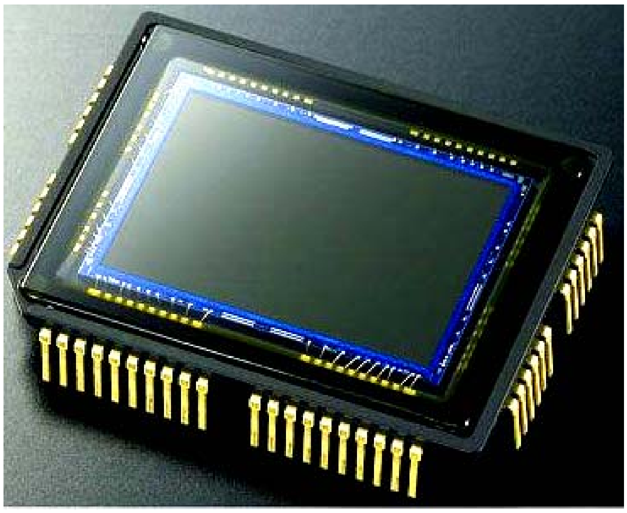
Fig. 22. External view of a modern CCD-matrix [26]

7. Implementation of innovative experiments to create a two-dimensional material graphene. Natives of Russia Andrey Konstantinovich Geim (Fig. 23) and Konstantin Sergeevich Novoselov (Fig. 24), working before his emigration at the Institute of Microelectronics Technology Problems and Highly Pure Materials of the Russian Academy of Sciences (Chernogolovka, Russia), in 2004 in the laboratory of the University of Manchester (Great Britain) opened a fundamentally new material – «graphene» [5, 28]. Graphene is a unique hyperfine material made on the basis of carbon $_6{}^{12}C$ with a graphite layer thickness of one atom [5]. Therefore, because of such a vanishingly small nanometric thickness (of the order of 0.1 nm), it is called a two-dimensional nanocrystalline material belonging to the second-order nanomaterials [5]. Carbon atoms in a thin graphene film are connected to a hexagonal two-dimensional crystal lattice (Fig. 25) [28].


Fig. 23. Prominent Russian-Dutch physicist Andre K. Geim, born in 1948, Nobel Prize Laureate in physics for 2010

Fig. 24. Prominent Russian-British physicist Kostya S. Novoselov, born in 1974, Nobel Prize Laureate in physics for 2010

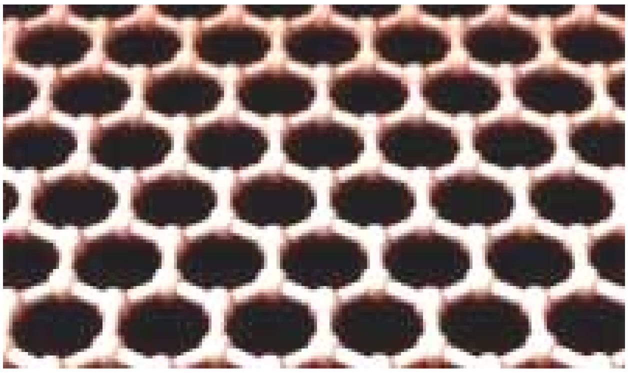

Fig. 25. External view of a fragment of a hexagonal crystal lattice of an atomic layer of graphene, in knots which contains carbon atoms $_6^{12}C$ [28]

Artificially obtained now graphene by chemical deposition of carbon vapor $_6^{12}C$ on the substrate (with its linear dimensions of several centimeters and more) showed surprising physicochemical properties. It is almost transparent material, it has incredible mechanical strength (100 times greater than that of steel) [28].

Graphene has a sufficiently high electrical conductivity (as in the widely used $_{29}^{63}Cu$ copper in electrical engineering) and is characterized by high thermal conductivity [28]. In his first experiments, A.K. Game and K.S. Novoselov miniature samples of new material were obtained with a rectangular piece of electrical graphite and an ordinary adhesive tape – adhesive tape. Applying the scotch to the flat surface of graphite and tearing it off, they found it under a microscope and found plaque-monolayers of carbon [28]. It turns out that everything is simple!

The study of physicochemical properties of graphene and its behavior under external influences of various physical factors (for example, mechanical loads, electric current, electric field, etc.) on it provided a number of possibilities for its technical application. It turned out that a practically transparent graphene conductor is well suited for the production of transparent touch screens, light panels, solar cells and electrochemical current sources, as well as for manufacturing high-frequency transistors with regard to mobile phones and ultrafast optic sensors in fiber communication [28]. The creation of graphene may in the near future lead to the emergence of a new class of nanoelectronics with a record low transistor thickness – up to 10 nm. The use of graphene in computer technology can lead to an increase in the speed of computers thousands of times. He practically does not stop «flying» through him free electrons. Therefore, it has a very low active resistance to electric current [28]. Moreover, the experimental data of A.K. Geim and K.S. Novoselov, as well as ivestigations in the Russian Federation showed that graphene or superthin graphite film can change its electrical resistance (more precisely, increase the electrical conductivity) when an external electric (electro-magnetic) field is applied to them [29]. These results, in the opinion of physicists, point to promising possibilities of using such materials in semiconductor or, more precisely, graphite electronics. In addition, it was found that when stretching graphene (it can be stretched to 20 % of the increase in the original linear dimension), it can turn into a good semiconductor [28]. This is due to the formation in this way of an appropriate «semiconductor» discontinuity in the energy spectrum of its atomic structure (in fact, due to an increase in the energy gap between its valence band and the conduction band) [11]. Such a new property of graphene with its high thermal conductivity opens certain prospects for the use of this new material in converter nanoelectronics. The attempts of physicists of the use of graphene, even as a mass micro-sensor, are interesting [28]. According to preliminary estimates by physicists, such «atomic» scales are capable of weighing even one molecule of substance! Technical problems in this case, experts who try to adapt graphene to the solution of similar super-thin (for us, we can say, just fantastic) physical tasks, certainly enough [28]. At present, many nanotechnologists, in close cooperation with engineering and technical workers, carry out solutions to complex applied problems in the industrial production of graphene with geometric dimensions necessary for modern technology (in fractions, units and tens of meters). Taking into account the exceptional scientific and technical significance for the technosphere of human society of the received and studied by A.K. Geim [30] and KS. Novoslov [31] new unique material, they *«for the basic experiments on the creation of two-dimensional material graphene»* and were awarded the Nobel Prize in physics for 2010 [5, 28].

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