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AN ANTHOLOGY OF THE DISTINGUISHED ACHIEVEMENTS IN SCIENCE AND TECHNIQUE. PART 37: NOBEL PRIZE LAUREATES IN PHYSICS FOR 2000-2004

***Purpose.** Implementation of brief analytical review of the distinguished scientific achievements of the world scientists-physicists, awarded the Nobel bonus on physics for period 2000-2004. **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 the Nobel Prizes on physics for period 2000-2004. **Originality.** Systematization is executed with exposition in the short concentrated form of the known scientific and technical materials, devoted creation of semiconductor geterostructures scientists-physicists, integral microcircuit, to the receipt of condensation of Boze-Einstein in rarefied gases of alkaline metals, finding out a space neutrino, opening of space sources of X-rays, development of theory of superconductors and superfluid liquids and opening of asymptotic freedom in the theory of strong interactions of elementary particles. **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 cooperant of further development of scientific and technical progress in human society.* References 36, figures 16.

Key words: **modern physics, achievements, semiconductor geterostructure, integrated circuit, condensation of Boze-Einstein in rarefied gases of alkaline metals, space neutrino, space sources of X-rays, theory of superconductors and superfluid liquids, asymptotic freedom in the theory of strong interactions of elementary particles**.

Приведен краткий аналитический обзор выдающихся научных достижений ученых мира, отмеченных Нобелевской премией по физике за период 2000-2004 гг. В число таких достижений вошли разработка полупроводниковых гетероструктур для высокочастотной техники и оптоэлектроники, изобретение интегральной микросхемы, получение конденсации Бозе-Эйнштейна в разреженных газах щелочных металлов, обнаружение космических нейтрино, открытие космических источников рентгеновского излучения, разработка теории сверхпроводников и сверхтекучих жидкостей и открытие асимптотической свободы в теории сильных взаимодействий элементарных частиц. Библ. 36, рис. 16.

Ключевые слова: **современная физика, достижения, полупроводниковая гетероструктура, интегральная микросхема, конденсация Бозе-Эйнштейна в разреженных газах щелочных металлов, космические нейтрино, космические источники рентгеновского излучения, теория сверхпроводников и сверхтекучих жидкостей, асимптотическая свобода в теории сильных взаимодействий элементарных частиц.**

Introduction. Nobel Prizes are unique international awards, whose prestige in the world is extremely high. Nobel Laureate in a solemn atmosphere in the presence of the King of Sweden on December 10 every year, beginning in 1901, is awarded a diploma, a gold medal (Fig. 1) and a large cash award, the amount of which has changed over the years. On the front side of the medal is a profile of the famous Swedish engineer-businessman Alfred Nobel (1833-1896), and on the back – along its perimeter the inscription «*Promotes the ennobling of life with discoveries in the field of arts*» [1]. This inscription was taken from the verse of the «Aeneid» by the Roman poet Maron Virgil (70-19 BC). There is also depicted nature in the image of a goddess descending from the clouds and holding in her hand a «cornucopia». Its veil is raised by a woman who embodies the «genius of science».

For the first Nobel Laureate in physics for 1901, Wilhelm Conrad Roentgen (1845-1923), the monetary compensation was 150 thousand SEK. In 2005 this amount was already 10 million SEK or about 1.3 million USD [1].

Fig. 1. External view of the gold medal of the Nobel Prize in physics (on the left – the front side of the coin, and on the right – the reverse, the diameter of the medal is 65 mm and the weight is 205 g) [1]

1. Creation of semiconductor heterostructures for high-frequency engineering and optoelectronics. In 2000, the Nobel Prize in Physics was awarded the results of important studies by the Russian Jaurès Alferov (Fig. 2), the German Herbert Krömer (Fig. 3) and the American Jack Kilby (Fig. 4).

Fig. 2. Prominent Russian physicist, Academician of the Academy of Sciences of the USSR and Russian Academy of Sciences Jaurès Ivanovich Alferov, born in 1930, Nobel Prize Laureate in physics for 2000

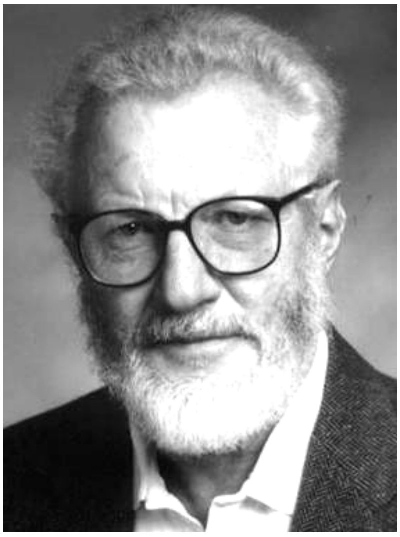

Fig. 3. Prominent German theoretical and experimental physicist Herbert Krömer, born in 1928, Nobel Prize Laureate in physics for 2000

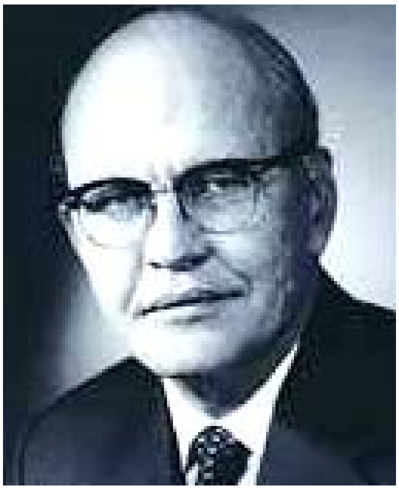

Fig. 4. American physicist and engineer-inventor Jack Kleyr Kilby, born in 1923, Nobel Prize Laureate in physics for 2000

The first two experimental physicists (the Russian J.I. Alferov and the German H. Krömer) of this high premium were awarded «*for the development of physics of semiconductor heterostructures for high-frequency engineering and optoelectronics*», and the third physicist (American engineer-inventor J.K. Kilby) – «*for the contribution to the discovery of the integrated circuit*» [1-4].

Nobel Laureates in physics J.I. Alferov and H. Krömer became one of the founders of modern information-based high-speed technology capable of transmitting a large amount of information in a short period of time. It was for this technique that they discovered and created fast-acting opto- and microelectronic devices based on semiconductor *heterostructures* [2-4]. These devices include high-speed transistors, laser diodes for information transmission systems in fiber-optic networks and powerful efficient light-emitting diodes. It is common knowledge that most semiconductor devices are based on the use of a *p-n*-junction formed between the surfaces (parts) of the same semiconductor with different types of its conductivity («electronic» or «hole»), created by introduction (introduction) into them (these surface or part) of the corresponding impurities (for example, phosphorus atoms P or Boron B) [5, 6]. Recall that the transistor effect was discovered in 1947 by American physicists John Bardin (1908-1991), Walter Brattein (1902-1987) and William Bradford Shockley (1910-1989), and the world's first semiconductor devices-transistors with *p-n-p* junction (crystalline germanium triodes-amplifiers with point contact) were created in 1949 [4]. In 1956, the noted US scientist-physicist «*for researching semiconductors and discovering the transistor effect*» was awarded the Nobel Prize in physics [1]. In addition, W.B. Shockley in 1949 predicted the possibility of implementing a semiconductor diode with a *p-n-* junction and developed his theory, and in 1951 he proposed using *heterojunctions* in transistors [1]. The *heterojunction* in the semiconductor structure is essentially a contact zone between two semiconductors of different chemical composition with different widths of their forbidden energy bands [4, 7]. The practical realization of *heterojunctions* made it possible to create electronic and optoelectronic devices of extremely small sizes up to atomic scales. Attempts to create such highly effective *heterojunctions* in the physics and technology of semiconductors for many years remained unsuccessful. To create an ideal *heterojunction*, physicists had to pick up two different semiconductors with practically the same atomic size as the elementary cells of their crystal lattices. The first in the world to solve this problematic physico-technical problem in the late 1960s was succeeded by our native scientist – then Candidate of Physical and Mathematical Sciences J.I. Alferov (his PhD. Thesis, devoted to the acquisition of ultrapure germanium and silicon crystals, he defended in 1961), who worked in the world-famous Leningrad Physicotechnical Institute (LPhTI) named after A.F. Ioffe [4, 8]. Note that later from 1987 to 2003 Doctor of Physical and Mathematical Sciences (he defended his Doctoral Thesis in 1970 in LPhTI on the results of studies of *heterojunctions* in semiconductors) J.I. Alferov, becoming in 1979 Academician of the Russian Academy of Sciences (in the period 1990-2013 he was also Vice-President of the Academy of Sciences of the USSR and the Russian Academy of Sciences), was the Director of this Institute [8, 9]. He and his colleagues at the LPhTI named after A.F. Ioffe by 1970, based on gallium Ga and arsenic As, created an effective *heterojunction* from semiconductors with close periods of the crystal lattice – the GaAs type and then, using aluminum Al, a triple semiconducting compound with a *heterojunction* of the AlGaAs type [4]. The development of technology for obtaining *heterojunctions* by epitaxial growth in vacuum of a crystalline film of one semiconductor on the surface of another has led to a further miniaturization of radio electronic devices up to nanometric dimensions [4, 8]. It was found that in a semiconductor active medium with linear dimensions (thickness) from 50 μm to 1 mm, it was possible to achieve very high optical light amplification indices necessary for the creation of high-power laser radiation in the field of quantum electronics. It should be noted that quantum transitions between the energy levels of a *heterostructural* semiconductor are used in semiconductor lasers [8]. However, physicists for a long time could not solve the very important problem connected with the fact that semiconductor lasers worked steadily only at low temperatures. Thus, the first semiconductor lasers created on Ga gallium and arsenic compounds As worked in the low-temperature range from 4 to 20 K [8]. Thanks to the development of J.I. Alferov semiconductor lasers have reliably earned (since 1969) and at room temperatures. Soviet scientists, physicists, actively worked alongside J.I. Alferov understood that under conditions of intense competition with Western firms, the relevant domestic developments in the field of semiconductor physics and technology had to be carried out in extremely short terms. On the example of the selfless labor of the outstanding modern scientist and physicist J.I. Alferov is convinced that success in life and science comes not just to a talented person, but to a talented and hard-working person [2, 4, 9]. Unseen prospects are now being opened to people thanks to new ways of processing and transmitting information, including optoelectronics. Microelectronics is replaced by nanoelectronics. The above-mentioned Nobel Laureates for 2000 [1] made their significant contribution to these most important fields of physics.

We note out that in 1952 H. Krömer defended his doctoral dissertation at the University of Göttingen on the subject of studying the effect of «hot» electrons in transistors [3]. In the 1950s he developed the theory of a bipolar transistor made on the basis of *heterostructures* and which could operate in a gigahertz frequency range. In 1963 he was independent of the Soviet scientist-physicist J.I. Alferov developed the physical foundations for the construction of semiconductor lasers using double *heterostructures*. These developments for many years were ahead of the development of radio and quantum electronics [3]. They found their practical application only in the period of the 1970-1980s with the development of atomic (molecular) *epitaxy* – oriented growth in a vacuum of one crystal on the surface of another (substrate) in the world [3, 10]. In the mid-1970s, H. Krömer, working as a Professor at the University of California, Santa Barbara, USA, studied molecular combinations of semiconductor *heterostructures* on a silicon substrate, including Ga gallium and phosphorus P, a compound of the form GaP, using molecular *epitaxy* as weel as proposed by J.I. Alferov at the LPhTI named after A.F. Ioffe compound of the form GaAs. Since 1985 H. Krömer has directed his research interests to the study of other semiconductor *heterostructures*, including indium In combinations with arsenic As is a compound of the type InAs, Ga gallium with antimony Sb, a compound of the form GaSb and aluminum Al with antimony. Sb is a compound of the AlSb type [3, 8].

2. Creating an integrated circuit. First of all, it should be noted that under the *integrated circuit* in low-current electronics is meant a microminiature electronic device whose elements are inseparably linked together constructively, technologically and electrically [10]. Microelectronics, grown on integrated circuits, has become the basis of many modern technologies. Therefore, it is not without reason that 1/2 of the Nobel Prize in physics for 2000 in the field of fundamental works on information and communication technologies was awarded by the Royal Swedish Academy of Sciences to American physicist and inventor J. K. Kilby (Texas Instruments, Dallas, USA) an integrated microcircuit. And all this work began in 1958, when J.K. Kilby created the first elementary integrated circuit on a germanium crystal. In February 1959, he filed an application for an integrated circuit to the United States Patent Office (a patent was issued to him in 1964), in which the transistor was manufactured with layer-by-layer *p-n-p* or *n-p-n* junctions [1, 8]. The fundamental development of the talented physicist and engineer-inventor J.K. Kilby proved to be truly priceless for the rapid development of modern information technologies in our entire world. At present, microchips (microcircuits) produce a wide range of electronic devices, ranging from watches to computers, managing complex ground and space objects. According to the apt statement of the member of the above-mentioned Academy of Sciences G. Grimmais [8]: «…*Without the development of J.K. Kilby on integrated circuits, it would be impossible to create personal computers, and without the development of J.I. Alferov* *and H. Krömer on semiconductor heterostructures would be impossible to quickly transmit huge information flows through communication satellites.*»

3. The discovery of Bose-Einstein condensation. The discovery of a new state of matter in extreme temperature conditions – the *Bose-Einstein condensate* [11] – in 1995 by American and German experimental physicists was another penetration of the inquisitive human mind into the secrets of the microscopic world of matter surrounding us. These pioneering scientists were talented physicists – Americans Eric Allin Cornell (Fig. 5), Carl Wieman (Fig. 6) and German Wolfgang Ketterle (Fig. 7) [1].

Fig. 5. Prominent American experimental physicist Eric Allin Cornell, born in 1961, Nobel Prize Laureate in physics for 2001

Fig. 6. Prominent American experimental physicist Carl Wieman, born in 1951, Nobel Prize Laureate in physics for 2001

The material substance, first obtained experimentally by working at various American research institutions (E.A. Cornell at the National Institute of Standards, K. Wieman at the University of Colorado, W. Ketterle at the Massachusetts Institute of Technology), these physicists as a result of the so-called condensation Bose-Einstein at ultralow temperatures (about $20 \cdot 10^{-9}$ K), in nature itself does not exist [12-15]. The possibility of the existence of matter in such a new physical state was predicted in the 1920s by the outstanding theoretical physicists from India Shatendranat Bose (1894-1974) and Germany Albert Einstein (1879-1955) [1, 16]. In June 1995 E.A. Cornell and C. Wieman experimentally obtained a small «speck» of Bose-Einstein substance, consisting of 2000 supercooled atoms of the alkaline rubidium element Rb.

Fig. 7. Prominent German experimental physicist Wolfgang Ketterle, born in 1957, Nobel Prize Laureate in physics for 2001

To obtain the Bose-Einstein condensation in the gas of this metal, for which it is characteristic that at practically low final temperature practically all the atoms (molecules) entering it make up one energy level corresponding to their zero momentum (the amount of motion) The experimenters «captured» the atoms of the alkaline chemical element rubidium Rb with «magnetic traps,» and then by their (atoms) super-deep cooling (to temperatures of the order of 10^{-5} K) the «web» of laser beams slowed down their motion [15]. We note that in the «magnetic traps» they used, the interaction of these atoms with the walls of a low-temperature vessel was excluded (the magnetic field of a parabolic configuration played the role of the wall of such a vessel). Using further the technique of physical experiment, similar to the usual evaporation («evaporative cooling method»), these physicists got rid of the most «hot» (fast) atoms and worked with these atoms in a state close to absolute zero temperature (at temperatures of the order of 10^{-8} K) [11, 15]. As a result of such hyperfine optical manipulations (nothing else could be introduced into the working volume of the condensed gas – otherwise, a unique condensed medium «died» [17]) at an atomic level at a fantastically low temperature (about $2 \cdot 10^{-8}$ K) succeeded to obtain a Bose-Einstein condensation of a rarefied gas with rubidium atoms Rb [15, 17]. In 1995, several months later, W. Ketterle succeeded not only in replicating the scientific results of E.A. Cornell and C. Wieman, but also obtained by using in such low-temperature experiments another alkaline element from the periodic system of chemical elements by D.I. Mendeleev sodium Na significantly larger amount of Bose-Einstein condensate (up to 10^5 supercooled atoms of this element) [17]. In addition, in 1997 W. Ketterle, in studying this unique Bose-Einstein condensate of a rarefied gas of alkali metal (with a density of the order of 10^{21} m^{-3}), showed that the behavior of sodium Na atoms in such a condensate is completely consistent and in it a cluster of these atoms Fluctuates in unison and coherently. He managed to form a kind of laser «atomic ray» consisting of light particles (photons) rather than light quasiparticles (photons) from the new aggregate state of matter [15]. Professor of Physics Daniel Kleppner on the discovery of Bose-Einstein condensation said the following noteworthy words [15]: *«... Demonstration of the fact that atoms can exist in a kind of quantum-mechanical unison state will have a significant impact on many sections of physical knowledge. The picture of the fusion of atomic waves and the realization, so to speak, of an atomic laser, amazed the scientific imagination of many physicists»*. Scientists-physicists actually took 70 years to experimentally confirm the Bose-Einstein condensate theory proposed in 1924-1925 [14]. Where can this applied new discovery of outstanding physicists find application? First of all, when creating super-precision atomic clocks, ultraminiature electronic circuits and quantum computers with unimaginable speed [15, 17]. In 2001 E.A. Cornell, C. Wieman and W. Ketterle «*for the experimental observation of Bose-Einstein condensation in rarefied gases of alkali metal atoms and for the first fundamental studies of the properties of such condensates*» were awarded the Nobel Prize in physics [1]. About this important event in the world of science Academician of the Russian Academy of Sciences Yu.M. Kagan (Research Center «Kurchatov Institute», RF) said [17]: *«... the Nobel Prize in physics for 2001 marked outstanding work, which is destined to play a significant role in modern science»*.

4. Detection of cosmic neutrinos. In 2002, the American physicist-chemist Raymond Davis Jr. (Fig. 8) and the Japanese experimental physicist Masatosi Kosiba (Fig. 9) «*for the creation of neutrino astronomy*» and the Italian experimental physicist Riccardo Giacconi (Fig. 10) «*for the discovery of cosmic X-ray sources*» became the next Nobel Prize Laureates [18]. After defending in 1942 at the Yale University of the USA a doctoral dissertation on the subject from the field of physical chemistry and service in the US Army associated with the testing of chemical weapons, R. Davis Jr. was at the Brookhaven National Laboratory dealing with the peaceful use of atomic energy [19]. Here he decided to take up the physics of neutrinos, one of the nine absolutely stable particles [1, 20].

Fig. 8. Prominent American physicist-chemist Raymond Davis Jr. (1914-2006), Nobel Prize Laureate in physics for 2002

Fig. 9. Prominent Japanese experimental physicist Masatosi Kosiba, born in 1926, Nobel Prize Laureate in physics for 2002

Fig. 10. Prominent Italian hysicist-astronomer Riccardo Giacconi, born in 1931, Nobel Prize Laureate in physics for 2002

Note that in the late 1940s neutrinos existed only in the form of a theoretical postulate. Experimental results in the physics of elementary particles on this subject in the world were not yet. In his first nuclear experiments,

R. Davis Jr. decided to implement the idea of 1946 by the Italian theoretical physicist Bruno Pontecorvo (1913-1993) who later became a famous Soviet physicist in the field of nuclear physics (Academician of the Academy of Sciences of the USSR since 1964 and the Russian Academy of Sciences since 1991) [1]. This idea consisted in recording neutrinos emerging in the core of nuclear reactors using a nuclear reaction of the following form [1, 19]: ${}_{17}^{37}Cl + \nu_e \rightarrow {}_{18}^{37}Ar + e^-$. This reaction, involving the capture of the electron *neutrino* ν_e by the chlorine isotope, should lead to the formation of an isotope of argon and an electron e^-. In 1955, as a chlorine-containing medium trapping the *neutrino* ν_e, he used a container with a volume much more than 3.78 m^3 filled with carbon tetrachloride and located near the nuclear power reactor at the US object in the Savannah River Site area [19]. However, in these *neutrino* ν_e detection schemes, the final result for scientists turned out to be negative for the reason that *antineutrinos* $\nu_e^{\sim}$ appeared in the nuclear reactors used, and experimental setup of R. Davis Jr. was sensitive only to the *neutrino* ν_e. However, the purposeful R. Davis-Jr. in the 1960s decided to use his experimental method for detecting and measuring solar (cosmic) *neutrinos* ν_e in the radiation flux from the Sun. To this end, an installation with a chlorine-containing liquid (perchlorethylene) was already installed at a depth of 1400 m in the deep mine of Homestake, located near the city of Lid (South Dakota, South Dakota, USA) with a volume of 378 m^3 [19]. In 1970, using this unique experimental setup and the chlorine-argon method of detecting elementary particles, R. Davis-Jr. was able for the first time in the world register solar *neutrinos* ν_e. Moreover, he experimentally showed that the velocity of a nuclear reaction of the form ${}_{17}^{37}Cl + \nu_e \rightarrow {}_{18}^{37}Ar + e^-$ is 2.1 ± 0.3 of solar neutrino units (this was equivalent to the flow in a chlorine-containing capacity of the specified volume of one nuclear interaction in 1 s per 10^{36} atoms of the nuclear target) [1]. The probability of such a nuclear act of interaction was negligible. R. Davis Jr. was able to convince the world scientific community of the real existence in the microcosm of the matter of events occurring at a frequency of several tens of times a month. Therefore R. Davis Jr. is rightfully considered one of the founders of neutrino astrophysics.

In 1955, M. Kosiba, who graduated from the University of Tokyo in 1951, defended his doctoral dissertation at the University of Rochester, on a topic devoted to ultrahigh-energy phenomena in cosmic rays [21]. In the 1970s, these scientific studies and interests in the field of high-energy physics led M. Kosiba to an attempt to deepen our knowledge of such representatives of the microworld of matter as *muons* and *neutrinos* [20]. He designed the «Kamiokande» elementary particle detector, originally designed to register in the frame of the German-Japanese project JADE decay products on the nuclear target of accelerated protons, was used to detect cosmic *neutrinos* ν_e [21] in the DESY proton accelerator (Hamburg, Germany). In the process of an explosion in the space of the supernova 1987A, he succeeded in registering 12 pieces on the indicated detector. Cosmic *neutrinos* ν_e, and nine of which he recorded in the first two seconds of this grand cosmic phenomenon. These experimental results were the first direct experimental data confirming the theories of processes developed earlier by astrophysicists that occur during the collapse of the stars of our Universe. In particular, the theory of «neutrino cooling» of these «living» billions of years and sometime «dying» unique cosmic objects unique in size and internal processes [22] regularly observed by us on the night sky.

5. Discovery of cosmic X-ray sources. To begin with, we point out that in 1960 astronomers learned to obtain the image of the Sun in the X-ray range for the first time. In 1962, a group of US scientists, including the future Nobel Laureate R. Giacconi, with the help of installed on a neglected and existed in the near-Earth space about 6 minutes rocket the Geiger counter [1, 20], it was possible to open the first X-ray source outside the solar system (star X-1 in the constellation of Scorpio) [23].

Inspired by this success, R. Giacconi initiated the development and creation of the satellite «UHURU» (this name in translation from the African language «swahili» means «FREEDOM» [10, 23]) for X-ray astronomy launched into near-earth orbit in 1970. This US satellite Turned out to be the most technically advanced astronomical device in the world in the 1970s [23]. It was with his help that astronomical scientists succeeded in discovering in space more than 400 new astronomical objects, including the first «X-ray pulsars» and «black holes» [24]. A new success of R. Giacconi was the launch in 1978 of the orbital X-ray observatory «EINSTEIN» created under his scientific guidance in the USA (it was named after the outstanding German-American theoretical physicist Albert Einstein [1, 16]). The sensitivity of the X-ray equipment of this observatory was so high that it made it possible to detect objects in outer space with luminosity millions of times weaker than from the above-mentioned X-1 star. In 1990, under the scientific leadership of R. Giacconi, the world's largest space telescope «HUBBLE» named after the famous American astronomer Edwin Powell Hubble (1889-1953), was created and put into orbit around Earth [24]. After the elimination in 1993 by American astronauts of mistakes made during its assembly in the terrestrial conditions and the defects caused by them in its work on the unique images received with its help and transmitted to Earth, humanity was faced with a completely new, magnificent in clarity and resolution majestic picture of ours Universe [23]. In 1999, again under the inspirational creative start of R. Giacconi, a new space X-ray observatory, «CHANDRA», was built in the USA, which was named after the famous American astrophysicist and Nobel Prize Laureate in physics for 1983 («*for studying the structure and evolution of stars*») S. Chandrasekhar (1910-1995) [1, 23]. For several years of work in the near-earth orbit, its unique equipment has made it possible to detect supermassive «black holes» in the nuclei of a number of galaxies and x-ray «pulsars» as well as to obtain unique images of many stars, nebulae and other heavenly objects In X-rays that are invisible to the human eye [23]. The scientific contribution of astronomer R. Giacconi to astrophysics and the invention of original X-ray telescopes that led to the discovery of sources of intense cosmic X-rays and the creation of a new section in astronomical science – X-ray astronomy, and was appreciated in 2002 by members of the Nobel Committee of the Swedish Royal Academy of Sciences [25].

6. Creation of the theory of superconductors and superfluid liquids. In 2003, the Nobel Prize in physics was awarded to three outstanding theoretical physicists «*for the pioneer contribution to the theory of superconductors and superfluid liquids*» [25, 26]. The laureates of this prestigious award were [1]: Russian-American Alexej Alexeevich Abrikosov (Fig. 11), Russian Vitaly Lazarevich Ginzburg (Fig. 12) and British-American Anthony James Leggett (Fig. 13). A.A. Abrikosov, working at the Institute of Physical Problems of the Academy of Sciences of the USSR (Moscow), in 1955 defended his Doctoral dissertation in the field of high-energy quantum electrodynamics [26]. Further, he directed his creative efforts to unravel the secrets of the superconductivity of matter. By that time, the three outstanding American theoretical physicists John Bardin (1908-1991), Leon Cooper (born in 1930), and John Schrieffer (born in 1931) had already created a microscopic theory of material superconductivity (the BCS theory) awarded in 1972 with the Nobel Prize in physics [1, 27]. This theory for the superconductivity of pure metals (superconductors of the first kind [26], based on the idea of «Cooper electronic pairs») was not able to substantiate the physical mechanisms of the appearance of this phenomenon in alloys (superconductors of the second type [26]) having practical application and preserving superconducting properties under the action of strong magnetic fields on them with magnetic flux density of 1 T and more (for a magnetic field strength of 10 kOe and higher) [26-29]. A.A. Abrikosov was able to explain the properties of superconductors of the second kind [26].

Developing the theoretical approaches presented in 1950 by well-known Soviet physicists in the phenomenological theory of Ginzburg-Landau superconductivity, in 1952 he used the regular lattice of magnetic lines to explain this phenomenon in superconductors of the second kind («the Abrikosov vortex lattice») surrounded by circular microcurrents [30]. He put forward a new idea of the existence in hyperconductors of hyperfine regions of the normal phase [1, 26, 27].

Fig 11. Prominent Russian-Americal theoretical physicist, Academician of the Academy of Sciences of the USSR and Russian Academy of Sciences Alexej Alexeevich Abrikosov, born in 1928, Nobel Prize Laureate in physics for 2003

Fig. 12. Prominent Russian theoretical physicist, Academician of the Academy of Sciences of the USSR and Russian Academy of Sciences Vitaly Lazarevich Ginzburg (1916-2009), Nobel Prize Laureate in physics for 2003

Fig 13. Prominent British-American theoretical physicist Anthony James Leggett, born in 1938 г, Nobel Prize Laureate in physics for 2003

In 1957, A.A. Abrikosov, refining his scientific constructs in the field under consideration, developed a theory according to which in normal type II superconductors there are simultaneously normal and superconducting phases [1, 27]. He carried out a detailed calculation of the structure of such a «mixed» state in superconductors of the second kind, which showed that the normal phase in them arises in the form of thin filaments («Abrikosov vortices»). These filaments, having a thickness comparable to the penetration depth Δ_M of the magnetic field in a superconductor of this kind (as a rule, $\Delta_M \approx 10$ nm [27]) permeate the entire volume of the material of the superconductor. Moreover, as the strength of the external magnetic field increases, the concentration of these filaments increases in it [31]. The zone of normal regions also grows accordingly. At a critical level of magnetic field strength, a material of type II superconductor loses its superconducting properties. In 1960, A.A. Abrikosov together with the future Academician of the Academy of Sciences of the USSR (since 1987) and Russian Academy of Sciences (since 1991) L.P. Gorkov created a theory with respect to superconductors containing magnetic impurities in their composition, and also predicted a new phenomenon of gapless superconductivity [1, 27].

V.L. Ginzburg, working since 1940 at the theoretical Department of the Institute of Physics named after P.N. Lebedev of the Academy of Sciences of the USSR (PhIAN), in 1942 (in difficult years for citizens and scientists of the Soviet state and the military evacuation period of the PhIAN in Kazan) defended his Doctoral dissertation on the theory of microparticles with higher spins [32]. He repeatedly asked the relevant military authorities to go to the front as a volunteer, but his requests were not satisfied (apparently, he was destined to fulfill in life something different and no less important). Since 1943, he switched at the PhIAN on topics related to the nature of the phenomenon of superconductivity of matter, which at that time had no physical explanation. In 1950, V.L. Ginzburg, together with the future Nobel Prize winner in physics in 1962 («*for pioneering research in the theory of the condensed state of matter, especially liquid helium*» [1]), Academician of the Academy of Sciences of the USSR Lev Davidovich Landau, developed a theory of superconductivity («Ginzburg-Landau theory») [32]. This theoretical development is considered the most significant scientific contribution of V.L. Ginzburg in the physical nature of the phenomenon of superconductivity. In 1958, V.L. Ginzburg, together with the future Academician of the Academy of Sciences of the USSR (since 1990) and Russian Academy of Sciences (since 1991) L.P. Pitaevsky developed a phenomenological theory of superfluidity of matter (the «Ginzburg-Pitaevsky theory») [1, 32]. Investigations in the physics of superfluid liquids allow humanity to penetrate deeper into the complex and often unknown processes occurring in matter at ultralow temperatures in the lowest and orderly energy state of its atoms.

In 1964, A.J. Leggett defended his doctoral dissertation in the field of condensed matter physics related to high-temperature superconductivity and superfluidity of matter at the University of Oxford (Oxford, England) and from 1983 worked as a professor of theoretical physics at the University of Illinois, Illinois, USA. We point out that A.J. Leggett developed a theory of superfluidity of the light helium isotope ${}_2^3He$ at ultralow temperatures [1]. He carried out deep theoretical studies of macroscopic quantum coherence and processes of scattering of matter waves in a number of quantum systems important for practice. He initiated theoretical studies of macroscopic dissipative systems and the application of special condensed systems to test the basic assumptions of quantum mechanics (in particular, the possibility of extending the quantum formalism to the macroscopic level) [1].

7. Discovery of asymptotic freedom in the theory of strong interactions of elementary particles. The Nobel Prize in hysics for 2004 was awarded to three American theoretical physicists «*for the discovery of asymptotic freedom in the theory of strong interactions*» [33]: David Jonathan Gross (Fig. 14), Hugh David Politzer (Fig. 15) and Frank Antony Wilczek (Fig. 16). In 1966, D.J. Gross defended his Doctoral Thesis in physics at the University of California (Berkeley, USA) [33, 34].

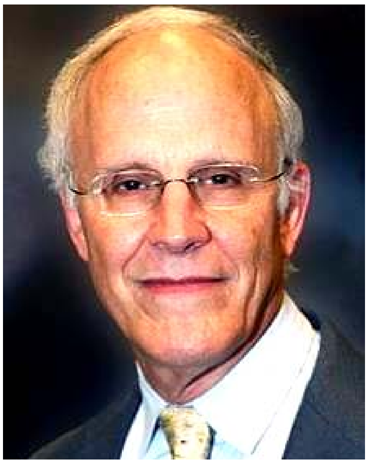

Fig. 14. Prominent American theoretical physicist David Jonathan Gross, born in 1941, Nobel Prize Laureate in physics for 2004

D.J. Gross in 1973 together with his PhD student F.A. Wilczek discovered «asymptotic freedom», according to which a strong interaction between *quarks* weakens with a decrease in the distance between them [34, 35]. Note that under «*quarks*» in the physics of elementary particles we mean hypothetical particles (they are not directly fixed in the world by a direct experimental method) with a fractional electric charge (1/3 and 2/3 of the elementary negative electron charge $e^{-}=1.602\cdot10^{-19}$ C [20]) [10]. According to one of the proposed hypotheses, it is believed that, probably, from *quarks* elementary particles (*hadrons*) consist which participate in the microworld in strong interactions.

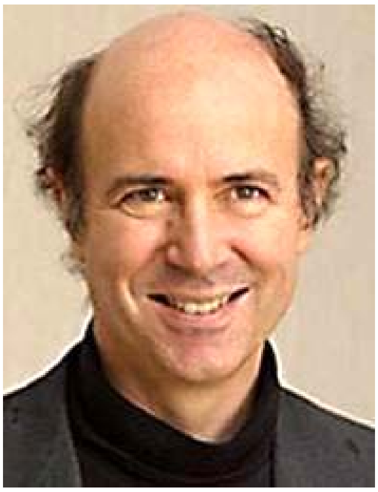

Fig. 15. Prominent American theoretical physicist Hugh David Politzer, born in 1949, Nobel Prize Laureate in physics for 2004

Fig. 16. Prominent American theoretical physicist Frank Anthony Wilczek, born in 1951, Nobel Prize Laureate in physics for 2004

According to theoretical data by D.J. Gross and F.A. Wilczek obtained by them at Princeton University (Princeton, USA), in the case of a very close arrangement of *quarks*, they should behave like free particles. This is precisely the phenomenon of «asymptotic freedom» discovered by theoretical physicists for the considered elementary particles of a new type [1]. Similar results were obtained in 1973 in theoretical studies of the interaction of *quarks*, and by H.D. Politzer who worked at Harvard University in the USA [36].

Further developments in the physics of elementary particles and high-energy physics have shown that the phenomenon of «asymptotic freedom», discovered by American theoretical physicists, played a key role in the development of quantum chromodynamics, which deals with the theoretical aspects of strong interactions of representatives of the microworld [36].

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