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The nanostructured or colloidal state is the fifth aggregate state of substance

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Abstract

The article shows that the basis of nanotechnology is the discovery in the early 20th century of a colloidal (ultradispersed) or nanostructured state of substance, in which the dimensions of physical and/or chemical dispersed phases distributed in the dispersion medium of a substance have dimensions less than 100 nanometers, at least in one coordinate. Since any substance, regardless of its chemical composition, can be converted to a nanostructured state, this state should be considered the fifth aggregate state of substance, along with the solid, liquid, gaseous and plasma states. The transfer of substances and / or materials to the nanostructured state can be carried out by numerous different methods, which defines a wide range of nanotechnologies. And since the nanostructured state is a new aggregate state of substance, it has unique physical and chemical properties compared to the usual solid substance.

Keywords: Substance, Nanotechnologies, Dispersed phase, Dispersion medium, Aggregate states of a substance, Colloidal, Ultradispersed or nanostructured state of a substance.

Introduction

The author don't agree with the opinion presented in many books and articles that the founder of nanotechnologies, to be the first to formulate their principles in 1959, is the well-known american physicist, Nobel Prize winner Richard Feynman [1]. The colloidal ultradispersed or, as they say now, nanostructured level of organization of substance with the dimensions of objects, at least on one axis of measurement, in the sub100 nanometer region was actually discovered by professor of the St. Petersburg Mining Institute Peter von Weimarn in 1910. He formulated this discovery as a fundamental principle of the universality of the colloidal state of substance [2]: **"The colloidal state is not separate, due to any features of the composition of the substance. Under certain conditions, each substance can be obtained in a colloidal state".**

Thus, any substance can be obtained in the form of a colloid and, therefore, it is necessary to talk not about colloidal substances, but about the colloid state of substances [3].

However, the contemporaries of P. von Weimarn and their followers considered that in colloidal systems, dispersed particles and dispersion media can form either different substances or one substance in different aggregate states, so it was decided that colloids are heterogeneous systems containing one of the substances in the ultradispersed state [4].

In fact, the presence of defects and chemical contaminants (foreign atoms) in all solids and materials allows us to consider them as heterogeneous dispersed systems in the same aggregate state, formed from two or more physical phases - regions of the same chemical composition with different internal structure geometry and/or chemical phases - regions of different chemical composition separated by partition surfaces [5].

Therefore, as proved by the author in [3]. **The principle of universality requires the introduction of a colloidal or nanostructured state of substance as the fifth aggregate state in our natural World,** in addition to the solid, liquid, gaseous and plasma states of substance.

In addition, the author assumes that, based on the general laws of development of the condensed state of substance, there must also be a liquid nanostructured state of substance.

Properties of the substance

Substance in nature is divided into physical substance and chemical substance [6, 7]. The physical substance includes elementary and subatomic (sub-nuclear) particles and antiparticles that are not associated in atomic form. The difference between them is only in the direction of movement of their own internal energy carriers (in the direction of spin) [8]. Thus, everything that exists in the natural World is a specific energy (energy-informational) form or state of a unified Matter, so there are no types of Matter and Antimatter [5, 8].

A chemical substance, usually referred to simply as a substance, refers to particles and objects associated in atomic form that contain atomic nuclei and electrons. Naturally, the atomic nuclei of a chemical substance include elementary particles and antiparticles of a physical substance.

Classical chemistry postulates [7]: **"the properties of substances in the condensed (solid or liquid) state are determined by the properties of the atoms or molecules that form these substances.**" The same, but in other words, is stated by classical physics, which "**does not define the limits of the structural divisibility of substance, but establishes that the elements that determine the basic physical properties of substance are atoms, molecules, and ions" [6].**

However, as shown by the author on the basis of the system approach and deductive method in the works [3, 5]: **"since substances are systems, their physical and chemical properties cannot be determined by virtue of the integrity (emergence) of systems only by the properties of their elements: atoms, ions, radicals and molecules».** The physical and chemical properties of a substance in the condensed state are determined by the size, shape, and mutual location in space of structural units (nano objects) - groups of atoms, ions, or molecules that form its spatial structure (internal structure), and depend on the conditions for transferring the substance to the condensed state, as well as the conditions for its formation and operation in this state.

For example, high pressures change the internal structure of solids without changing their chemical composition, but this leads to changes in their physical and chemical properties. The germanium (Ge) semiconductor becomes a metal and the ytterbium (Yb) metal turns into a semiconductor at pressures greater than 120×10^3 atmospheres [6]. These effects are especially evident when solid films are deposited in a vacuum, when the condensation conditions are not only temperature and pressure, but also the energy of the deposited atoms and molecules, the chemical nature of the substrate, the degree of purity and the class of treatment of its surface [5].

Therefore, it is necessary to clarify the position given in the educational and reference chemical literature [7]: **"a molecular substance remains chemically unchanged as long as the composition and structure of its molecules remain unchanged, and a non-molecular substance-as long as its composition and the nature of the bonds between atoms remain unchanged".** This provision can only be applied to substances in the gaseous and partially liquid state. For solids and materials, it should be formulated as [3]: **"any substance (material) in the solid state remains chemically unchanged as long as its composition and internal structure (structure) remain unchanged".**

Nanostructuring of substances and the definition of nanotechnologies

The conditions for obtaining, forming, and processing solid substances and materials determine the shape, size, and density of defects, physical and chemical phases, as well as the area of interphase interfaces within their volume, which together determine the structure and, consequently, their physical and chemical properties. The transfer of a substance to a colloidal (ultradispersed) state is called nanostructuring, which should be understood not only as obtaining it in the form of free nanoparticles and nanolayers, but also as creating and forming nanostructures and nanolayers on the surface of the substance, and in the volume of physical and/or chemical nanophases, as well as nanopoles (pores), which can be considered as a kind of nanoobjects separated from the rest of the structure by interface surfaces.

Substances, materials, and media in the colloidal state with the sizes of phases, particles, structures, and layers in the range (1.0 - 100) nm are called **nanosystems**, and the particles, structures, layers (films), phases, and cavities themselves are called nanoparticles, nanostructures, nanolayers, (nanofilms), nanophases, and nanopores, respectively, and their totality is usually referred to as **nanoobjects.**

Technology, in the production sense, refers to methods of controlled conversion of substances, energy, and information in the process of manufacturing products, processing and recycling materials, assembling finished products, quality control, and management [9]. Then: **nanotechnologies** are methods for the controlled production of substances, materials and media in a nanostructured (colloidal, ultradispersed) state [3].

The nanostructured state of any substance has its own unique physical and chemical properties. The unique behavior of a nanostructured substance represents it's a new aggregate state. Impact on nanostructured substance triggers systemic changes in the entire mass of this substance (in the entire nanostructured system). Growing large crystals from small seedings and thick epitaxial films on seed monolayers clearly confirms this position. Therefore, the production of nanostructured substances and materials is always accompanied by the study of these properties and measurement of characteristics and subsequent use in various branches of science, technology and industry.

Thus, by choosing and controlling the conditions for obtaining, forming and processing solids, it's can in practice always be transferred to a nanostructured aggregate state with new physical and chemical properties compared to analogues with micro - and macrostructure, i.e., to obtain sets of their artificial (non-existing in nature) allotropic or polymorphic modifications [3, 10].

Development of nanotechnologies

In 1974, the term "nanotechnologies" was introduced to science by professor Norio Taniguchi of the University of Tokyo, and in the following years it became very widespread [11, 12]. However, as noted in the introduction, the first nanotechnology was **colloidal chemistry,** discovered by Peter von Weimarn in 1910. In any chemistry textbook, starting from the 30s of the 20th century, one can read [13]: **"between the world of molecules and microscopically visible particles there is a special state of substance with complex inherent in this state of new physical and chemical properties is colloidal (ultradispersed) state of substance".** The colloidal state of the substance is characterized by the degree of dispersion (fragmentation) of the dispersed phase in the dispersion medium in the region (10^5 – 10^7) cm^{-1}. The degree of dispersion D is inversely proportional to the size b of the dispersed phase D = 1/b. Therefore, in colloidal systems, the films have a thickness, and the fibers and particles have a diameter size in the range (1.0 - 100) nm **(table 1)**, which fully corresponds to the modern nanostructured level [13].

Classification of the state of a substance by its degree of dispersion

Table 1

State substance	Fragmentation of the substance	Size particles, nm	Degree dispersion D, cm^{-1}	Number of atoms in one particle, pcs	Means observations
Macroscopic	Coarse-grained	10^7 - 10^5	10^0 - 10^2	>10^{18}	Naked eye
Microscopic	Fine-disperse	10^5 - 10^2	10^2 - 10^5	>10^9	Optical microscope
Colloidal (or nanostructured)	Ultradisperse	10^2 - 10^0	10^5 - 10^7	10^9 - 10^2	Ultra microscopes, REM, TEM, SPM
Molecular, atomic and ionic	Molecular, atomic and ionic	10^0 - 10^{-1}	>10^7	<10^2	High-resolution (<0.1 nm) TEM

Note to table 1: REM and TEM - scanning and transmission electron microscopes; SPM - scanning probe microscopes (electronic and scanning microscopes appeared in this table at the time of their invention)

Colloidal chemistry is the basis of numerous **sol-gel technologies** for obtaining a wide range of nanoobjects, such as nanoparticles, films of nanometer thickness, porous materials with pore sizes in the nanometer region and other. Sols are colloidal systems (colloidal solutions) with liquid (**lyosols**) or gaseous (**aerosols**) dispersion media, in the volume of which other dispersed phases are distributed in the form of liquid droplets, gas bubbles or small solid particles, the size of which lies in the range from 1 to 100 nm. **Gels** are colloidal systems with a liquid dispersion medium in which particles of the solid or liquid dispersed phase form a spatial structural grid. They are solid ("gelatinous") bodies that can retain their shape, have elasticity and plasticity. **Gels** with the aqueous dispersion medium are referred to as **hydrogels,** with alcohol - **alkogels**, with a hydrocarbon - **organogels** (common name **"lyogels"**) [10].

As the 20th century progressed, more specialized disciplines such as **chemistry of polymer and physical chemistry of surface** in the late 50s and **supramolecular chemistry** in the late 70s began to emerge from such a wide-ranging science as **colloidal chemistry** [10].

Nanoscale biological structures (viruses, proteins, genes, amino acids, DNA, RNA) have been the subject of research in the biology of ultradispersed systems since the last quarter of the 20th century, and in particular in areas such as **molecular biology, genetics,** and **virology.**

If the size of colloidal particles of a material is smaller than the critical lengths that characterize many physical phenomena, then such a material has new unique physical and chemical properties of a quantum mechanical nature. Quantum mechanical effects in colloidal systems (nanostructured materials) are studied and used to create new quantum devices by the **physics of low-dimensional structures,** which is the most dynamically developing field of modern **solid state physics.**

The field of colloid chemistry, which studies the physical chemistry of the processes of deformation, destruction, and formation of materials and dispersed structures, has evolved into a discipline called **physical and chemical mechanics** of solids and ultradispersed structures. The main task of physical and chemical mechanics is to create materials with the desired properties and optimal structure for the purposes of their application [10].

Another branch of science and industry that studies and creates elements, structures, and devices in the sub 100 nanometer size ranges is **microelectronics,** as well as its areas such as **functional, molecular** and **quantum electronics,** and its direction such as **optoelectronics, cryoelectronics, magnetoelectronics,** and **nanoelectromechanical systems** (NEMS). Indeed, the main microelectronics technology – CMOS - technology in the 21st century has crossed the 100 nm limit for element sizes in the horizontal plane (length and / or width) in the mass production of advanced products such as microprocessors (MP) and dynamic random access memory (DRAM). Integrated circuits (IC's) have long used functional layers with a thickness in the range (1 – 100) nm, and since the beginning of its development, microelectronics has been based on the processes of deposition, etching, doping and modification of materials occurring at the atomic, molecular and macromolecular levels.

Thus, it can be argued with good reason that in the 21st century, **microelectronics** has turned into **nanoelectronics** [10].

Methods of obtaining nanoobjects

Nanoobjects can be formed from larger continuous objects of the macro-or microscopic level by dispersing them (grinding, scattering) (**dispersion methods of nanotechnology - the "top-down" approach**) and from smaller discrete objects (molecules, atoms, ions, structural units) of the atomic-molecular level of a substance by their condensation (combining, compacting) (**condensation methods of nanotechnology - the "bottom-up" approach) (Figure 1**). It should be noted that nanoobjects obtained by condensation methods are more stable than those obtained by dispersion methods [5, 10].

Nanosystems, which include nanostructured substances, materials, and media, can also be formed from nanoobjects by dispersion and condensation methods.

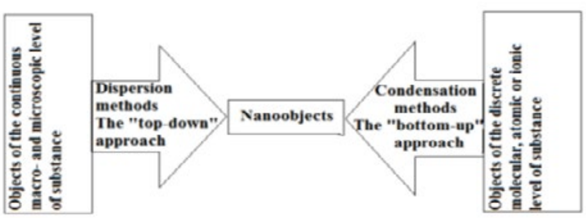

Figure 1: Methods of obtaining nanoobjects [5].

Conclusion

Thus, "nanotechnology" is a concept that includes a huge set of different methods, equipment, and objects in various branches of science, technology, and industry, allowing you to translate substances, materials, and media into a nanostructured aggregate state in which they have new physical and chemical properties.

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