# *Our Posthuman Future.*[1]
# Consequences of the Nanotechnology Revolution.[2]

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## 1. Abstract:

The main aim of this paper is to **indicate some of the dangers** arising from **nanomedicine** - indirectly from **nanotechnology**. Chosen aspects of nanomedical operations are presented, both currently being undertaken, and planned for the near future. The author tries to show what can be their **dark side**.
Keywords: nanotechnology, nanomedicine, nanomaterials, nanoobjects, control, dangers, dark side, nanotech revolution.

## 2. Introduction:

While an ordinary member of the North-Atlantic civilization still struggles to get fully accustomed to the most important achievements of the ICT revolution, there are already new, different, and much more serious challenges he or she will have to face. These challenges were generated by the biotechnology and nanotechnology revolutions. Some selected consequences of the biotechnological revolution underwent already a serious scrutiny[3]. One can, therefore, say that we are aware of particular important threats that were generated by this technology, or could be generated by it in the future. Less well known and less analyzed are the potentially **negative consequences of the nanotechnology revolution**. This is due mainly to the fact that the subject of nanosciences is presently not known widely enough to allow such analyzes on a large scale. In addition, the nanosciences are still in their initial phase, and because of that it is impossible to present – in a complete and accurate manner – the area of potential benefits and threats they could cause.

Nanotechnology is being popularized in the media, but what reaches eyes and ears of an average information consumer usually has bears all marks of informational noise.[4] The situation is similar to the eighties, when mass media has made a buzzword out of Lanier's "virtual reality", impressing the public without ant restraint with imagined possibilities and applications of this "miraculous", "revolutionary" technology.

The reason for the appearance of the informational noise was (and still is) the lack of real knowledge regarding the subject matter. And the subject of complex computer simulations (virtual reality) seems to be much less complicated than even the most basic issues from the field of nanotechnology, which makes it even harder to present the **real problems of nanotechnology** at a level accessible to the average, educated hamburger-eater. The sad, to my mind, conclusion is that knowledge – in the proper sense of the word – of nanotechnology will have to remain **the domain of very small scientific elite**. For the wider audience, what remains will be what falls off the science's table or what will be specially prepared for them –

1 This obvious reference to the title of the well-known Fukuyama paper seemed the most appropriate to express the intent of this paper. Cf.: Fukuyama, Francis (2002), Our Posthuman Future. Consequences of the Biotechnology Revolution.

2 Converted *(*.pdf)* from *(*.html)*: [source: http://mumelab01.amu.edu.pl/ethicomp2007/ethicomp2007_EN.html]. Original paper was published in: T. W. Bynum, S. Rogerson, K. Murata [Eds.], (2007), Glocalisation: Bridging the Global Nature of Information and Communication Technology and the Local Nature of Human Beings, Proceedings of the Ninth International Conference ETHICOMP 2007, Vol. 1, pages 307 – 317, Meiji University, Tokyo, Japan.

3 Ibid.

4 Cf.: Berube, David, M. (2006) Nano-hype: The Truth Behind the Nanotechnology Buzz.

like cat or dog food. By definition, it will contain waste, surrogates, substances enhancing taste, texture and smell, etc.

This paper is an attempt to join the attempts to popularize the possibilities and real achievements of nanomedicine – indirectly of nanotechnology. However, I try to exclude from the narrative everything that does not find confirmation in achievements of natural sciences. In section 3, I focus on key issues of definition, trying to explain what the intent of using the “nano” prefix is in various situations, and how close it is to the intent of using the “micro” prefix, which most people are familiar with. To present a full picture, I include a set of important definitions from official UE documents from year 2005. At the end I propose a short **definition of the term “nanotechnology”**.

In section 4, I try to answer the question what nanomedicine is. I propose my own **definition of nanomedicine**, based on real nanomedical procedures and procedures against possibility of which I could not find arguments, and which have all traits of nanomedical procedures.

In section 5, I present the main issue, which is the analysis of usage of nanomaterials, nanoobjects (nanostructures) in nanomedical practice: in diagnosis, therapy and prevention. Here the first questions appear concerning solving the problems follow as a direct consequence of those actions.

In Recapitulation – section 6 – I present, in what I believe is orderly fashion, the main components of the “black scenario” of nanomedical revolution (for today's degree of development of science, medicine and ICT). I consider, as a key issue, the danger to which a patient of a nanomedical therapy is subjected, in which nanoobjects are used which are able to carry and deliver biochemical substances into living organism. Because existing control systems of such objects are not able to control them completely and unconditionally, their use in bio-organisms (humans, animals, plants) should be considered to be especially dangerous in regard to the safety of the species, and no less dangerous in regard to the issue of social safety.

It would be a mistake to assume that the subject matter of this paper has not been discussed earlier and is still not being discussed today by other authors. It is hard to find one's way around in the avalanche of publications dedicated to every conceivable effect of nanotechnological revolution, and every paper written with speed characteristic of my generation (2 – 3 months) can touch upon similar issues, raised in a similar fashion[5] (and almost at the same time) by others. I regret that I could not take all of those publications into consideration, and I promise to do so in the near future.

## 3. Chosen issues of definition:

To avoid misunderstandings, and to make the following line of reasoning easier to understand, it would behoove the reader of this paper to be familiarized with basic terminology. I shall do so with greater care than usual[6], as many humanities scholars take part in ETHICOMP, for whom natural sciences are not always daily bread; many readers not attending the conference will be in the same situation.

The prefix “*nano”* (from Greek) has been used for a long time to define **different units of**

5 E.g.: Hunt, Geoffrey & Mehta, Michael (2006), Nanotechnology: Risk, Ethics and Law.

6 My task would be easier if the reader had in front of him the document Official Journal of the European Union, 28 June 2005, entitled **Opinion of the European Economic and Social Committee on the ‘Communication from the Commission: Towards a European strategy for nanotechnology’.**

**measure** and denotes a $10^{-9}$ multiplier. For those who finished school many years ago, another phrasing might be useful, namely that the "*nano"* prefix denotes **one billionth part** of the given unit. For example: one nanometer [*n*m], is one billionth part of a meter, which in the notation preferred by men of natural sciences will become $10^{-9}$ meter; one nanosecond [*n*s], is one billionth of a second – $10^{-9}$ second; one nanoampere [*n*A], is one billionth part of an ampere (an ampere is the unit of measure of electric current intensity) – $10^{-9}$ A. In general, it can be said that when dealing with values of any units that are on order of "nano", we are in the world of the unimaginably small – incredibly small sizes, incredibly short times, incredibly small intensities of electric current; in case of sizes (distance, length), they can only be observed under an electron microscope.

Taking the above into consideration, a layman could ask – does the term "nanotechnology" mean one billionth part of a technology? Or maybe some very small technology?

Of course, the answer is: no! The "nano" prefix used in "nanotechnology" is closer in meaning to usage of the "micro" prefix in some popular compound terms. For instance, most educated people know that the term "microprocessor", means a **processor of a very small size**, or to be more precise: a processor whose logic and switching elements (diodes and transistors) and connections between them in the processor's structure have lengths of order of one billionth part of a meter. Probably a much smaller fraction of those people knows that the compound term "microelectronics" means a **branch of electronics concerned with construction, operation and technology** of active and passive elements[7], of sizes of order of one millionth of a meter[8]; more complex structures (objects) which are built from the mentioned microelements can also be of sizes of this order. Microprocessors and other semiconductor integrated circuits are typical examples of complex microelectronic structures.

The meaning inherent in "nanotechnology" is closer to the meaning inherent in "microelectronics" – taking into account the difference in meaning of "technology" and "electronics", of course. If we take into account that in the considered field the terms "nanomaterials" and "nanostructures" are also used[9], then we can assume that – to put it simply – **nanotechnology is a field of technical science concerned with issues of production and usage of nanomaterials and nanostructures.**

Many nanomaterials and nanostructures can serve as "raw materials" for production of more complex objects. Some of them reach complete functionality and great usefulness for mankind while not leaving the *nano*scale (staying nanoobjects). However some nanomaterials and nanostructures reach final functionality, including significant usefulness for mankind only after a subtle "transformation" to the macroscale.[10] Both the former and the latter option **belong to the field of nanotechnology.**

The whole issue can also be explained according to an established standard – let us use the text of the aforementioned UE document:

2.1 **Nano —** means one billionth of a whole. In this case, nano is used to mean a

7 Active elements are mainly diodes and transistors, e.g. electrical signal amplifiers, logic and switching elements, and their more advanced brethren – microprocessors. Passive elements are mainly resistors and capacitors.

8 Today's boundary for microelectronics is 100 nm. This is almost nanoelectronics.

9 Even a basic description of the terms "nanomaterials" and "nanostructures" would require dozens of sentences. Because of that, the explanation of those terms has been moved to a separate part of the text. Cf.: the appendix at the end of the paper.

10 E.g.: unsoilable clothing, safer sun-tan lotions and creams, more durable fibers, more efficient batteries and fuels, new composites, more durable tools, safer clothes, etc. See: (in Polish) Tomczak, J. (2006) Zagrożenia wypływające z nanotechnologii. http://www.nanotechnologia.republika.pl/Zagrozenia_nanotechnologia.pdf. Accessed: 2006.12.12.

billionth of a metre.

2.2 **Micro —** means one millionth of a whole. In this case, it means one millionth of a metre.

2.3 **Nanosciences —** The nanosciences are a new approach to traditional science (chemistry, physics, electronic biology, etc.) and deal with the basic structure and behaviour of materials at the level of atoms and molecules. These sciences in fact study the potential of atoms in the various scientific disciplines (1).

2.4 **Nanotechnologies —** These technologies enable atoms and molecules to be manipulated so as to create new surfaces and objects that, having a different make-up and arrangement of atoms, have properties that can be used in day-to-day life (2). These are technologies that deal with billionths of a metre.

2.5 **In addition to the above definition, it is worthwhile going into greater detail from a scientific point of view. The term nanotechnology** describes a multidisciplinary approach to the creation of materials, mechanisms and systems, by means of the nanometric scale control of materials.

2.6 **Nanomechanics —** The dimensions of an object begin to be important in determining its properties when the scale of its dimensions is of one or a few dozen nanometres (objects made of a few dozen or a few thousand atoms). Within this range of dimensions, an object composed of 100 iron atoms has physical and chemical properties that are radically different to one composed of 200 atoms, even if they are both made of the same atoms. Similarly, the mechanical and electromagnetic properties of a solid made up of nanoparticles are radically different to those of a traditional solid of the same chemical composition and are affected by the properties of the individual constituent units.

2.12 **Microelectronics —** This is a branch of electronics that deals with the development of integrated circuits, built within individual semiconductor regions, with minute dimensions. Microelectronics can currently create individual components with dimensions in the realms of 0.1 micrometre, or 100 nanometres (5).

2.13 **Nanoelectronics** — This is a science that studies and produces circuits that are made using technologies and materials other than silicon and that work on a substantially different set of principles (6).

2.17 **Biomimetics** (13) **—** This is the science that studies the laws underpinning molecular structures existing in nature. Knowledge of these laws could enable **artificial nanomotors** to be created, based on the same principles as those existing in nature (14).

## 4. Nanomedicine:

Unfortunately, the European Union document, whose fragments we liberally quoted in the paragraph above, lacks a definition of the term "nanomedicine", and it appears occasionally in the latter part of the document.[11]

What, therefore, is nanomedicine?

11 "8.6.1 The **CCs** should be able to **carry out and transfer high-quality research** aimed at application and innovation, using nanotechnology, particularly in fields such as **nanoelectronics, nanobiotechnology and nanomedicine**." In: Official Journal of the European Union 28 June 2005. See: ref. # 6.

One of the most popular, most often used example illustrating **nanomedical procedure** is the use of nanoobjects[12] to locate cancer cells in living organism. It turns out that a nanoparticle (e.g. “quantum dots”) made of cadmium selenide, possesses two properties invaluable to anti-cancer treatment. First, it can penetrate into cancer cells after being introduced into the organism, and second, it emits light when excited with ultraviolet radiation. One does not need Drexler's acumen to notice that a qualitatively new tool in cancer diagnostics has appeared (a sensor), allowing more precise pinpointing of cancer tumors. It makes surgical procedures easier, when the cancer is advanced, and allows to use noninvasive therapy (pharmaceuticals, radiotherapy), precisely tuned to position and size of the cancerous tumor. Nanosensors able to locate tumors several thousand cells in size have already been constructed, therefore it is possible to diagnose the disease in very early stages.

Another example illustrating nanomedical procedures is a documented use of nanoobjects to destroy cancer cells in the organism of a mouse. So called “nanoshells”[13] coated with a layer of gold were introduced into mice's organism with an induced cancer tumor. An important trait of those nanoshells – important to medical diagnostics and therapy – is their propensity to gather in gaps of tumors of cancerous cells (nanoshells are about 120 nm in size and are 170 times smaller than cancer cells). An impulse of laser light in infrared spectrum, which passes harmlessly through living tissue, is absorbed by the gold layer on the nanoshells. The gold heats up to high temperature, which thermally annihilates cancerous tissue. None of the mice used for the experiment died, and the cancerous tumors have been destroyed. This method is considered to be safer and cheaper than surgery, chemotherapy, and radiotherapy.[14]

Among nanomedical procedures is also everything which joins documented results (cf. above examples) with results which we are expecting (and which we are looking for). It seems reasonable to expect that the nanosensor mechanism described in the first example could be expanded with a – let us call it provisionally – a transport section. The resulting nanostructure would be able to locate the indicated tissues (in this case – cancerous cells), and in addition – to deliver into their immediate vicinity certain biochemical substances (first and foremost – medicines). Depending on the assumed or possible method of releasing the medicinal substance by the transport section, it could be applied in a way impossible for traditional medicine to achieve – directly to ill cells and only there.

We know from media reports that NASA carries out a long-term nanomedical program as part of its preparations for the space travel to Mars. The program is aimed at solving many problems which result from long-lasting weightlessness, one of them being bone diseases. The NASA scientists attempt to construct nanoobjects which could be inserted into the body of an astronaut in order to monitor the processes of unwelcome bone changes (sensor function), and in case a change is detected – deliver a cure (transport and dispensing function), which means an effective therapy during travel.

If it were necessary to describe what nanomedicine is more closely (I am afraid to use the term “define” in this case), then based on the examples of nanomedical procedures presented earlier, we could risk saying that **nanomedicine is a branch (part, area) of medicine, which utilizes advances of nanotechnology and other related sciences (including nanosciences) in treatment and prevention of disease**. It consists – should consist – of research on how nanoobjects should be equipped and how they should be used to fulfill the mission of medicine

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12 Nanoparticles.

13 Nanoshells, belong to the nanoobjects category (nanostructures, nanoparticles). More at: http://en.wikipediawiki/Nanoshell. Accessed: 2006.12.12.

14 Cf.: Wikipedia: http://en.wikipedia.org/wiki/Medical_nanotechnology. Accessed: 2006.12.12.

– on one hand. On the other hand – nanomedicine should investigate in what way using nanoobjects in diagnostics, therapy and prevention can ensure full biological (eg. genetic) and social safety to the individual and community.

## 5. What next? Potential problems. Some speculation:

For a long time, it has been a truism that new inventions and discoveries cause as many disadvantages as advantages. Let us ask how this problem would look, or could look, if nanomedicine significantly increased in importance and became a larger part of social life?

Let us say this again: nanomedicine is a branch (part, area) of medicine, which utilizes advances of nanotechnology and other related sciences (including nanosciences) in treatment and prevention of disease.

### 5. 1. Diagnosis

The item considered above – in fact a simple case of a nanostructure (a quantum dot) made of cadmium selenide, used as a cancer detector in living organism, raises at least a few questions. The first must concern the issue of nanostructure removal after the diagnostic task is completed. In case of surgical intervention, it seems relatively simple: removal of the cancerous tumor means the removal of the sensor at the same time – or at least the probability of removing the now-unnecessary device is high. But what should be done if the picture of the tumor delivered by the nanosensor rules surgical intervention out, and doctors opt for pharmacological treatment instead? To reiterate, how to remove the unneeded nanoelements from the organism then?

Next question concerns the “detection spectrum” in constructed and used nanosensors. The problem is whether one kind of sensor is able to recognize all, or at least the majority of cancer cells, or if it is necessary to construct separate nanoobjects for every kind of cancer? In the latter case, let us repeat the earlier question – how to remove unnecessary nanosensors from the organism after they have fulfilled their diagnostic purpose?

In a broader sense, the issue from the paragraph above raises the question about the “detection spectrum” of the nanosensors in qualitative aspect. Cancer, even in its diversity, is only one of many diseases. Should the necessity of introducing a large number of nanosensors to the organism arise, to ascertain pathological changes other than caused by cancer, then the question about the way to remove unneeded nanoelements from the organism will become much more dramatic.

The development of nanoscience and nanotechnology could lead to an attempt to build a universal nanosensor, working on a different principle than those used in the first, simple constructions described above (quantum dots made of cadmium selenide). It is not hard to notice that a narrowly specialized nanostructure has a host of limitations, and that an effective structure should be more similar to an intelligent robot, or a vehicle moving around inside the organism. A vehicle equipped with a nanosensor array, ready to detect pathological changes. A vehicle that will not drop anchor at every pathological spot, but will note that it exists and move on, and pass on the information in some way, e.g. by sending signals to an outside diagnostic device associated with that universal sensor.

Such a state of affairs – if it were to come to pass – creates a lot of new problems, apart from the “old” questions regarding the way of removing the nanosensor from the organism after it completes its diagnostic task. In both cases – the “first generation” nanosensor and the universal nanosensor (“new generation”), the issue of their safe removal from the organism, and organisms of all animals appearing in the human digestive tract, is extremely important.

### 5. 2. Therapy – prevention

Nanomedical treatments can be conducted in several ways. However, the main way – in a sense that it has traits of a generic model – it can be reduced to the following outline; we have sketched this situation when we tried to answer the question of what nanomedicine is. The constructed nanoobject is “loaded” with medicinal substance and introduced to the organism. After reaching the destination, the substance is released – in the case of the example of a cancerous tumor – directly to the cells of the diseased tissue. The nanoobject's mission will be completed and, similarly to every example considered before, there remains the problem of removing the “empty packaging” left afterwards.

This simple outline – the generic principle – must be more complex in every real case of nanomedical therapy. It is easy to notice that it does not contain anything concerning, e.g. fundamental problem of control – from locating diseased areas, to medicine release mechanism.

And there are many problems. The issue of locating areas for medicine to be released can be solved in several ways, depending on the chosen sensor model, as explained in section 5.1. In case of the “new generation” sensor, new problems appear, concerning nanoobject's communication with the part of diagnostic (and therapeutic) apparatus outside the organism. Namely, a safe data exchange system has to be created – of an unprecedented scale – allowing to correctly identify different areas of the organism. A safe data exchange system must also be created to control the release mechanism of the medicine “loaded” onto the nanoobject. It is possible that other considerations (e.g. a peculiar character of the medical case) will cause us to use nanoobjects constructed with “reserves”, which will force us to ensure safe control of medicine dosage, that is – of the process of timed release of parts of the load. Other causes, also belonging to the “peculiar medical case” category, could cause us to use nanoobjects loaded with several medicines, which will entail creation of safe controls of release of medicines in proper order, that is – of the process of timed release of qualitatively different parts of the load.

## 6. Recapitulation: chosen consequences. Black scenario:

As evidenced by sections 3-5, nanomedicine is concerned with ways of utilizing various nanoobjects to perform examinations, diagnose diseases and conduct effective therapy.

To the field of nanomedicine belongs also prevention, broadly understood. Specialized nanoobjects are used for permanent monitoring of human bodies, and for transmitting the obtained information either to remote data banks or to other nanoobjects located in the body of the same individual. Yet another area of interest for nanomedicine is the production of biochemical substances adapted for cooperation with nanoobjects used in diagnostics or treatment. For obvious reasons, problems related to the remote control of above mentioned nanoobjects also belong to the field of nanomedicine. The concern is about subtle issues of programming their activities and communication with other devices (particularly ones outside the organism) to track and control important aspects of nanoobjects' behavior. A question arises, whether this idyllic picture of nanomedicine is the only side?

My answer is: no. Nanomedicine also has its **dark side**. Chief among the possibilities of the dark side of using nanoobjects introduced into the human body is the possibility to construct these objects in a way that would create “programmed threats,” to use Eugene Spafford's and his colleagues'[15] term. To be more specific (focusing only on one facet of the functions of intro-bodily nanoobjects), let me refer to the following:

- While inserting into a human body nano-objects capable of receiving, transporting, and releasing biochemical substances, and of monitoring the body's vital functions, one can do it with the knowledge and permission of that particular individual, **or without it** (e.g. by special forces or terrorists).
- Nanoobjects capable of receiving, transporting, and releasing biochemical substances within a human body can be used **not only for the purpose of curing**, but also for causing harm, e.g., through delivering toxic substances.
- Nanoobjects capable of receiving, transporting, and releasing biochemical substances within a human body can be used for carrying medicines, **but of a wrong kind, and intended to harm** rather than cure (by overdose, or to force certain behavior by use of e.g. psychotropic substances, etc.).
- Nanoobjects capable of transporting and releasing biochemical substances in human body can be equipped with a **control system dependent on an arbitrary, subjective** (in bad sense of the word) **decision of an individual (or institution)** who controls the portion of the control system outside the organism.
- **Control over nanoobjects** capable of transporting and releasing biochemical substances in human body and of monitoring its state and functions **can be taken over by unauthorized** institutions (e.g. by special forces or terrorists)

## 7. Conclusion:

Keeping in mind all (so far only potential) advantages of nanomedical solutions, we should remember the old truth that nanotech revolution, as any other, has its dark side. If we do not manage to stave off attempts to realize black scenarios of development of new civilization (already digital) in time, using our minds and sense of humanity, not yet stripped away from the majority of us, then our humanity will end up on the history's junkpile, not unlike Atlantis. Our grandchildren will (maybe) know that something like that existed at one time (allegedly), but what it really was... ?

I devote the text of this paper to describing a part of this dark side of nanotech revolution, trying to point out potential ethical and legal dilemmas, which inevitably must accompany the application of its achievements. I deeply believe that only in this way we can avoid the realization of the sinister prediction from the title of Fukuyama's paper.

## 8. Appendix:

**Nanostructure**

A material structure assembled from a layer or cluster of atoms with size of the order of nanometers. Interest in the physics of condensed matter at size scales larger than that of atoms and smaller than that of bulk solids (mesoscopic physics) has grown rapidly since the 1970s, owing to the increasing realization that the properties of these mesoscopic atomic ensembles are different from those of conventional solids. As a consequence, interest in artificially assembling materials from nanometer-sized buildings blocks arose from discoveries that by controlling the sizes in the range of 1-100 nm and

15 Cf.: Spafford, Eugene, H. (et al.) (1989). Computer Viruses: Dealing with Electronic Vandalism and Programmed Threats. ADAPSO.

the assembly of such constituents it was possible to begin to alter and prescribe the properties of the assembled nanostructures. SEE MESOSCOPIC PHYSICS.

Nanostructured materials are modulated over nanometer length scales in zero to three dimensions. They can be assembled with modulation dimensionalities of zero (atom clusters or filaments), one (multilayers), two (ultrafine-grained overlayers or coatings or buried layers), and three (nanophase materials), or with intermediate dimensionalities

Multilayers and clusters. Multilayered materials have had the longest history among the various artificially synthesized nanostructures, with applications to semiconductor devices, strained-layer superlattices, and magnetic multilayers. Recognizing the technological potential of multilayered quantum heterostructure semiconductor devices helped to drive the rapid advances in the electronics and computer industries. A variety of electronic and photonic devices could be engineered by utilizing the flow-dimensional quantum states in these multilayers for applications in high-speed field-effect transistors and high-efficiency lasers, for example. Subsequently, a variety of non-linear optoelectronic devices, such as lasers and light-emitting diodes, have been created by nanostructuring multilayers. SEE ARTIFICIALLY LAYERED STRUCTURES; LIGHT-EMITTING DIODE; SEMI-CONDUCTOR HETEROSTRUCTURES; TRANSISTOR.

The advent of beams of atom clusters with selected sizes allowed the physics and chemistry of these confined ensembles to be critically explored, leading to increased understanding of their potential, particularly as the constituents of new materials, including metals, ceramics, and composites of these materials. A variety of carbon-based clusters (fullerenes) have also been assembled into materials of much interest. In addition to effects of confinement, interfaces play an important and sometimes dominant role in cluster-assembled nanophase materials, as well as in nanostructured multilayers. See Atom Cluster, Ceramics; Fullerene

Synthesis and properties. A number of methods exist for the synthesis of nanostructured materials. They include synthesis from atomic or molecular precursors (Chemical or physical vapor deposition, gas condensation, chemical precipitation, aerosol reactions, biological templating), from processing of bulk precursors ( mechanical attrition, crystallization from the amorphous state, phase separation), and from nature (biological systems) Generally, it is preferable to synthesize nanostructured materials from atomic or molecular precursors, in order to gain the most control over variety of microscopic aspects of the condensed ensemble: however, other methodologies can often yield very useful results. See Vapor Despostion. [In: *Encyclopedia of Science and Technology* (ed. 5), McGraw-Hill, New York 2006, p.1464.]

## Nanomaterials

In their broadest definition, nanostructured materials show structural features with sizes in the range from l nm to a few hundred nanometers in at least one dimension. This very general criterion actually includes very diverse physical situations.

First, as is apparent from the previous section, each nanostructured material is associated with a specific novel property or a significant improvement in a specific property resulting from the nanoscale structuring. As a consequence, the type of nanostructuring used must be based on a spatial dependence of some parameter related to the property under consideration. This parameter could be, for example, the material density, transport parameters, or the dielectric constant. Another consequence is mat the upper size limit of the structural features varies depending on the property considered, from a molecular size for molecular-sieve properties up to the wavelength of light for the optical properties. Second, in addition to the nanometer-scale structuring, a larger- scale ordering of the unit patterns may be necessary for the existence of the property sought. For example, the particular optical properties of opals mentioned above require the silica nanospheres to show a long-range order with a coherence length well beyond a micron. The same considerations hold for quantum-well superlattices, for example. In other cases, the nanosized building blocks do not need long-range order to provide a specific property, but still require some degree of short-range organization. For example, an electrical conductivity appears only above a critical percolation density of conducting particles. Finally, some properties of nanostructured materials simply reflect a corresponding intrinsic property of their individual building blocks. This is the case, for instance, in nanoparticles embedded in glass or polymer matrices for optical-filtering applications.

Two main technological approaches may be denned:

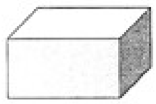
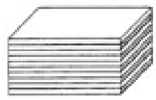
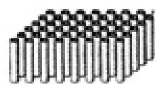
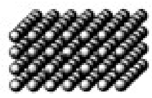
The top-down manufacturing paradigm consists in downscaling the patterning of materials to nano-meter sizes. This allows the generation of materials which are coherently and continuously ordered from macroscopic down to nanoscopic sizes.

• The bottom-up paradigm is based on the atomically precise fabrication of entities of increasing size. It is the domain of macromolecular and supramolecular chemistry (dendrimers, engineered DNA, etc.) and of cluster and surface physics (epitaxy, self-assembly, etc.).

Mesoscopic materials form the subset of nanostructured materials for which the nanoscopic scale is large compared with the elementary constituents of the material, i.e. atoms, molecules, or the crystal lattice. For the specific property under consideration, these materials can be described in terms of continuous, homogeneous media on scales less than that of the nanostructure. The term "mesoscopic" is often reserved for electronic transport phenomena in systems structured on scales below the phase-coherence length $A\phi$, of the carriers.

Most of the common nanomaterials can be classified in terms of dimensionality, according to the number of orthogonal directions *X, Y,* Z in which the structural patterns referred to above have dimensions $L_{X,Y,Z}$ smaller than the nanoscopic limit $L_o$. This leads to the classical definitions of dimensionality summarized in Table 5.3-1. – see: end of the paper. [In: *Springer Handbook of Condensed Matter and Materials Data*, W. Martienssen & H. Warlimont (Eds.) Springer Berlin Heidelberg 2005, Berlin.]

**Table 5.3-1** Examples of reduced-dimensional material geometries, and definitions of their dimensionality and of the associated type of confinement

| | | | | |
|---|---|---|---|---|
| $L_{X,Y,Z} > L_0$ | No nanostructures | No confinement | Bulk material |  |
| $L_{X,Y} > L_0 > L_Z$ | Two-dimensional (2-D) nanostructures | One-dimensional (1-D) confinement | Wells |  |
| $L_X > L_0 > L_{Y,Z}$ | One-dimensional (1-D) nanostructures | Two-dimensional (2-D) confinement | Wires |  |
| $L_0 > L_{X,Y,Z}$ | Zero-dimensional (0-D) nanostructures | Three-dimensional (3-D) confinement | Dots |  |