SCALING LAWS AND RAW MATERIALS OF NANOTECHNOLOGY

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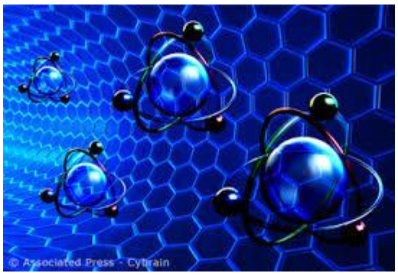
ABSTRACT: *In other cases, scaling performance up to the level of human utility is simply a matter of massive parallelization. Nanoreactors synthesizing a medicinal drug simply need to work in parallel for a reasonably short time to generate enough of the compound for a therapeutically useful dose. With information processors, the problem is the user interface: a visual display screen must be large enough to dimply a useful amount of information, a keyboard for entering instructions and data must be large enough for human fingers, and so forth.*

INTRODUCTION:

Most of the materials around us are composites. Natural materials such as wood are highly structured and built upon very sophisticated principles. The basic structural unit is cellulose, which is a polymer of the sugar glucose. The *motif* of strong fibers embedded in a sticky matrix is very widely exploited, other examples being glass fiber– and carbon fiber-reinforced polymers.

MATERIALS:

Essentially, the contribution of nanotechnology to this effort is simply to take it to the ultimate level, in the spirit of "shaping the world atom-by-atom". "Nanostructured" is defined as "possessing a structure comprising contiguous elements with one or more dimensions in the nanoscale but excluding any primary atomic or molecular structure". Carbon-based materials, especially fullerenes in carbon nanotubes, are often considered to be the epitome of a nanomaterial. Carbon has long been an intriguing element because of the enormous differences between its allotropes of graphite and diamond. The carbon nanomaterials are based on another new form, grapheme.



DEVICES:

A device turns something into something else. Synonyms are machine, automaton, transducer, encoder, and so forth. Possible motivations for miniaturizing a device are:

- Economizing on material. If one can accomplish the same function with less material, the device should be cheaper, which is often a desirable goal-provided that it is not more expensive to make. The material costs are disregarded, it is typically more expensive to make something very small.

Example: a watch is more expensive than a clock, for equivalent timekeeping precision.

- Performance (expressed in terms of straightforward input-output relations) may be enhanced by reducing the size. This is actually quite rare. For most micro electromechanical system (MEMS) devices, such as accelerometers, performance is degraded by downscaling.

Downscaling:

An accelerometer (which transduces force into electricity) depends on the intertie of a lump of matter for its function, and if the lump becomes too small, the output becomes unreliable. Similarly with photodetectors (that transducer photons into electrons): due to the statistical and quantum nature of light, the smallest difference between two levels of irradiance that can be detected increases with diminishing size. On the other hand, there is no intrinsic lower limit to the physical embodiment of one bit of information.

- Functionality may be enhanced by reducing the size. Using the s
- ame examples as in the previous item, it would not be practicable to equip mass-produced automobiles with macroscopic accelerometers with a volume of about 1 liter and weighing several kilograms.

SYSTEMS:

The essence of a system is that it cannot be usefully decomposed into its constituent parts. Two or more objects constitute a system if the following conditions are satisfied:

- One can talk meaningfully of the behavior of the whole of which they are the only parts
- The behavior of each part can affect the behavior of the whole

- The way each part behaves and the way its behavior affects the whole depends on the behavior of at least one other part
- No matter how one subgroups the parts, the behavior of each subgroup will affect the whole and depends on the behavior of at least one other subgroup.

Typically, a single nanodevice is complex enough to be considered a system, hence a "Nanosystem" generally signifies a system whose components are nanoscale devices.

ISSUES IN MINIATURIZATION:

Considering the motor-car as a transducer of human desire into translational motion, it is obvious that the Nano automobile would be useless for transporting anything other than Nano-objects. The main contribution of nanotechnology to the automotive industry is in providing miniature sensors for process monitoring in various parts of the engine and air quality monitoring in the saloon; additives in paint giving good abrasion resistance, possibly self-cleaning functionality, and perhaps novel aesthetic effects; new ultra strong and ultra-light weight composites incorporating carbon nanotubes for structural parts; sensors embedded in the chassis and bodywork to monitor structural health; and so forth.

Scaling up:

In other cases, scaling performance up to the level of human utility is simply a matter of massive parallelization. Nanoreactors synthesizing a medicinal drug simply need to work in parallel for a reasonably short time to generate enough of the compound for a therapeutically useful dose. With information processors, the problem is the user interface: a visual display screen must be large enough to display a useful amount of information, a keyboard for entering instructions and data must be large enough for human fingers, and so forth.

OTHER MOTIVATIONS:

The burgeoning worldwide activity in nanotechnology cannot be explained purely as a rational attempt to exploit "room at the bottom". Two other important human motivations are doubtless also playing a role. One it is simply "it hasn't been done before"-the motivation of the mountaineer ascending a peak previously untrodden. The other is the perennial desire to "conquer nature". Opportunities for doing so at the familiar macroscopic scale have become very limited, partly because so much has already been done- in Europe, for example, there are hardly any marshes left to drain or rivers left to dam, two of the most typical arenas for "conquering nature"-and partly because the deleterious effects of such "conquest" are now far more widely recognized, and the few remaining undrained marshes and undammed rivers are likely nowadays to be legally protected nature reserves. But the world at the bottom, as Feynman picturesquely called it, is un controlled and largely unexplored.

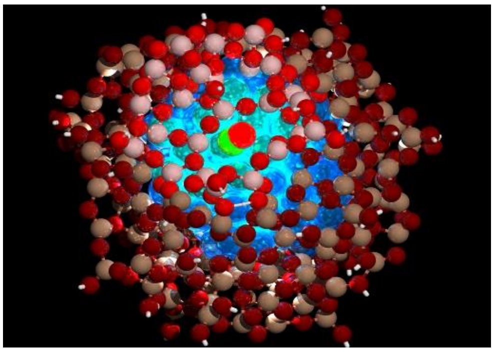
Finally, the space industry has a constant and heavily pressing requirement for making payloads as small and lightweight as possible. Nanotechnology is ideally suited to this end user-provided nanomaterials, devices and systems can be made sufficiently reliable.

NANOPARTICLES:

One can use either a top-down (comminution and dispersion) or bottom-up (nucleation and growth) approach. The decision which to adopt depends on which can deliver the specified properties, and then on cost.

Commination and dispersion means taking bulk material and fragmenting it. Crushing and grinding have typically been treated as low-Technology operations. Theoretical scientists seeking to formalize phenomenological mechanistic rules (e.g., random sequential fragmentation) have found they have had little impact on the industry.

Nucleation and growth describes the first-order phase tradition from on atomically dispersed phase to a solid condensed phase. During the first stage of the transition fluctuations in the homogeneous, metastable parent phase result in the appearance of small quantities of the new phase. The unfavorable process of creating an interface opposes the gain in energy through the reduction in supersaturate, of the parent phase, leading to a critical size of nucleus , n*, above which the nucleic develop rapidly and irreversibly into the new phase.



NANOFIBRES:

Terminology. "Nano fibers" is the generic term describing Nano-objects with two external dimensions in nanoscale. A nanorod is a rigid Nanofiber, a nanotube is a hollow nanofiber, and a nanowire is an electrically conducting nanofiber. Three approaches can be used to synthesize nanofibers. For some substances, under certain conditions, the natural growth habit is acicular. Therefore, the nucleation methods described in the previous section can be used to generate nuclei, followed by a growth stage to elongate them.

NANOPLATES:

Until now, thin coatings on a substratum have not been considered as Nano-objects, but simply as thin films, because typically they have been more than 100 nm thick. Exceptions are Langmuir films, transferred to solid substrata using the Langmuir-Boldgett and Langmuir-Schaefer techniques; these films might only be a few nanometers thick. Exceptionally laterally cohesive Langmuir films can be manipulated as free-standing objects. Nevertheless, the trend is to develop thinner functional surfaces by coating or otherwise modifying bulk material, and insofar as the coating or modification is engineered with atomic precision, it belongs to nanotechnology.

Langmuir films and the Lang-Blodgett and Langmuir-schaefer techniques.

The precursors are molecules of general formula XP, where X is (typically) an apolar chain (e.g., an alkyl chain), called the “tail”, and P is a polar “head” group such as oligoethylene oxide, or phosphatidyl choline. We spread on water they mostly remain at the water/air interface, where they can be compressed to form two-dimensional liquid-likr and solid-like arrays. The Langmuir-Blodgett technique refers to the transfer of floating monomolecular films to solid substrata by vertically dipping them into and out of the bath. In the Langmuir-Schaefer technique, the substratum is pushed horizontally through the floating monolayer.

GRAPHENE-BASED MATERIALS:

Graphene. The graphene lamellae stacked to make bulk graphite were from the ease of their detachment (e.g., writing with graphite on paper) known to be only weakly bound to each other. Individual sheets of graphene can actually be peeled off graphite using adhesive tape. Alternatively, a crystal of silicon carbide can be heated under vacuum to 1300 c; the silicon evaporates and the remaining carbon slowly reorganizes to form some graphene.

Carbon nanotubes. The carbon nanotube is a seamless tube made by rolling up graphene. It was long known that carbon filaments are formed by passing hydrocarbons over hot metal surfaces, especially iron and nickel. The actual nature of carbon nanotubes was however only established relatively recently. Multiwall carbon nanotubes consists of several concentric tubes of graphene nested inside each other. The three methods for producing carbon nanotubes are the laser furnace, the carbon arc (I.e., vaporizing graphitic electrodes), and (plasma enhanced) chemical vapor deposition. Carbon nanotubes are often closed at one or both ends by a hemisphere of fullerene. Carbon nanoparticles. Fullerene (also known as soluble carbon or Bucky balls) can be thoughts of as graphene curled up to form an enclosed spherical shell. They exist as C60, C70, etc. They can be made in a cabon arc, but burning a hydrocarbon feedstock with strict control of the oxygen supply is a more controllable methods.

BIOLOGICAL EFFECTS OF NANOPARTICLES:

The toxicity of chemicals and materials can arise in two ways :

- Triggering an adverse immune response
- Acting as a poison

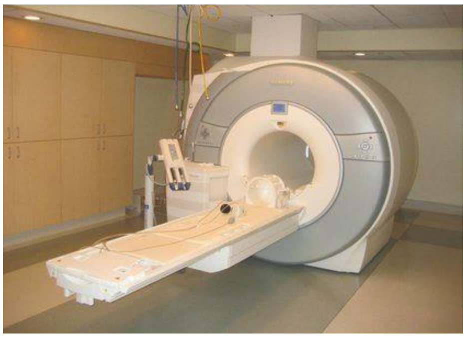
The immune response engendered by an artificial material in contact with the blood or tissues typically arises because proteins dissolved in the blood or other biofluids adsorb onto the surface of the material and change their conformation (generally because of an entropic driving force). The native protein is thereby transformed into a foreign protein, recognized as such by circulating immune cells, which trigger the usual apparatus for eliminating foreign invaders into action. Any immovable artificial material will become a permanent site of inflammation. Poisoning usually has a specific biochemical mechanism. Typically, a poison binds to the active site on enzyme, preventing it form binding its customary substrate. The classic example is carbon monoxide, which binds the harem group of Hemoglobin, very effectively outcompeting oxygen binding. Mercury-containing clinical thermometers that happen to break in the mouth of patient are dangerous because of jagged pieces of glass, not because of the toxicity of the matter.

ELECTRONIC DEVICES:

For devices in which information is represented as electrostatic charge, a scalar quantity, the lower limit of its magnitude is the charge *e* of a single electron. Neglecting noise and equivocation issues, single electron devices can be achieved by downscaling the components of a conventional transistor. Developments in fabrication technologies have led to devices with the same architecture as their microscopic counterparts. Truly nanoscale devices using electrons involve single-charge transport in minute tunnel junctions. Several different devices configurations designed to exploit the discrete nature of electric charge transport have been or are being investigated.

MEGNETIC DEVICES:

Electrons have spin as well as charge. This is of course the origin of ferromagnetism, and hence magnetic memories, but their miniaturization has been limited not by the ultimate size of a ferromagnetic domain but by the sensitivity of magnetic sensors. The influence of spin on electron conductivity was invoked by Neville Mott in 1936, but remained practically uninvestigated and unexploited until the discovery of giant magnetoresistance (GMR) in 1988. Spintronics, sometimes called magnetoelectronic, which may be loosely defined as the technology of devices in which electron spin plays a role, has three main directions now:



- The development of ultrasensitive magnetic sensors for reading magnetic memories
- The development of spin transistors, and in which the barrier height is determined by controlling the nature of the electron spins moving across it
- The development of devices in which logical states are represented by spin.

PHOTONIC DEVICES:

Another kind of superlattice is made from alternating layers of wider and narrower band gap semiconductors (for example, n-Al GaAs and GaAs, respectively) called a quantum well. Semiconductor lasers, in which a voltage is applied across the semiconductor crystal that in effect constitutes a fabry-perot cavity to create a nonequilibrium population distribution of electrons and holes, whose luminescent recombination generates photons stimulating further emission, were already in existence when Dingle and Hendry showed that using quantum wells as the active lasing medium would result in more efficient lasers with lower threshold currents, essentially because quantum confinement of the charge carriers and the optical modes enhances carrier-radiation interaction; moreover the lasing wavelength could be tuned by changing the thickness of the layers. Again, real progress was only made with improvements in the technology of ultrathin film fabrication.

MECHANICAL DEVICES:

Careful analysis of the size-dependent performance of micro electro mechanical system (MEMS) such as accelerometers revealed that their performance is degraded if they are further miniaturized down to the nanoscale. Nevertheless, continuing advances in the technologies of structuring materials such as silicon, not only to create layered electronic devices but also mechanical devices, as well as the advent of graphene-based materials, have generated renews interest in mechanical devices that can now be made at the nanoscale (nano electro mechanical systems, NEMS). NEMS should however also be very valuable as mass sensors (by the same token, manufacturing variability may be problematical).

CONCLUSION:

A large fraction of the atoms of a nanocantilever are inevitably at its surface , and in some cases it has been found that the addition of molecules to the cantilever surface *increases* resonant frequency because they stiffen the surface “skin”, and this effect predominates over the decrease expected from the increase of resonant mass.A significant NEMS engineering challenge is the detection of displacements in the picometre or even femtometer range at gigahertz frequencies.

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