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Nanoscience and nanotechnology: An overview

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The following report provides a broad overview of the field of nanoscience/nanotechnology. The discipline is defined, challenges facing the field identified, and future prospects discussed. Recommendations for further research are indicated.

In 1959, Richard Feynman delivered a speech to the American Physical Society in which he proposed the idea of studying things at the atomic level[i], an idea that would come to be called nanoscience and nanotechnology. Within the last five years, nanotechnology has become a buzzword among science and technology circles, and even popular media, but what exactly is “nanoscience and nanotechnology” and what potential does it have to improve our lives? In what follows, these questions will be addressed in a broad overview of the current state of the field. Additionally, challenges facing the field will be identified and future prospects discussed.

Nanotechnology is defined as the manipulation of matter at the nanoscale[ii] (100,000 times smaller than the diameter of the human hair), enabling the discovery of new phenomena and applications.[iii,iv] Nanoscience is understood more broadly as the science behind the ability to employ nanotechnology. The potential that this ability appears to hold is seemingly all-pervasive in improving the quality of human life,[ii] with developing applications in the manufacturing of improved materials for aircraft and automobiles, faster and smaller communications devices and electronics, more efficient environmental innovations, improved security devices, and targeted drug delivery systems.[ii,iv] Perhaps one of the most exciting potential applications of nanoscience is the treatment (and even elimination) of disease through nanomedical applications.

Nanomedical applications of nanostructures include nanoparticles and nanovehicles.[v] Three examples of nanoparticles used in nanomedicine are colloidal gold, ironoxide crystals (used in MRIs to detect cancer, etc.), and quantum dots (used to target tumors, for example). Nanoparticles can also be used for drug delivery applications, including nanocapsules that are able to resist being rejected by the immune system and nanoporous materials that enable targeted delivery of medication.

Nanovehicles involve the use of “therapeutic and diagnostic agents [that] can be encapsulated, covalently attached, or adsorbed on to such nanocarriers”[vi] and would be administered by ingestion or injection. An example of therapeutic use is pharmacy-on-a-chip technology that is used to regulate insulin levels, among other uses. These devices are activated through magnetism, heat, or by having sensors on the surface that recognize the conditions required for medication release. Another area of nanomedical application is in tissue regeneration; however, little has been done in this area to date. Nanomedical research is still in its infancy and it is presently unknown when the applications described above will be fully developed or available for human use. Despite these promising applications, the nascent field faces many challenges, three of which will be discussed here: fabrication methods, disciplinary barriers, and assessment and management of risk.[iii,vii]

The development of nanotechnology is largely dependent on the availability of cost-effective and accessible methods to manufacture nanostructures.[viii] Scientists are utilizing existing methods for microelectronics (e.g., computer chips) such as photolithography. Unfortunately, these methods are not well-suited to nanofabrication because they are too difficult and cost-prohibitive to scale down to the nanoscale (e.g., the smallest size handled by microelectronic methods is 100 nanometers). New methods are therefore needed for design and fabrication at the nanoscale. These methods include both top-down and bottom-up approaches. Top-down methods involve creating a structure and then "carv[ing] out or add[ing] aggregates of molecules to a surface". Bottom-up methods, which have been referred to as "the holy grail" of nanoscience/nanotechnology[ix], involve building nanostructures atom by atom.[x]

Thus, the methods currently available (e.g., optical or magnetic tweezers) are inadequate for providing a full treatment and understanding of one or two molecule structures. Moreover, such techniques are still in crude stages of development and will need to be refined before any useful properties for replication can be understood. Recent research suggests that results from attempts to characterize these structures are not consistent in their findings and thus provide only a beginning (albeit necessary) attempt at characterizing nanostructures at the nanoscale.[xi,xii,xiii] Successful development of bottom-up methods appear to hold the most potential for advancements in nanofabrication; however, such developments are not forthcoming, largely because a full understanding of how self-assembly methods work in nature is simply not yet known.

Understanding nature's nanofabrication methods is of crucial importance not just to biologists working at the nanoscale, but to scientists working in many disciplines that stand to benefit from developments in nanoscience and nanotechnology including engineering and materials science. Interdisciplinary by nature, the field of nanoscience/nanotechnology requires close partnership among the different scientific and technological disciplines in order to develop quickly and efficiently. Toward this end, Whitesides and Alivisatos[iii] advised that nanoscience R&D be developed in academe, industry and national labs. However, bringing together disciplines which have developed independently from each other is no easy task. Nanoscience/nanotechnology requires an interdisciplinary collaboration across the sciences that would allow, for example, the integration of biological principles with electronics and the development of the appropriate tools to do so. Ideas for nanofabrication are currently being developed in many different disciplines[x] in a convergence of disciplinary approaches that is vital to the design appropriate methods that will drive the development of nanoscience and nanotechnology.[xiv]

The third challenge facing the field that will be discussed here is what has been broadly referred to as "social and ethical implications" of nanoscience and nanotechnology. These implications include the management of risk as well as the management of public perception of risk.[ii] The comparison between toxicity of nanomaterials and that of asbestos has been made and several studies have been released that indicate toxicity of nanoparticles in fish.[iv] Vicki Colvin, director of Rice University's Center for Biological and Environmental Nanotechnology suggested that second-order effects of nanomaterials must be evaluated at the outset in order to sustain public support for the development of nanotechnology.[vii]

The discussion of toxicity highlights the broader issue of social concern with the development of nanotechnology and nanoscience, including issues of privacy, accessibility, and ethical concerns. The nature of revolutionary change such as that which characterizes technological development makes it impossible to predict what the future holds for such technology.[ii] Yet, uncertainty does not excuse the scientific community from the responsibility of considering future impacts, adverse as well as beneficial, of new technologies on society and the environment.

In short, in tandem with the development of appropriate nanofabrication methods, research is needed that considers all aspects of the development of nanoscience and nanotechnology, including evaluation of toxicity and other health and environmental risks, as well as a full consideration of social and ethical concerns (e.g., privacy issues, equity issues, workforce training, etc.) In the meantime, the scientific community (and the community at large) must wait and see how the development of the field unfolds. If history is any indicator of what to expect with new technologies, the only thing that can be said with any certainty is that the field will develop in ways not yet imagined.

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