The Fascinating World of Nanoscience

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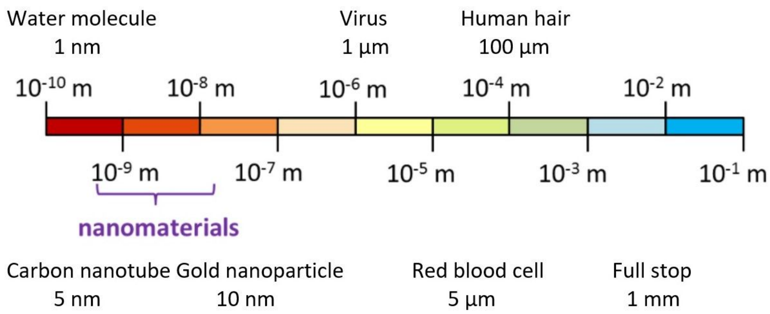


1 Introduction

The nanoscience field has come a long way and continues to grow every year. It is hard to imagine some of the amazing developments made since the initial mention in 1959 by Richard Feynman. More than 60 years later we continue to be amazed by this tiny scale with the prospect to make technology with large applications. Currently nanotechnology is revolutionizing the way we used to do things ranging from the use in computing, experimental medical treatment, and even breaking down waste. Although people still seem to confuse nanotechnology with nanoscience as time progresses more and more fields are becoming aware of the utility that nanotechnology can bring. This paper will focus on phenomena involving the surface area which include *Collective Surface Area, Singular Surface Area,* and *Surface to Volume Ratio* as well as all the applications that arise from it. I believe that by getting an understanding at the fundamental level we can find ways more ways nanoscience can help us further the ability of our technology and ensure the prosperity mankind.

2 What is a "Nanophenomena"?

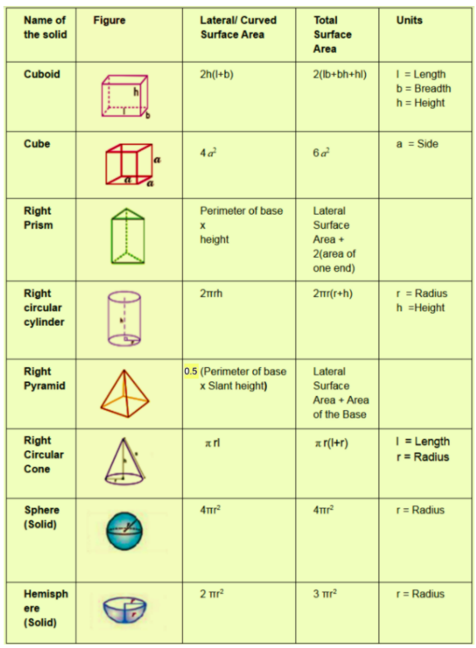
In nature exists certain phenomena that sometimes take time to explain or can baffle scientists, the nature of the nanoscale is no different. In nanoscience such phenomena exist that can bring with them a reevaluation on how we think about certain things. *Nanophenomena* are weird properties that are present at the nanoscale that seem to defy science. There are many different phenomena that occur such as: thin film interference, non-reflecting coatings, etc. All these phenomena can be attributed to the same thing however, the size. Because anything at the nanoscale is so minute, structures tend to be a few molecules or atoms in size. Size is responsible for the weird behavior nanomaterials exhibit. Because at the nanoscale we're working with atoms and molecules the border between classical mechanics and quantum mechanics is blurred. It is no secret quantum mechanics are weird, and when you're working in a field that borders those same interactions we are sure to experience unexpected behaviors.

3 Surface Area

3.1 What is Surface Area?

Surface area is a straightforward concept. The area which the material covers is the surface area. A ball has a surface area that covers everything withing the sphere. Cubes have a surface area of every side added up. Surface area is an important idea in nano science because of the properties it gives nano materials. See Figure 1 below for a general idea of surface area. Surface area is an important aspect of any material science because of the needed knowledge to manipulate it. Different fields can include anything from electrochemistry [3] or even biology. This article [4] discusses the use of surface area to verify the initial believed length of the digestive tract. The applications of surface area are everywhere which is no surprise that it is a major factor when working at the nanoscale.

Figure 1: Surface area and formulas of different shapes.



Name of the solid	Figure	Lateral/ Curved Surface Area	Total Surface Area	Units
Cuboid		2h(l+b)	2(lb+bh+hl)	l = Length b = Breadth h = Height
Cube		$4a^2$	$6a^2$	a = Side
Right Prism		Perimeter of base x height	Lateral Surface Area + 2(area of one end)	
Right circular cylinder		2πrh	2πr(r+h)	r = Radius h =Height
Right Pyramid		0.5 (Perimeter of base x Slant height)	Lateral Surface Area + Area of the Base	
Right Circular Cone		π rl	π r(l+r)	l = Length r = Radius
Sphere (Solid)		$4\pi r^2$	$4\pi r^2$	r = Radius
Hemisphere (Solid)		$2\pi r^2$	$3\pi r^2$	r = Radius

3.2 Why Surface Area is Important

We know what surface area is, now how can we use the concept it to our advantage? Suppose you're building a house and in order to main structural integrity various 'load bearing' walls or columns have to be built and placed in different places. Sometimes a wall may create a less than desired layout, but because they are needed not much can be done. Most of the times these walls are reinforced with wood or concrete, but in order to hold the roof these materials require large surface areas. If we could decrease the size of said material while maintaining the strength we could design houses and building with minimal design interference. This is one of the many practical uses for developing nano materials. Although the idea is simple and straightforward, the work required in the lab can be complex and usually expensive. However, the thousands of applicable uses of nanotechnology makes it something worth exploring and developing further. In this journal published in 2014 [5], Wong talks about the added benefits from using nano materials for building materials such as weatherproofing, self-cleaning, and the ability to cut down pollution. Further back in 2010 [6], there's been work dedicated into using nanotechnology in concrete to help with the building structures.

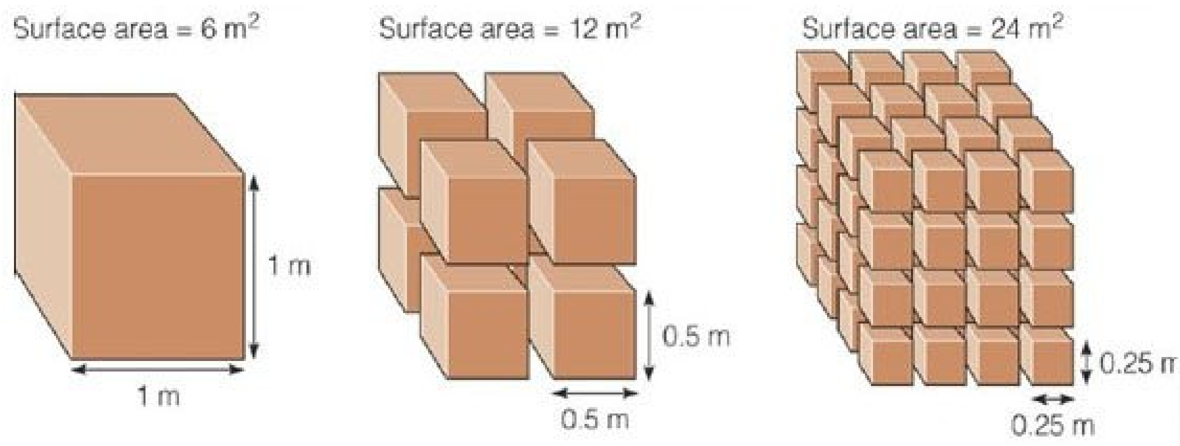
4 Collective Surface Area

$$A_{collective} = \Sigma A_{particles} \tag{1}$$

4.1 Divisible Cube

Collective surface area at its core is the idea of power in numbers. The basic idea is that in the process of dividing an object you create more separate surface area. In a situation where you have a cube divided into 4 smaller cubes you now have $4 * (6a^2)$ as per the surface area of a cube in Figure 1. For a visual representation see Figure 2.

Figure 2: As a cube is divided surface area increases.



As can be seen the surface area greatly increases every time the division is done. If done enough times you can end up with millions of tiny cubes with just nanometers of size per side. Each of these can be a bond to another cube thus amplifying the strength of the structure. To find the theoretical number of nanocubes the following formula can be used:

$$N_{nc} = \frac{6m^2}{600nm^2}\left(\frac{10^9 nm}{m}\right)^2 = 1 * 10^{16} \tag{2}$$

Where N_{nc} is the number of Nanocubes. The number of nanocubes can now be used to find the volume which they take up using:

$$1 * 10^{16} * \left(\frac{10nm^3}{nanocube}\right)\left(\frac{m}{10^9}\right)^3 = 1 * 10^{-8}m^3\left(\frac{100cm}{m}\right)^3 = 0.01cm^3 \tag{3}$$

This shows that $1 * 10^{16}$ nanocubes take up 0.01 centimeters while still maintaining the strength. An impressive feat and display of the innovation available through the study of nano science. This is but one of the many things that can be accomplished.

5 Singular Surface Area

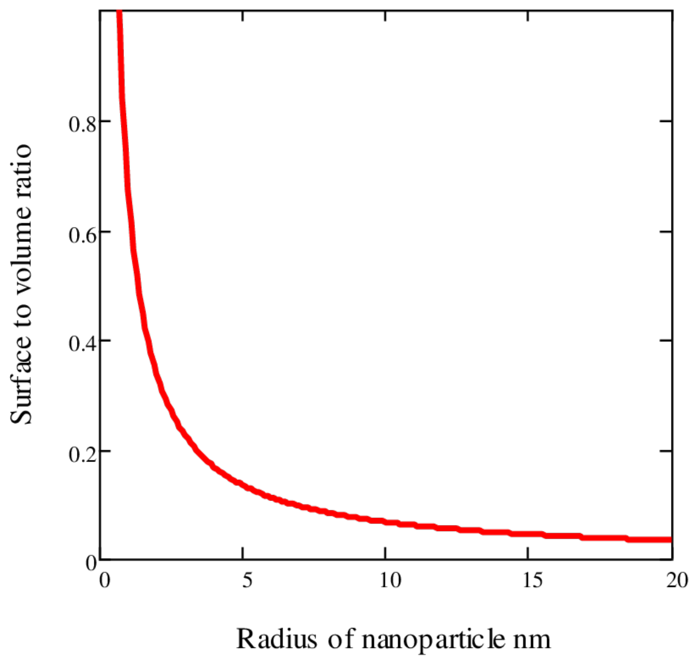
5.1 The Simple Cube

Area and volume grow at different proportions. Area of a cubes is the dimension squared, while volume is the dimension cubed. Singular surface area is the area of a nanoparticle. As the dimension becomes smaller the surface area increases and the ratio between the two becomes more and more prominent. The small table below goes over the general idea of this concept based on the simple cube, a cube with the dimension of 1 meter as it decreases.

Dimension	Area in m^2	Volume in m^3	S/V Ratio
1 m	6	1	6
0.1 m	6 x 10^{-2}	6 x 10^{-3}	60
0.01 m	6 x 10^{-4}	6 x 10^{-6}	600
0.001 m	6 x 10^{-6}	6 x 10^{-9}	6,000
1 x $10^{-6}m$	6 x 10^{-12}	6 x 10^{-18}	6 x 10^{6}
6 x $10^{-9}m$	6 x 10^{-18}	6 x 10^{-27}	6 x 10^{9}

Table 1: Simple Cube.

Figure 3: This graph demonstrate the correlation between size and surface area.



6 Surface Area to Volume Ratio

As was seen in Figure 3 the surface to volume ratio d^2/d^3, where d is the dimension, is maintained and grows as the dimension shrinks. This relationship is vital to the world of nanoscience. Most bulk structures are built of millions of atoms which lead to bigger structures, and this makes it easier to work with. However, when working at the nanoscale we're working with just a few particles. For this reason it is important to know just how many atoms are involved within certain parameters such as volume. To find the number we can first find the volume of the surface by using:

$$V_{surface} = \frac{4}{3} * \pi * R^3 - \frac{4}{3}\pi(R-d)^3 \quad (4)$$

Where:

- $V_{surface}$ is the surface layer
- R is the radius
- d is the atomic diameter

Then we can use the formula:

$$V_{atom} = \frac{4}{3} * \pi * \left(\frac{d}{2}\right)^2 \quad (5)$$

To find the the volume available.

Afterwards both results can be used to find the number of atoms at the surface:

$$N_{s-element} = \frac{V_{surface}}{V_{atom}} \tag{6}$$

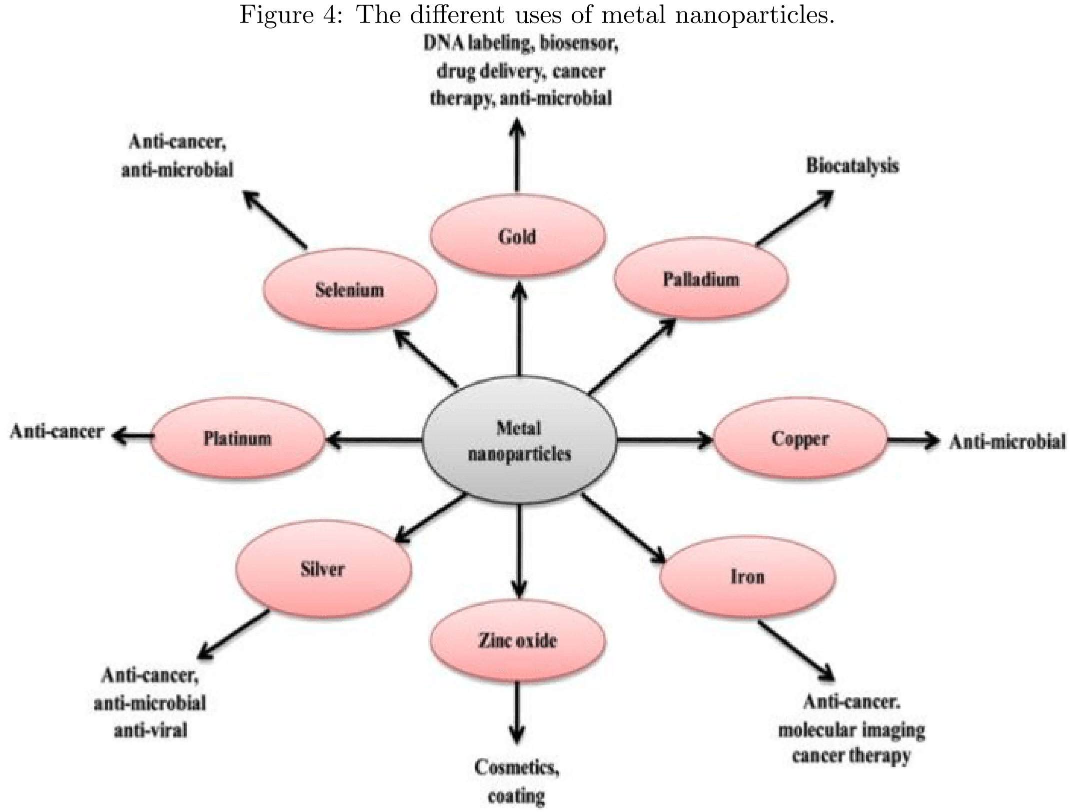
Where $N_{s-element}$ is the number of atoms within the colloid. By knowing exactly the amount we're working with we can be more precise with the structures we're trying to build and how many particles we're packing into a given volume.

7 Utility

7.1 Metal Nano Particles

The property of vast surface area tends to become useful as a catalysis for interactions between surfaces. This means that, although useful, this property leads for a nano particle to interact quickly thus making it unstable. However, the growing field of material science offers solutions to this problem. One way is to cover the material in a nano shell to overcome the stability issue [7]. It is discussed that by enveloping the metal nanoparticle it makes it a more viable material that can be used in different applications. Some of the key utilities are recyblebility, photo/electo-catalysis, and higher selectivity. Recyclebility is a major attribute. Currently, nano materials and the production of them are extremely expensive, however if we can find a way to increase how reusable they are it would drive cost down. Not to mention more money for research and support. To say surface to volume ratio is important is an understatement.

Figure 4: The different uses of metal nanoparticles.



7.2 Nanotechnology and Medicine

Figure 4 does a great job at showing the different use for each metal nanoparticle. Silver, Selenium, and Iron are extremely useful in creating nanotechnology that can combat diseases such as cancer. Others such as gold can assist with therapy as well as the development of targeted drug delivery methods. The possibilities are endless for nanotechnology in different fields.

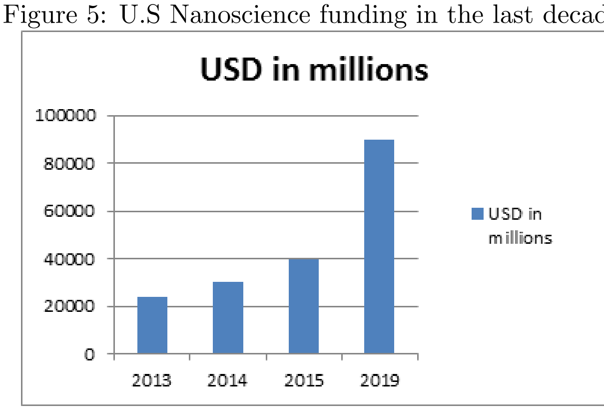
8 Nanoscience ≠ Nano Problems

With the many absolutely great innovations that nanotechnology can bring why aren't we doing everything with nanotechnology? In a perfect world we would shift to new technology as it became available and move forward, unfortunately we're far from that point. There are many factors to consider as to why more isn't allocated to this research, but there's two in particular that stand out.

8.1 Resources

Although a good amount of money is being spent to fund research in nanoscience, it isn't enough. For one, producing nanomaterials is extremely expensive. Even the entry point is quite pricey. Some of the older versions of equipment such as Atomic Force Microscopes and Scanning Electromagnetic Microscopes are still priced at more than 300 thousand dollars. That's a huge starting investment for microscopes, and you still need other machines to build the technology itself. On top of that equipment is extremely sensitive which means that any form of issue with it will result in costly repairs. Unfortunately another thing associated to the lack of funding is another resource, time. You can't mass produce nanomaterials currently because of the precision it requires to work with nanoparticles. Although funding has been increasing over the last few years [8] the associated costs are still difficult to fund.

Figure 5: U.S Nanoscience funding in the last decade.

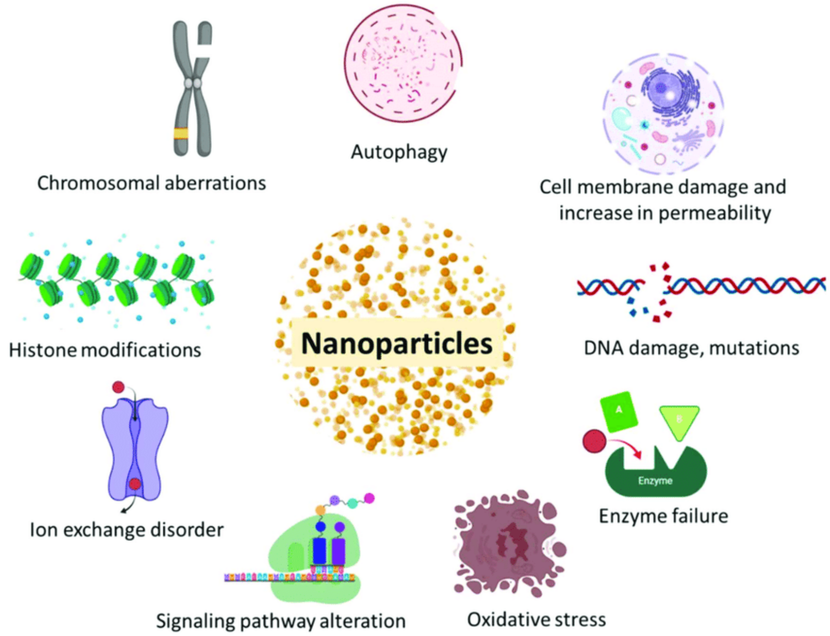


As can be seen funding has been steadily increasing to almost 5 times the amount in 2013 in present day 2022. The rise in spending could be the newfound applications particularly in the medical and material fields. Nanotechnology has introduced a new way to tackle certain illnesses or diseases that we weren't able to fight before. The hope is that as more applications become viable the funding continues to climb.

8.2 Environmental Issues

Environmental problems always arise when working with new technology. When you're at the frontier of something new you don't know what to account for. This has long been a concern in nanoscience. There's plenty of publications referring to the possible pollution by nanoscience [9]. Waste management is an important thing to consider because nanomaterials tend to made with metals which at long exposure can cause illness. A reason for this is simple, nanotechnology is small. Just because it can't be seen does not mean it isn't there. In fact, viruses are typically at the nanoscale in size, and they still manage to get us sick. An argument with nanotechnology is waste, how to dispose of used material since we usually require electron microscope to see them. Along with because of the scale nanomaterials can cause toxicity in a different kind of way. Nanotechnology is so small that it can get in the way of enzymes bonding in your body. It can also cause DNA damage leading to mutations such as cancer. Nanotechnology is a great innovative field, but it requires care and responsibility.

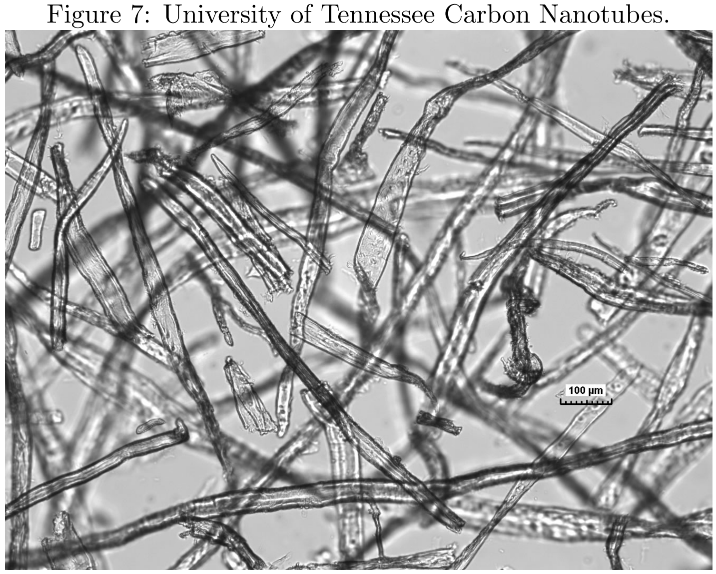
Figure 6: The multiple conditions that can be caused by nanoparticle toxicity.



9 Final Thoughts

Nanoscience is a field that definitely was ahead of the available technology. However, it has grown to be a field that grows in a symbiotic relationship with others. As technology gets better the ability to produce better and significant improvements on nanotechnology grows, and as nanotechnology grows bigger strides forward are made that allows us to further our technological capacity. I've enjoyed and learned a great deal reading about this field and I believe more people should take time to be inspired by it. We currently live in a truly great time in human history where technology has opened paths into many fields. We live in a time where we have the means to study some of the more baffling sciences. We live in a time where we don't have to trade comfort for knowledge, we can have both. Nanoscience is the way into the future, and just like computing I believe we'll reach a point where it will be accesible and affordable for everyone to enjoy the benefits discussed in this paper.

Figure 7: University of Tennessee Carbon Nanotubes.



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