Challenges and opportunities

-Understanding the Basic Properties of Nanoparticles

K-STATE
Physics Education Research Group

Outline

I. Motivation
- To understand the Basic Physics behind nanoparticles

II. Aim
- To introduce the new field of Science to the students and teachers and excite them

III. Scope
- The study of unique phenomena could change the understanding of matter and lead to different types of questions and answers related to air pollution,health care,energy etc.

On 29th Dec.1959, Richard Feynman presented a visionary and prophetic lecture at a meeting of the American Physical Society, entitled

“There is Plenty of Room at the Bottom”

where he speculated on the possibility and potential of nanosized materials.

What is Nano Science and What is so special about Nanoscale ?

•Why do we want to study such small things?

•How do we see such small things?

•How do we make such small things?

When we study chemistry we deal with atoms and molecules and realm of matter of dimensions generally less than one nanometer (atomic scale).

When we study condensed matter physics, we deal with solids of an infinite array of bound atoms or molecules of dimensions greater than 100nm (micro scale).

Chemistry

↓

Study of Atoms
and
Molecules

↓

Size
Less than 1nm

Condensed Matter
Physics

↓

Deals with solids of an
infinite array of bound
atoms or molecules

↓

Size
Greater than 100nm

A significant gap exists between 1nm and 100nm

Nanosized particles exhibit different properties than large particles of the same substance

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The Basic Question Is

Why do these properties change at nanoscale ?

Do we have enough knowledge of science to explain these properties or

Do we have to develop new science ?

How do we excite the students so they come up with new ideas ?

So when we study phenomena at this scale we…

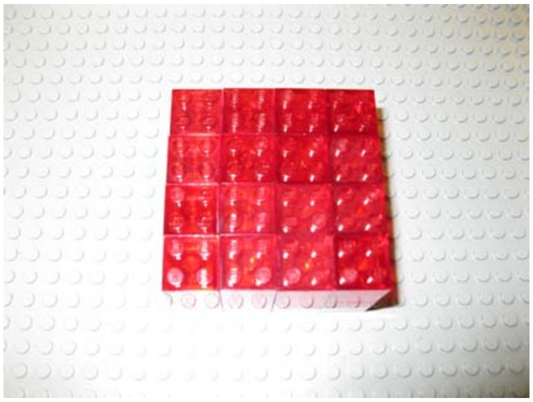
Learn/improve our understanding about the nature of matter

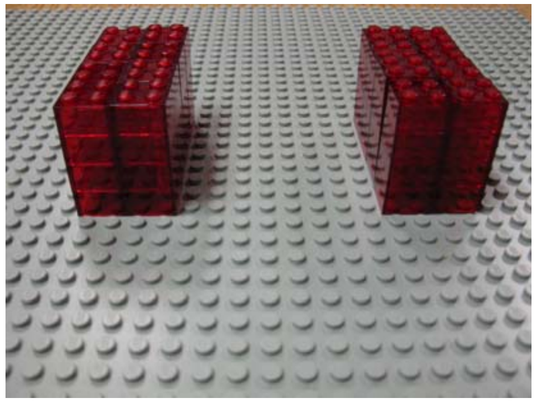
Develop new theories.

Lead to new questions and answers in many areas, including, air pollution health care, energy, technology etc.

Activity 1

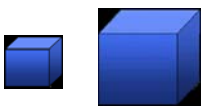
1. Construct a cube or parallelopiped using Lego.
   Measure the length, breadth and height.
   Calculate its Volume and Total Surface Area.
   Find the Total Surface Area to Volume Ratio.
2. Now, divide the fig into two pieces as shown in the fig.
   Again, find the Total Surface Area to Volume Ratio.
3. Further divide each piece into two more pieces and find the Total Surface Area to Volume Ratio.



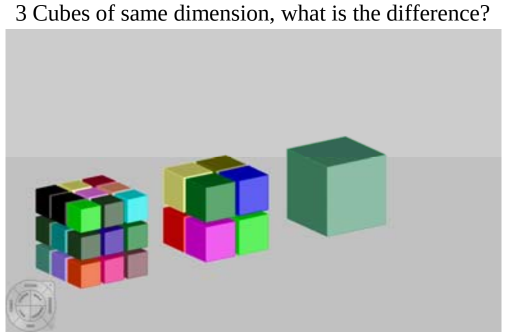


Activity 2

Can you predict which cube has larger SVR ?



3 Cubes of same dimension, what is the difference?



1. **Draw a cube.**
   Let the length of each side = 1m
   Calculate its Volume and Total Surface Area.
   Find the Surface Area to Volume Ratio.

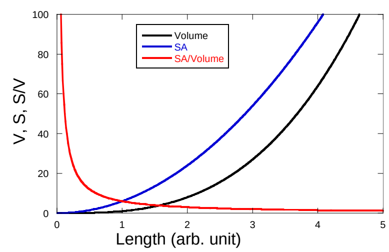
2. **Now, cut the cube into 8 (=2^3) pieces that are of 0.5m per side.**
   Again, find the Surface Area to Volume Ratio.

3. **Further, cut the cube into 27 (=3^3) pieces and find the Surface Area to Volume Ratio.**

4. **Draw your conclusion.**

5. **Explore the Relationship between V vs L, SA vs L and SA/V vs L.**

Cubes with different Lengths :



Consider a Cube with length of each side = 1m
Since it has six faces, its surface area = 6 sq.m.
Its volume = 1 cubic meter
Surface Area to Volume Ratio = 6/1 = 6

If we cut the cube into 8 (=2^3) pieces that are of 0.5m per side , then the surface area of each piece = (1/2)x(1/2) x6 = 1.5 sq.m.
But there are 8 pieces, total surface area = 1.5x8 = 12 sq.m.
Surface Area to Volume Ratio = 12/1 = 12

If we further cut into 27 (=3^3) pieces, then the surface area of each piece = (1/3)x(1/3) x6 = (2/3) sq.m.
But there are 27 pieces, total surface area = (2/3)x27 = 18 sq.m.
Surface Area to Volume Ratio = 18/1 = 18

cubebuilding_final.exe

The Surface Area :

It is measured in the unit of $\frac{Sq.m}{g}$.

Surface Area $S = \frac{Area}{\rho.Volume} = \frac{A}{\rho V}$

$For\ Sphere:\ S = \frac{6}{\rho d}\ where\ d$ **is the diameter.**

$For\ Cylinder:\ S = \frac{4}{\rho d}\quad (d << L)$ **[Area of the two ends of the cylinder (Wire) is neglected]**

$For\ Disk:\ S = \frac{2}{\rho L}\quad (L << d)$ **[Area of the side of the Disk neglected)**

$For\ Cube:\ S = \frac{6}{a\rho}\quad a$ **is length of the each side of the cube.**

Length parameters a, d **and** L **are expressed in nm and Density** ρ **is in** $\frac{g}{cm^3}$

For the same volume : $S_{cube} = 1.24\ S_{sphere}$

Relation Between Surface Area of a Cylinder and a Sphere for the same volume

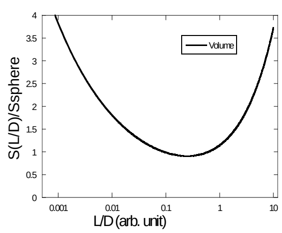
General Expression:

$$S\left(\frac{L}{D}\right) = 0.382\ S_{sphere}\left[2\left(\frac{L}{D}\right)^{\frac{2}{3}} + \left(\frac{D}{L}\right)^{\frac{1}{3}}\right]$$

When $\frac{L}{D} = 1$, $S\left(\frac{L}{D}\right) = 1.146\ S_{sphere}$

For Cylinder: L = Length
D = Diameter
For Sphere : r = Radius

$r = \frac{1}{2}\left(\frac{3D^2L}{2}\right)^{\frac{1}{3}}$ When the $V_{cylinder} = V_{sphere}$



The above fig shows that Nanostructure of a particular mass or a particular volume have much higher surface area when they are flat or elongated in shape.

Macroscale Surface Area to Volume Ratio

A typical material possesses:

~ 10^{23} atoms/cm^3 (volume density)
~ 10^{15} atoms/cm^2(surface density)
Assume that we have a cube with side of length = 1 cm.
Total number of atoms ~ 10^{23} atoms/cm^3 × $(1\ cm)^3$ ~ 10^{23}
Total number of surface atoms ~ 10^{15} atoms/cm^2× 6 × $(1\ cm)^2$ ~ 6× 10^{15}

Ratio of surface to total atom ~ 6×10^{15} / 10^{23} ~ 6× 10^{-8}

Nanoscale Surface Area to Volume Ratio

A typical material possesses:

~ 10^{23} atoms/cm^3 (volume density)
~10^{15} atoms/cm^2 (surface density)
Assume that we have a cube with side of length = 1 nm = 10^{-7}cm.
Total number of atoms
~ 10^{23} atoms/cm^3 × $(10^{-7}cm)^3$ ~ 100
Total number of surface atoms
~ 10^{15} atoms/cm^2 × 6 × $(10^{-7}cm)^2$ ~ 60

Ratio of surface to total atoms ~ 60/100 ~ 0.6

Surface Area is very Large !

A change In size of building blocks of the same cube have shown changes in their surface area drastically, this simple characteristic of surface geometry is the foundation of Nano-technology."

NANOSCALES OBJECTS

HAVE A GREATER SURFACE AREA THAN VOLUME

VERY IMPORTANT PROPERTY

HIGH SURFACE AREA TO VOLUME RATIO

Nanoscale Melting Temperature

Size decreases

Surface energy increases

Melting point decreases

e.g. 3 nm CdSe nanocrystal melts at 700 K compared to bulk CdSe at 1678 K

The increasing proportion of surface atoms with decreasing particle size compared with bulk metals makes small metal particles become highly reactive catalysts as surface atoms possess more energy than bulk atoms.

Size Dependent Properties

1) Chemical properties – reactivity, catalysis
2) Thermal properties – melting temperature
3) Mechanical properties – adhesion, capillary forces
4) Optical properties – absorption and scattering of light
5) Electrical properties – tunneling current
6) Magnetic properties – superparamagnetic effect

1. What is the range of nanoscale ?

2. What is the smallest size that the human eye can see ?

3. Name TWO properties of nanoparticles which differ from large objects of the same objects.

4. Explain why surface to volume ratios are important in determining the property of a substance.

Activity 3:

Scale makes difference !

Indicate the value of 'x':

10^X m	(1 femtometer)	x = ?
10^X m	(1 angstrom)	
10^X m	(1 nanometer)	
10^X m	(10 nanometers)	
10^X m	(1 micron)	
10^X m	(100 microns)	
10^X m	(1 millimeter)	
10^X m	(10 millimeters)	
10^X m	(1 meter)	

Activity 4:

In this activity, you will explore your perceptions of different sizes. Indicate the size by placing an "X" that is closest to your guess from the following key.

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 ìm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 ìm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]
F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10^{0} meters]
G. Between 1 meter and 10 meters [Between 10^{0} and 10^{1} meters]
H. More than 10 meters [More than 10^{1} meters]

	A	B	C	D	E	F	G	H
1. Width of a human hair								
2. Length of a football field								
3. Diameter of a virus								
4. Diameter of a hollow ball made of 60 carbon atoms (a"buckyball")								
5. Diameter of a molecule of hemoglobin								
6. Diameter of a hydrogen atom								
7. Diameter of a human blood cell								
8. Length of an ant								
9. Height of an elephant								
10. Wavelength of visible light								
11. Height of a typical adult person								
12. Length of a school bus								
13. Diameter of the nucleus of a carbon atom								
14. Length of a postage stamp								
15. Length of an adult's little finger								

1. What is the range of nanoscale ?

2. What is the smallest size that the human eye can see ?

1. 1-100nm (in at leas one dimension)
2. The nacked eye can see down to about 20 microns i.e. 20000 nm.

3. Name TWO properties of nanoparticles which differ from large objects of the same objects.

4. Explain why surface to volume ratios are important in determining the property of a substance.

3. Nanoparticles have lower melting point because there is a greater percentage of atoms at the surface require less energy to overcome intermolecular force of attraction
Nanoparticles have a greater percentage of atoms at the surface and thus greater reactivities.

4.When S/V is low, more particles are in the interior of the substance and they are experiencing the similar forces. When S/V is high, more particles are on the surface and they experience forces from the substance as well as from the surroundings. So reaction rate increases.

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 ìm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 ìm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]
F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10^{0} meters]
G. Between 1 meter and 10 meters [Between 10^{0} and 10^{1} meters]
H. More than 10 meters [More than 10^{1} meters]

	A	B	C	D	E	F	G	H
1. Width of a human hair				x				
2. Length of a football field								x
3. Diameter of a virus		x						
4. Diameter of a hollow ball made of 60 carbon atoms (a"buckyball")		x						
5. Diameter of a molecule of hemoglobin		x						
6. Diameter of a hydrogen atom	x							
7. Diameter of a human blood cell				x				
8. Length of an ant					x			
9. Height of an elephant							x	
10. Wavelength of visible light			x					
11. Height of a typical adult person							x	
12. Length of a school bus								x
13. Diameter of the nucleus of a carbon atom	x							
14. Length of a postage stamp						x		
15. Length of an adult's little finger						x		

1. D 2. H 3. B 4. B 5. B 6. A 7. D 8. E 9. G 10. C 11. G 12. H 13. A 14. F 15. F

10^{X} m	(1 femtometer)	x=-15
10^{X} m	(1 angstrom)	x=-10
10^{X} m	(1 nanometer)	x=-9
10^{X} m	(10 nanometers)	x=-8
10^{X} m	(1 micron)	x=-6
10^{X} m	(100 microns)	x=-4
10^{X} m	(1 millimeter)	x=-3
10^{X} m	(10 millimeters)	x=-2
10^{X} m	(1 meter)	x=0

Conclusions

Hands on activities

1. **give students a feel –How small is nanoscale.**
2. **give students practice to calculate surface area and volume and to determine the relationship – How SVR changes with the shape or size of an object.**
3. **give an understanding of how and why SVR changes dramatically in the nanometer scale.**

Thank you !