Challenges and opportunities

- Understanding the Basic Properties of Nanoparticles

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

A significant gap exists between 1nm and 100nm.

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 parallelepiped 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?

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 $L$. 
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

The Surface Area :
It is measured in the unit of \( \text{m}^2 \).

Surface Area \( A = \frac{4 \pi r^2}{3} \) where \( r \) is the diameter.

For Cylinder : \( A = \pi l \) where \( l \) is the length of the cylinder. 

For Disk : \( A = \pi r c \) where \( r \) is the radius of the disk neglected.

For Cube : \( A = 6a^2 \) where \( a \) is length of the each side of the cube.

Length parameters such as \( l, r \) and \( a \) are expressed in mm and Density \( \rho \) is in 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:

For Cylinder: \( L = \text{Length} \)
\( D = \text{Diameter} \)
For Sphere : \( r = \text{Radius} \)

\[ \frac{L}{D} = 1 \quad \frac{x}{\left( \frac{D}{r} \right)^2} = 1.146 \]

When \( \frac{L}{D} = 1 \), \( \frac{x}{\left( \frac{D}{r} \right)^2} = 1.146 \cdot x_{sphere} \)

Macroscale Surface Area to Volume Ratio

A typical material possesses:

\(~10^{23} \text{ atoms/cm}^3\) (volume density)
\(~10^{15} \text{ atoms/cm}^2\) (surface density)

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

Ratio of surface to total atom ~ \(~6 \times 10^{15}/ 10^{23}\) ~ \(~6 \times 10^{-8}\)

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.
### Nanoscale Surface Area to Volume Ratio

A typical material possesses:

- ~ $10^{23}$ atoms/cm³ (volume density)
- ~$10^{15}$ atoms/cm² (surface density)

Assume that we have a cube with side of length = 1 nm = $10^{-7}$ cm.

Total number of atoms:

\[ \approx 10^{23} \text{ atoms/cm}^3 \times (10^{-7} \text{ cm})^3 \approx 100 \]

Total number of surface atoms:

\[ \approx 10^{15} \text{ atoms/cm}^2 \times 6 \times (10^{-7} \text{ cm})^2 \approx 60 \]

Ratio of surface to total atoms: $\frac{60}{100} \approx 0.6$

### 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.

### 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

### 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

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**NANOSCALES OBJECTS**

**HAVE A GREATER SURFACE AREA THAN VOLUME**

**VERY IMPORTANT PROPERTY**

**HIGH SURFACE AREA TO VOLUME RATIO**

**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.**
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 \( x \):

- \( 10^3 \text{ m} \) (1 femtometer)
- \( 10^4 \text{ m} \) (1 angstrom)
- \( 10^5 \text{ m} \) (1 nanometer)
- \( 10^6 \text{ m} \) (10 nanometers)
- \( 10^7 \text{ m} \) (1 micron)
- \( 10^8 \text{ m} \) (100 microns)
- \( 10^9 \text{ m} \) (1 millimeter)
- \( 10^{10} \text{ m} \) (10 millimeters)
- \( 10^{11} \text{ m} \) (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 µm) [between 10⁻⁷ and 10⁻⁶ meters]
D. Between 1 micrometer (1 µm) and 1 millimeter (1 mm) [between 10⁻⁶ and 10⁻⁵ meters]
E. Between 1 millimeter (1 mm) and 1 centimeter (1 cm) [between 10⁻⁵ and 10⁻⁴ meters]
F. Between 1 centimeter (1 cm) and 1 meter (m) [between 10⁻⁴ and 10⁻³ meters]
G. Between 1 meter and 10 meters [between 10⁻¹ and 10⁰ meters]
H. More than 10 meters [more than 10⁰ meters]
### 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.

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<th>$10^x$ m</th>
<th>Unit</th>
<th>$x$</th>
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<td>$10^{-15}$ m</td>
<td>(1 femtometer)</td>
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<td>$10^{-10}$ m</td>
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<td>(10 nanometers)</td>
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