FRESHER'S ONLINE BRIDGE COURSES: PHYSICS

VIT-AP UNIVERSITY

by

Dr. Vivek Shukla

Assistant Professor,

Department of Physics,
Vellore Institute of Technology,
Andhra Pradesh (VIT-AP University)
Amaravati, Andhra Pradesh-522237, India
mail- vivek.shukla@vitap.ac.in

What is Nanotechnology?

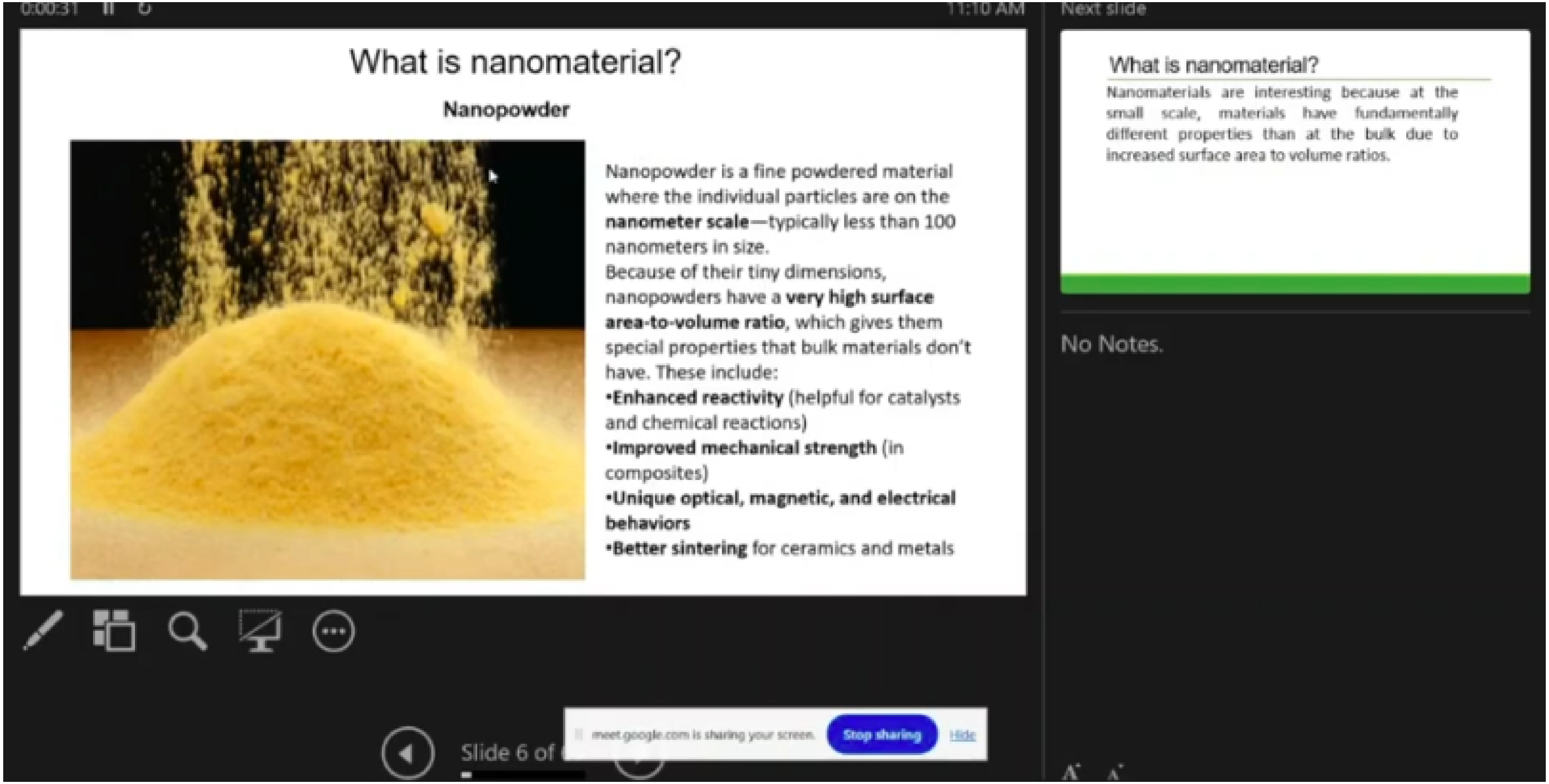
- Nanotechnology is the science, engineering, and application of materials and devices at the nanometer scale — typically 1 to 100 nanometers (a nanometer is one-billionth of a meter).
- It involves manipulating atoms and molecules to create new materials with unique physical, chemical, and biological properties that differ from their bulk counterparts.

Key points about Nanotechnology:

Scale: Works at the atomic and molecular level.

Goal: To design and control structures for specific functions.

Unique properties: Materials may exhibit higher strength, lighter weight, better electrical conductivity, im[illegible]ity, or novel optical behavior.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What is nanomaterial?
Nanopowder
Nanopowder is a fine powdered material where the individual particles are on the nanometer scale—typically less than 100 nanometers in size.
Because of their tiny dimensions, nanopowders have a very high surface area-to-volume ratio, which gives them special properties that bulk materials don't have. These include:
•Enhanced reactivity (helpful for catalysts and chemical reactions)
•Improved mechanical strength (in composites)
•Unique optical, magnetic, and electrical behaviors
•Better sintering for ceramics and metals
What is nanomaterial?
Nanomaterials are interesting because at the small scale, materials have fundamentally different properties than at the bulk due to increased surface area to volume ratios.
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What is nanomaterial?

Nanomaterials are interesting because at the small scale, materials have fundamentally different properties than at the bulk due to increased surface area to volume ratios.

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What is nanomaterial?

Increased interaction and reactivity is one of the by products of materials that are nanoscale, which means potentially using less of the material or that even on the nanoscale the properties are so utterly different from that of the bulk scale.

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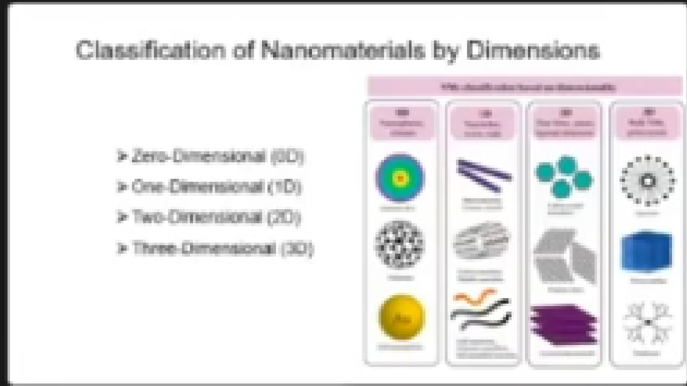
Nanomaterials' Characteristics

Most of them are novel, why?

One definition of novel materials is:
(new forms of existing materials with characteristics that differ significantly from familiar or naturally-occurring forms.)
Nanomaterials can have one, two or three dimensions in the nanoscale:



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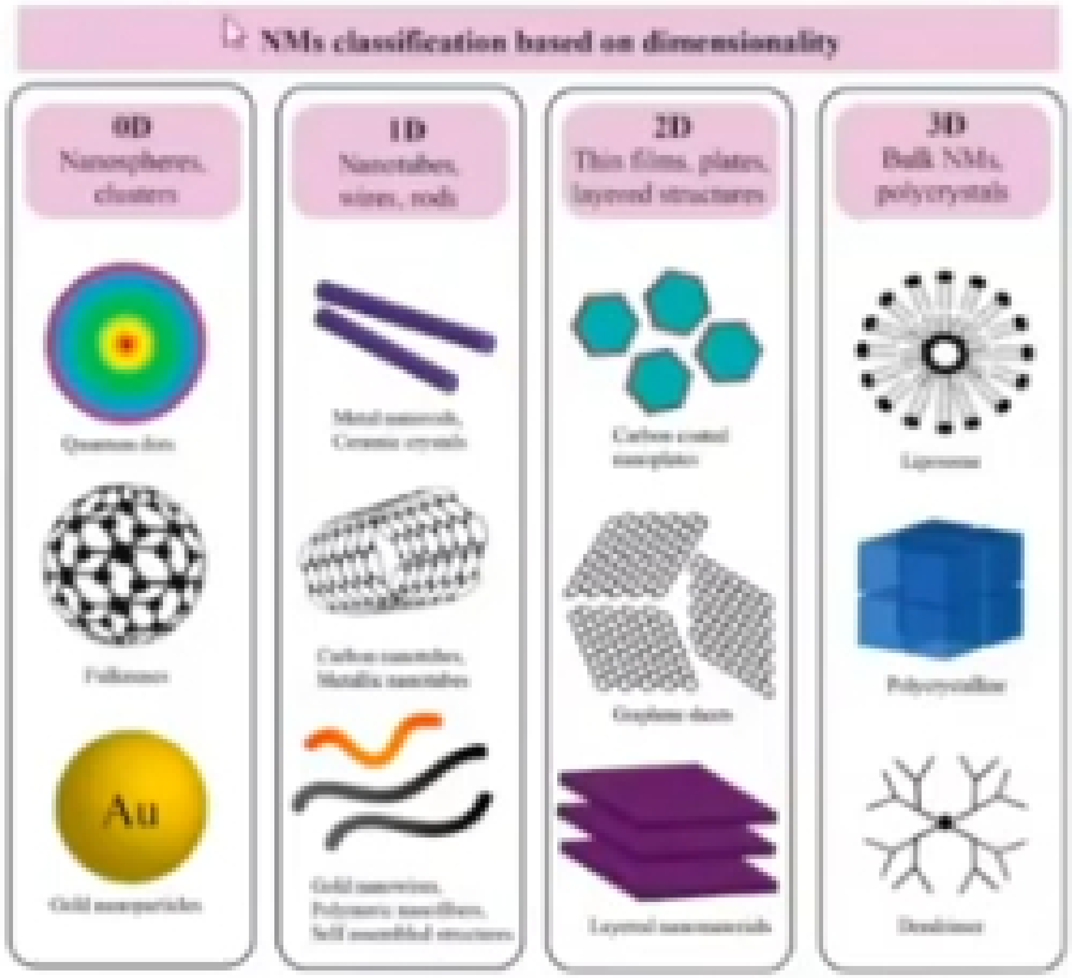
Classification of Nanomaterials by Dimensions

- Zero-Dimensional (0D)
- One-Dimensional (1D)
- Two-Dimensional (2D)
- Three-Dimensional (3D)



Zero-Dimensional (0D) Nanomaterials

Definition: All dimensions in the nanoscale range (1–100 nm).
Properties: No dimension exceeds the nanoscale; essentially nanoparticles.
Examples:
- Gold nanoparticles (AuNPs)
- Quantum dots (CdSe, PbS)
- Fullerenes (C_{60})

One-Dimensional (1D) Nanomaterials

Definition: Two dimensions in the nanoscale, third dimension much larger.

Properties: High aspect ratio, nanorods, nanowires, nanotubes.

Examples:

- Carbon nanotubes (CNTs)
- Zinc oxide nanowires (ZnO NWs)
- Silver nanorods

Two-Dimensional (2D) Nanomaterials

Definition: One dimension in the nanoscale, two dimensions much larger.
Properties: Sheet-like, large surface area, unique electronic properties.
Examples:
- Graphene
- Molybdenum disulfide (MoS_2) nanosheets
- Hexagonal boron nitride (h-BN) sheets

Three-Dimensional (3D) Nanomaterials

Definition: Extend in all three dimensions but composed of nanoscale building blocks.
Properties: Bulk materials with nanocrystalline structure or nanocomposites.
Examples:
- Nanocrystalline metals
- Nanocomposites (polymer matrix with nanosilica)
- Nanoporous materials

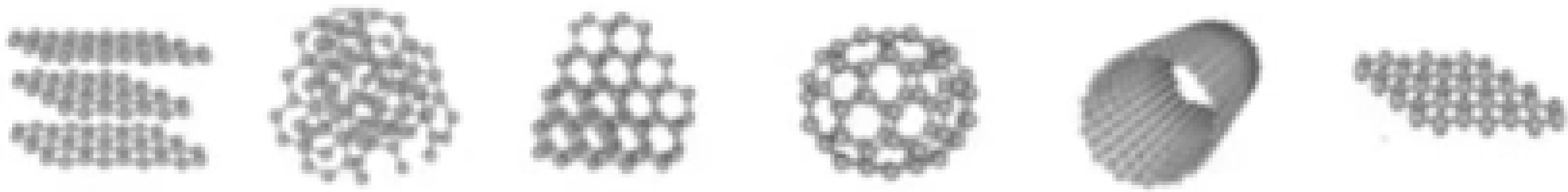
Types of Nanomaterials

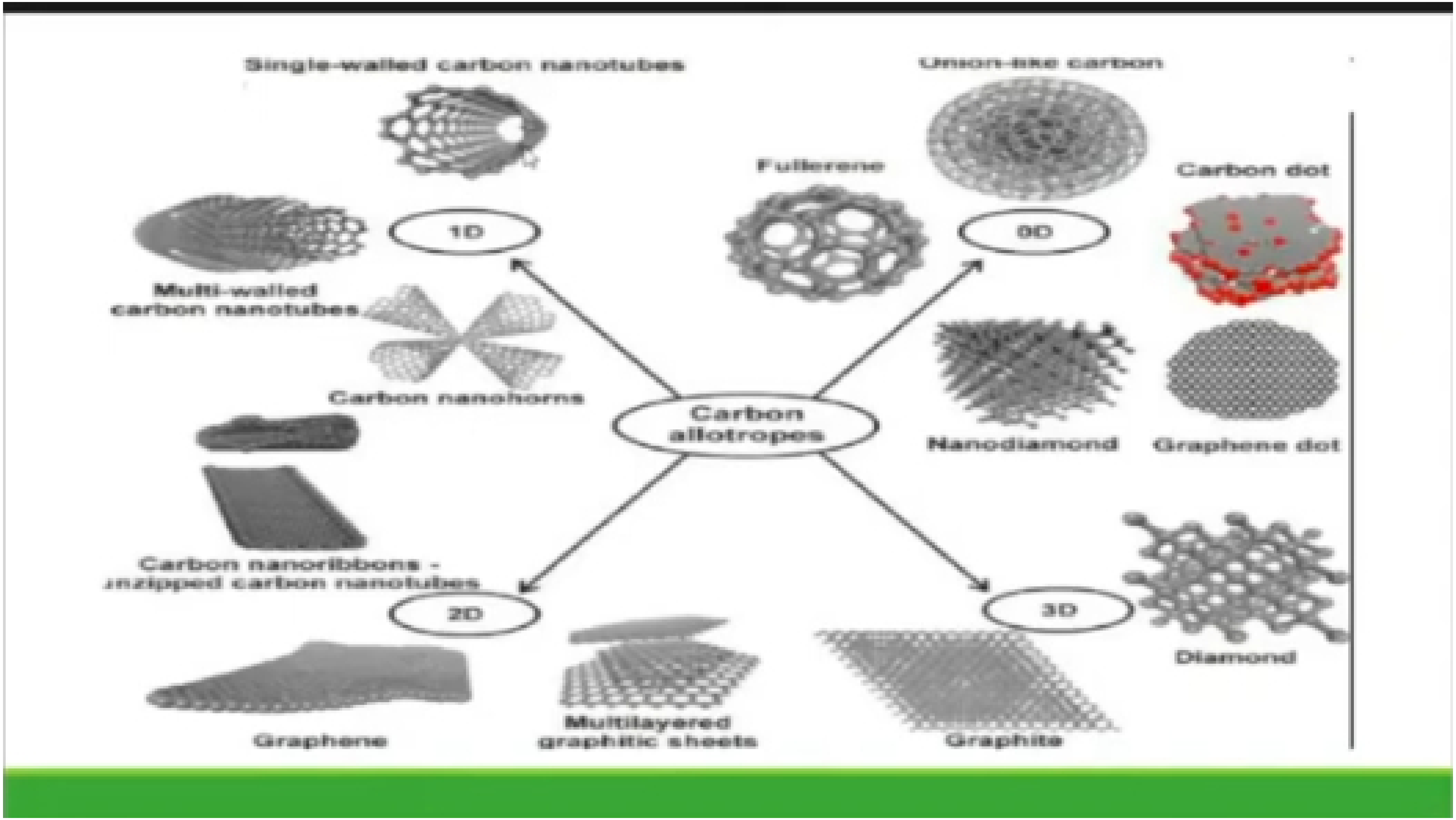
Most current nanomaterials could be organized into four types:

- Carbon Based Materials
- Metal Based Materials
- Dendrimers
- Composites

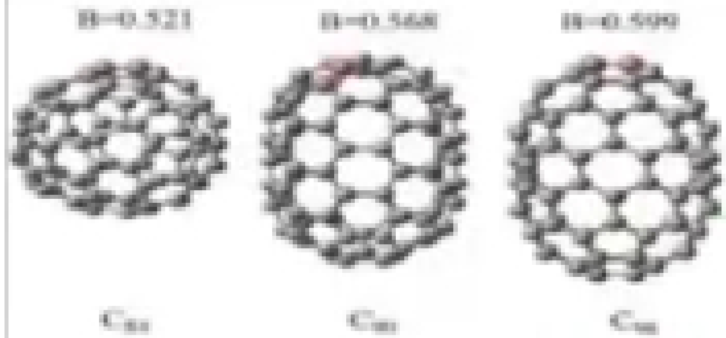
Types of Nanomaterials

Until recently, only two natural carbon allotropes were known: diamond and graphite. All nanomaterials composed of carbon atoms are termed as carbon-based or carbon nanomaterials. The Classification of carbon-based nanomaterials is most commonly performed according to their geometrical structure. Carbon nanostructures include particles that be tube-shaped, horn-shaped, spherical or ellipsoidal.

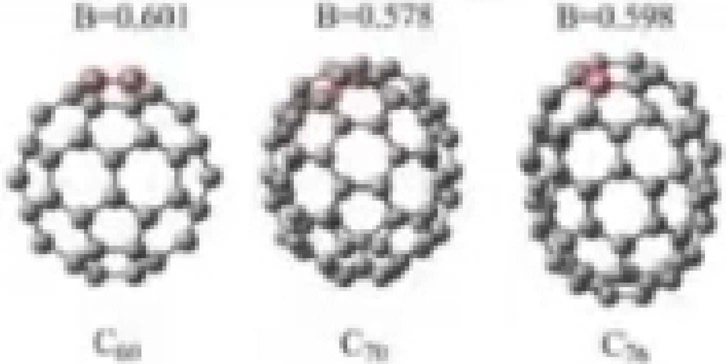




Single-walled carbon nanotubes
Union-like carbon
Fullerene
Carbon dot
1D
0D
Multi-walled
carbon nanotubes
Carbon nanohorns
Carbon
allotropes
Nanodiamond
Graphene dot
Carbon nanoribbons -
unzipped carbon nanotubes
2D
3D
Diamond
Graphene
Multilayered
graphitic sheets
Graphite

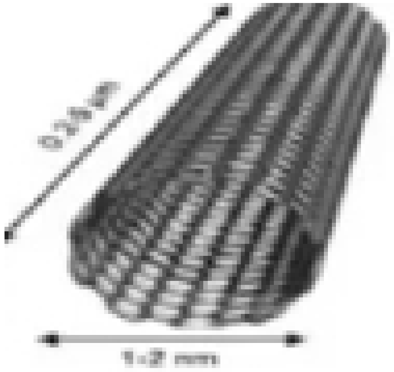


Fullerenes

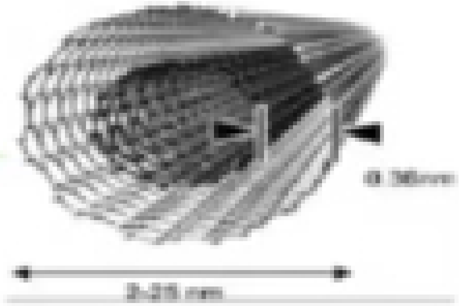


Fullerenes are an allotropic modification of carbon, often termed as a molecular form of carbon, or carbon molecules. The fullerene family includes a number of atomic C_n clusters ($n > 20$), composed of carbon atoms on a spherical surface. Carbon atoms are usually located on the surface of the sphere at the vertices of pentagons and hexagons. In fullerenes, carbon atoms are usually present in the sp2-hybrid form and linked together by covalent bonds. Fullerene C60 is the most common and best-investigated fullerene. The spherical molecule is highly symmetric and consists of 60 carbon atoms, located at the vertices of twenty hexagons and twelve pentagons. The diameter of fullerene C60 is 0.7 nm.

The Nobel Prize in Chemistry in 1996 was awarded jointly to Robert F. Curl Jr., Sir Harold W. Kroto, and Richard E. Smalley for their discovery of fullerenes.



Carbon nanotubes (CNTs)



CNTs are one of the carbon allotropes with exceptional properties suitable for technical applications. Carbon nanotubes are characterized by cylindrical structures with a diameter of several nanometers, consisting of rolled graphene sheets. Carbon nanotubes may vary in length, diameter, chirality (symmetry of the rolled graphite sheet) and the number of layers. According to their structure, CNTs may be classified into two main groups: single-walled nanotubes (SWCNTs) and multi-walled nanotubes (MWCNTs).

CNTs were first observed in 1991 by Sumio Iijima, but while his work is foundational in nanotechnology, it has not been recognized with a Nobel Prize.

Carbon nanotubes (CNTs)

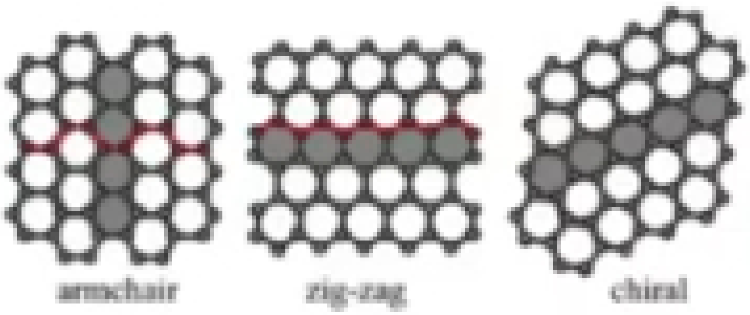
Generally, SWCNTs have a diameter around 1–3 nm and a length of a few micrometres. Multi-walled CNTs have a diameter of 5–40 nm and a length around 10 μm. The structure of CNTs leads to excellent properties with a unique combination of rigidity, strength and elasticity compared with other fibrous materials. For instance, CNTs show high thermal and electrical conductivity compared to other conductive materials

Carbon nanotubes (CNTs)

Electrical properties of SWCNTs depend on their chirality or hexagon orientation with respect to the tube axis. So, SWCNTs are classified into three sub-classes:

(i) Armchair (electrical conductivity > copper).
(ii) Zigzag (semiconductive properties).
(iii) Chiral (semi-conductive properties).

By contrast, MWCNTs consisting of multiple carbon layers, frequently with variable chirality, can exhibit extraordinary mechanical properties instead of outstanding electrical characteristics.



Graphene

Graphene is a two-dimensional allotropic form of carbon, formed by single layers of carbon atoms . In graphene, carbon atoms exhibit sp2-hybridization connected by σ- and π-bonds in a two-dimensional hexagonal crystal lattice with a distance of 0.142 nm between neighbouring atoms of carbon hexagons. Graphene also represents a structural element of some other carbon allotropes, such as graphite, carbon nanotubes and fullerenes.

Graphene

Graphene has many unique physical properties, such as extremely high mechanical rigidity and a high thermal stability. Also the electric properties of this carbon allotrope are fundamentally different from the properties of three-dimensional materials.

Nanomaterials' Characteristics

Category of nanomaterials	example
One-dimensional nanomaterials	layers, multi-layers, thin films, platelets and surface coatings. They have been developed and used for decades, particularly in the electronics industry.
Two-dimensional nanomaterials	nanowires, nanofibres made from a variety of elements other than carbon, nanotubes and, a subset of this group, carbon nanotubes.
Three-dimensional nanomaterials	are known as nanoparticles and include precipitates, colloids and quantum dots (tiny particles of semiconductor materials), and Nanocrystalline materials

When Nanotechnology started

In some senses, nanoscience and nanotechnologies are not new.

Chemists have been making polymers, which are large molecules made up of nanoscale subunits, for many decades and nanotechnologies have been used to create the tiny features on computer chips for the past 20 years.

When Nanotechnology started

However, advances in the tools that now allow atoms and molecules to be examined and probed with great precision have enabled the expansion and development of nanoscience and nanotechnologies.

Approaches of Nanotechnology (growth methods): Bottom-up or top-down?

Bottom-up approaches seek to have smaller components built up into more complex assemblies, while top-down approaches seek to create nanoscale devices by using larger, externally controlled ones to direct their assembly.

The top-down approach often uses the traditional workshop or micro-fabrication methods where externally controlled tools are used to cut, mill, and shape materials into the desired shape and order.

Bottom-up or top-down?

CNT synthesis can be done using both **bottom-up** and **top-down** approaches, but in practice, CNTs are almost always produced by **bottom-up methods** such as:

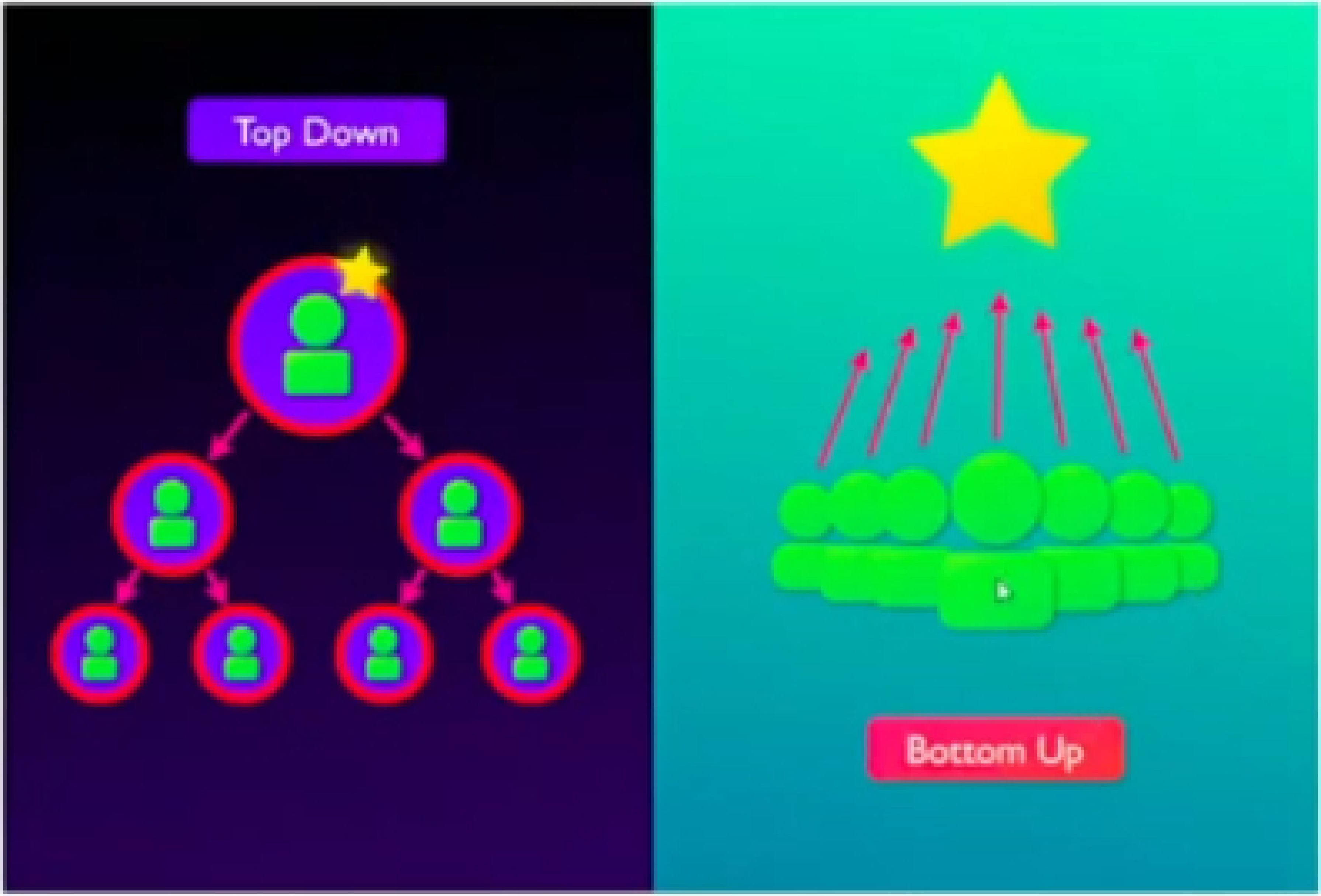
- **Arc discharge**
- **Laser ablation**
- **Chemical vapor deposition (CVD)**

These methods build the nanotube **atom-by-atom or molecule-by-molecule** from carbon sources, which is the hallmark of a **bottom-up approach** in nanomaterial synthesis.

Top-down methods (like lithography or etching) are more common for patterning or structuring existing materials, not for growing CNTs from scratch.

So — CNT synthesis = **Bottom-up method**.

Bottom-up or top-down?



Applications of Nanotechnology: General Applications

Application	Examples
Medicine	Diagnostics, Drug delivery, Tissue engineering, Cryonics
Information and communication	Memory storage, Novel semiconductor devices, Novel optoelectronic devices, Displays, Quantum computers
Heavy Industry	Aerospace, Catalysis, Catalysis, Construction Vehicle manufacturers
Consumer goods	Foods, Household, Optics, Textiles, Cosmetics, Sports
Environment	Soil remediation, Gas sensing, Air filtration, Water purification

Environmental Applications

Check http://www.nanowerk.com/products/product.php?id=160 for more details

Application	Examples
Carbon capture	Photocatalyst consisting of silica Nanosprings coated with a combination of titanium dioxide
Sensors	Pollutants sensors that able to detect lower limits with low cost
Remediation (decontamination, oil spill management)	Heavy metal decontaminant removes heavy metals such as lead, cadmium, nickel, zinc, copper, manganese and cobalt in a neutral pH environment without using any form of sulphur .
Wastewater treatment	Veolia Water Solutions & Technologies' ceramic membrane modules, utilizing the CeraMem technology platform, can be supplied with a variety of inorganic microfiltration and ultrafiltration membranes.
Energy	Heat distribution e.g. ceramic-like materials that provide sufficient reliability and durability of the entire structure
Drinking water purification	

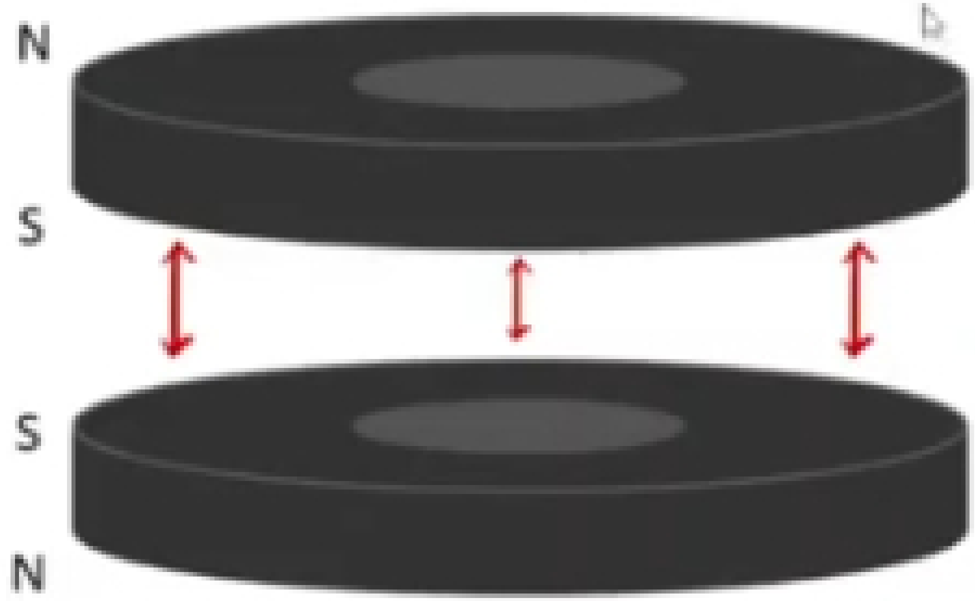
Magnetism

Students will recognize characteristics of gravity, electricity, and magnetism as major kinds of forces acting in nature.

- Investigate and explain that electric currents and magnets can exert force on each other.

1. Magnetic Levitation: Maglev Train

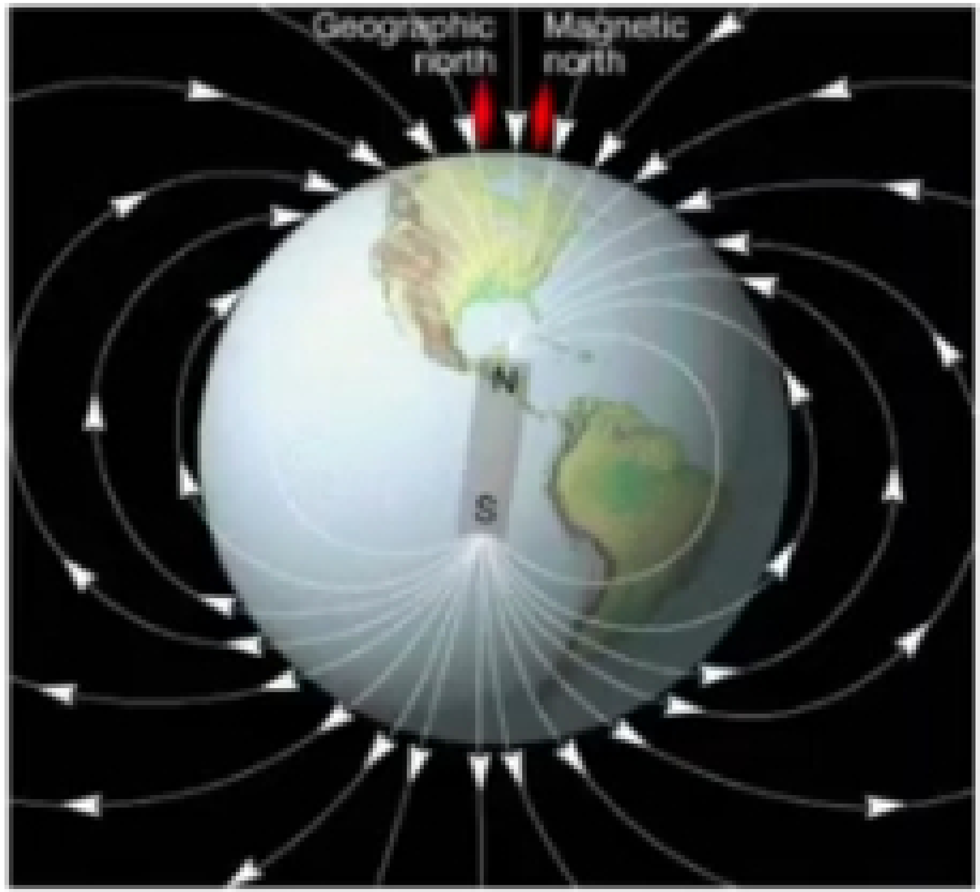
2. Magnetic Levitation: Maglev Train



Magnetic repulsion

- All magnets have a north pole and a south pole

- Like poles repel.
  Unlike poles attract




The core of Earth acts like a giant bar magnet.
N
S
Historically, people defined the north pole of a magnet as the end that points north
N
S
A compass needle always points north
N
E
W
S
That means the geographic north pole of the Earth is really a *south* magnetic pole since it attracts the north poles of magnets
S
N

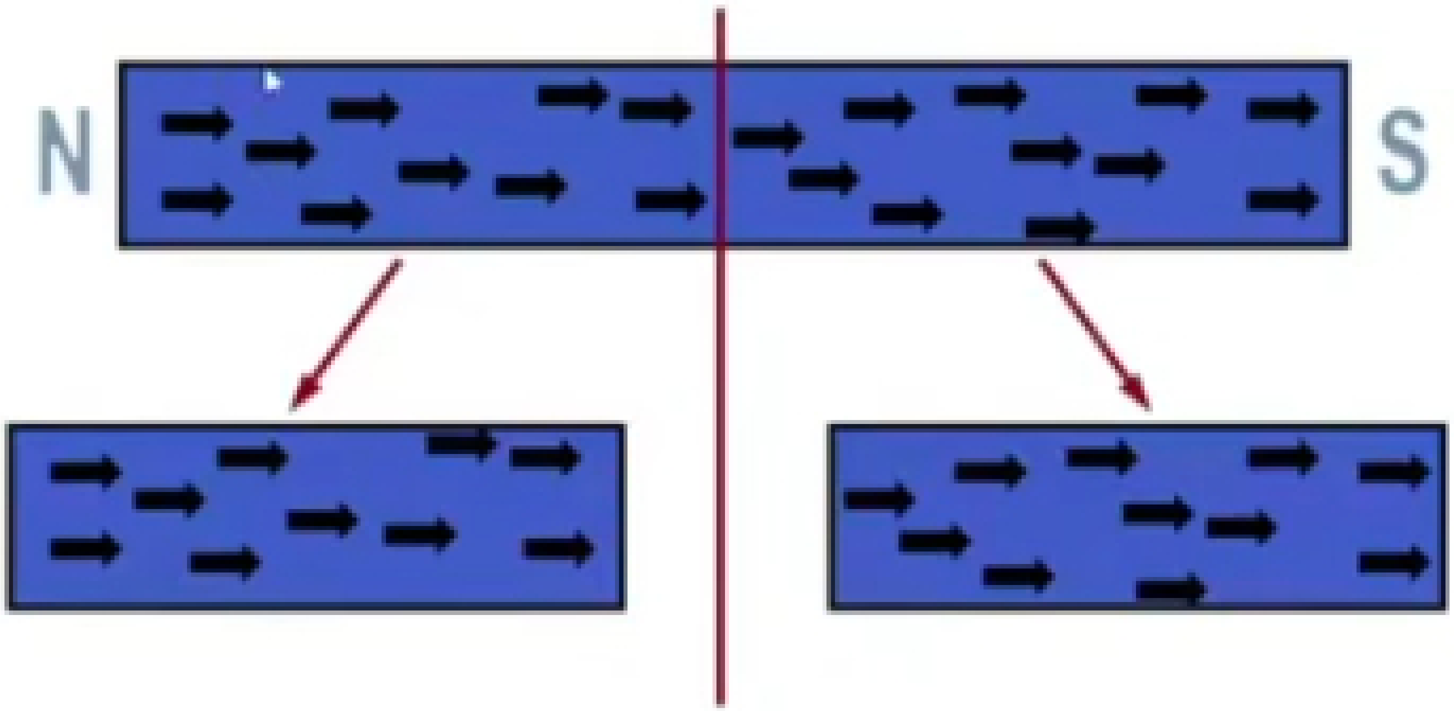
Interesting fact…

- The northern lights (aurora borealis) & southern lights (aurora australias) are results from the interaction between the solar wind and earth's magnetic field (makes the air glow).

Magnetic materials

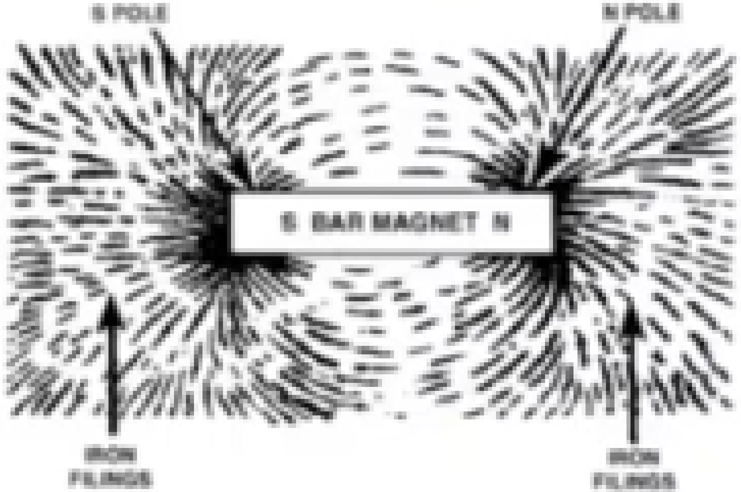
- Materials in which the domains will line up in order to form a magnetic field
- Examples: iron, cobalt, and nickel

What happens when you cut a magnet in half?



Magnetism:

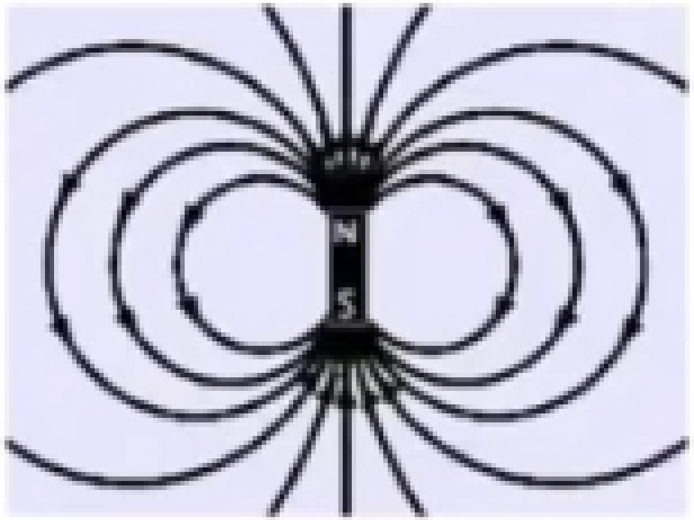
Magnetism is the force of attraction or repulsion of a magnetic material due to the arrangement of its atoms, particularly its electrons.

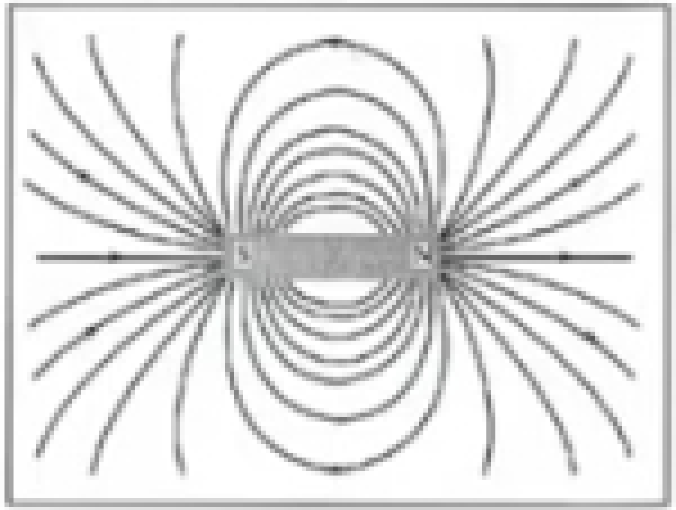


A large electromagnet used to lift scrap metal

MAGNETIC DIPOLE:

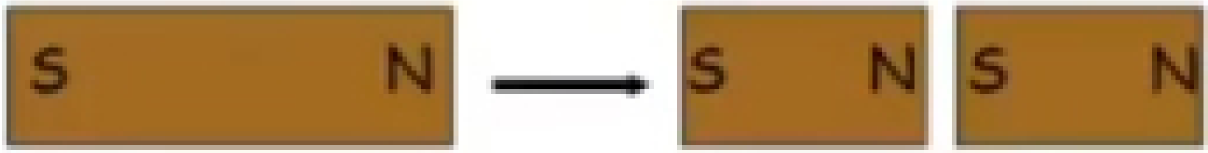
The ends of a magnet are where the magnetic effect is the strongest. These are called "poles." Each magnet has 2 poles - 1 north, 1 south.





Any two opposite poles separated by a finite distance constitute a magnetic dipole.

For Every North, There is a South



No Monopoles Allowed

Origin of magnetic moment

1. Orbital Motion - Orbital magnetic moment
2. Spin motion – Spin magnetic moment

- Theoretical laws of megnetic moments
- $\mu eff = \mu s.o = 2\sqrt{S(S+1)} = \sqrt{n(n+2)}$ BM
- n number of odd es
- If there is a possibility for contribution from the orbital angular momentum,
- **$\mu = \sqrt{L(L+1) + 4S(S+1)}$**
- **If L is greater than zero, its possible**
- **Of orbital contribution like 3d7 of oh**
- **Complexes of cobalt(II)**

- ✓ An atom is said to be magnet if it carries a permanent dipole moment.
- ✓ Every substance is formed from an assembly of atoms which can be either non-magnetic or magnetic.

The magnetic materials are classified into five groups depending on their response to the magnetic field.

1. Diamagnetic Materials
2. Paramagnetic Materials
3. Ferromagnetic Materials
4. Antiferromagnetic Materials
5. Ferrimagnetic Materials

DIAMAGNETISM

- ✓ Diamagnetism characterizes the substances that have only non-magnetic átoms (lack of permanent diople moment).
- ✓ Origin:
  - An electron moving around the nucleus results in magnetic moment.
  - Due to different orientations of various orbits of an atom, the net magnetic moment is zero in diamagnetic materials.
  - When an external field is applied the motion of electrons in their orbits changes resulting in induced magnetic moment in a direction opposite to the direction of applied field.

- ✓ The magnetization induced by the applied magnetic field is very weak and the magnetic lines of force are repelled.
- ✓ This magnetism is also exist in substances with magnetic atoms, but very weak and completely masked by the contribution of magnetic atoms.
- ✓ Relative permeability is slightly less than unity.
- ✓ The magnetic susceptibility is independent of applied magnetic field strength.

Magnitude of susceptibility	Temperature dependence	Examples
Small & negative	Independent	Organic materials, light elements
Intermediate & negative	Below 20K varies with field and temperature	Alkali earhs, Bismuth
Large & Negative	Exists only below critical temperature (Meissner effect)	Superconducting materials

PARAMAGNETISM

- ✓ The paramagnetic substances consists of magnetic atom that posses permanent dipole moment

- ✓ Origin
  - Each electron in an orbit has an orbital magnetic moment and a spin magnetic moment.
  - When the shells are unfilled there is net magnetic moment.
  - In the absence of the external field the net moments of the atoms are arranged in random directions because of thermal fluctuations. Hence there is no magnetization.
  - When external magnetic field is applied, there is tendency for the dipoles to align with the field giving rise to an induced positive dipole moment.
  - The induced magnetism is the source for paramagnetic behaviour.

- ✓ Paramagnetic susceptibility is small and positive and is independent of applied field strength.
- ✓ Spin alignment is random.

Magnitude of susceptibility	Temperature dependence	Examples
Small & positive	Independent	Alkali metals, transition metals, rare earths
Large & positive	$\chi = \frac{C}{T}$ Curie law $\chi = \frac{C}{T-\theta}$ Curie-Weiss law	

FERROMAGNETISM

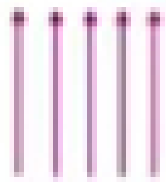
- Even in the absence of external applied field, some substances exhibits strong magnetization.

- This is due to a special form of interaction called exchange coupling between adjacent atoms that results in spontaneous magnetization of the substance.

- When placed inside a magnetic field, it attracts the magnetic lines of force very strongly.

- Each ferromagnetic material has a characteristic temperature called the ferromagnetic *Curie* temperature θ_f. Below this temperature the spontaneous magnetization exists.

- ✓ Spin alignment is parallel.



- ✓ Ferromagnetic materials exhibit Hysteresis.
- ✓ They Consists of a number of small regions which are called domains.

Magnitude of susceptibility	Temperature dependence	Examples
Very large & positive	$\chi = \frac{C}{T-\theta}$ For $T>\theta_f$ paramagnetic behavior For $T<\theta_f$ ferromagnetic behavior	Fe, Co, Ni, Gd

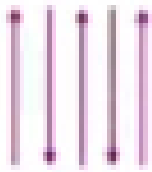
ANTI-FERROMAGNETISM

- ✓ Antiferromagnetism macroscopically similar to paramagnetism, is a weak form of magnetism.

- ✓ In certain materials when the distance between the interacting atoms is small the exchange forces produce a tendency for antiparallel alignment of electron spins of neighboring atoms.

- ✓ The magnetic susceptibility increase with the increase of temperature and reaches maximum at a certain temperature. This temperature is known as Neel temperature (T_N). Above this temperature the susceptibility again decreases.

Spins are aligned antiparallel

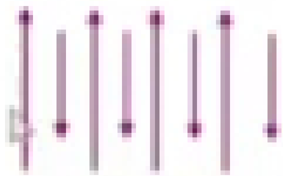


Magnitude of susceptibility	Temperature dependence	Examples
small & positive	$\chi = \frac{C}{T+\theta}$ when $T>T_N$ $\chi \propto T$ when $T<T_N$	Salts of transition metals

FERRIMAGNETISM

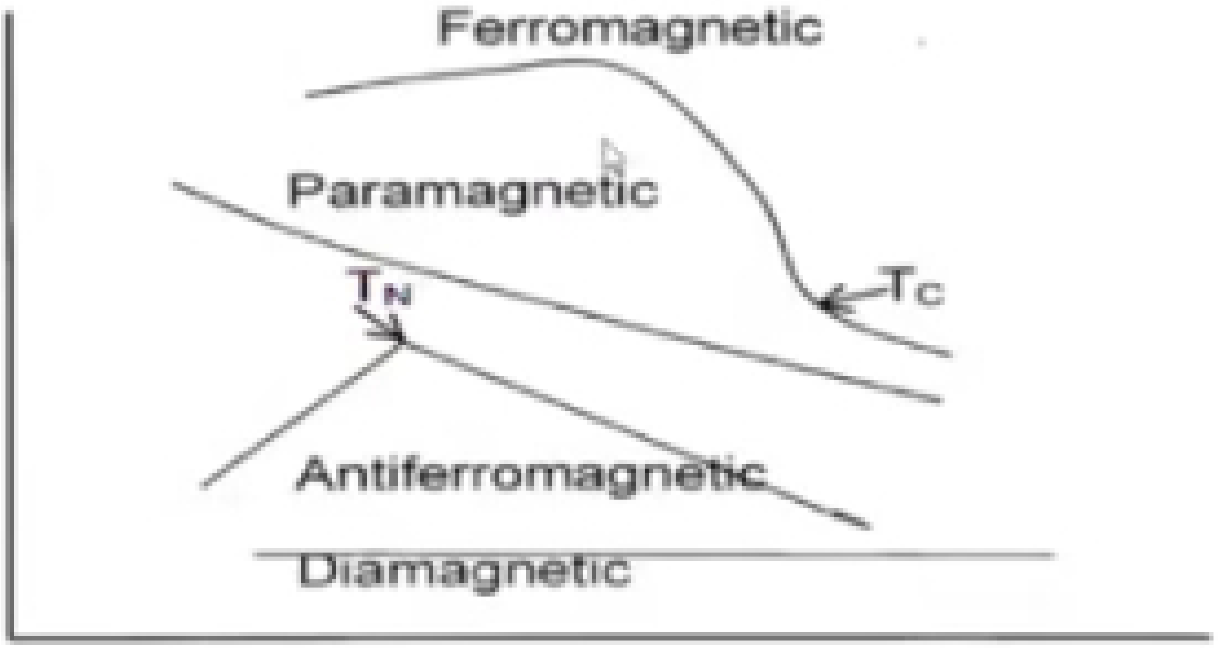
- ✓ This is a special case of antiferromagnetism.
- ✓ The net magnetization of magnetic sublattices is not zero, since antiparallel moments are of different magnitudes.
- ✓ Hence ferrimagnetic materials possesses a net magnetic moment.
- ✓ This moment disappears above a Curie temperature analogous to the Neel temperature.
- ✓ Above T_C, thermal energy randomizes the individual magnetic moments and the material becomes paramagnetic.

- ✓ Ferrimagnetic domains become magnetic bubbles to act as memory elements.
- ✓ Spin alignment is antiparallel of different magnitudes.



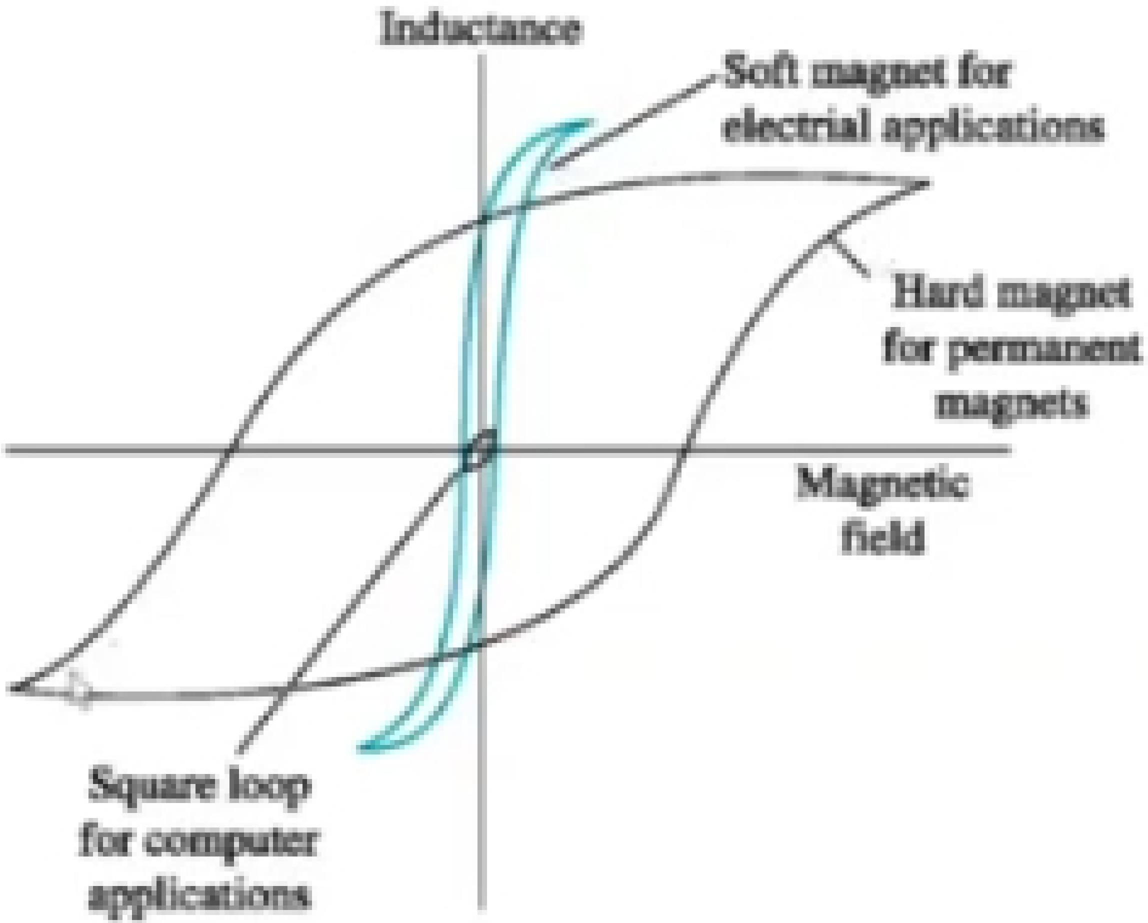
Magnitude of susceptibility	Temperature dependence	Examples
Very large & positive	$\chi = \frac{C}{T \pm \theta}$ when $T > T_N$ when $T < T_N$ behaves as paramagnetic material	Ferrites

Curei law X=C/T
Y-axis is Xg; X-axis is T in Kelvin



Applications of Magnetic Materials

- Soft Magnetic Materials - Ferromagnetic materials are often used to enhance the magnetic flux density (B) produced when an electric current is passed through the material. Applications include cores for electromagnets, electric motors, transformers, generators, and other electrical equipment.
- Data Storage Materials - Magnetic materials are used for data storage.
- Permanent Magnets - Magnetic materials are used to make strong permanent magnets
- Power - The strength of a permanent magnet as expressed by the maximum product of the inductance and magnetic field.



(a)

Figure 19.9 (a) Comparison of the hysteresis loops for three applications of ferromagnetic and ferrimagnetic materials.

TABLE 19-4 ■ ***Soft magnetic materials***

Name	Composition	Permeability (μ_r)		Coercivity (H_c) ($A \cdot m^{-1}$)	Retentivity (B_r) (T)	B_{max} (T)	Resistivity ($\mu\Omega \cdot m$)
		Initial	Maximum				
Ingot iron	99.8% Fe	150	5000	80	0.77	2.14	0.10
Low-carbon steel	99.5% Fe	200	4000	100		2.14	1.12
Silicon iron, unoriented	Fe-3% Si	270	8000	60		2.01	0.47
Silicon iron, grain-oriented	Fe-3% Si	1400	50,000	7	1.20	2.01	0.50
4750 alloy	Fe-48% Ni	11,000	80,000	2		1.55	0.48
4-79 permalloy	Fe-4% Mo-79% Ni	40,000	200,000	1		0.80	0.58
Superalloy	Fe-5% Mo-80% Ni	80,000	450,000	0.4		0.78	0.65
2V-Permendur	Fe-2% V-49% Co	800	450,000	0.4		0.78	0.65
Supermendur	Fe-2% V-49% Co		100,000	16	2.00	2.30	0.40
Metglas[a] 2650SC	$Fe_{81}B_{13.5}Si_{3.5}C_2$		300,000	3	1.46	1.61	1.35
Metglas[a] 2650S-2	$Fe_{78}B_{13}Si_9$		600,000	2	1.35	1.56	1.37
MnZn Ferrite	H5C2[b]	10,000		7	0.09	0.40	1.5×10^5
MnZn Ferrite	H5E[b]	18,000		3	0.12	0.44	5×10^4
NiZn Ferrite	K5[b]	290		80	0.25	0.33	2×10^{12}

[a] *Allied Corporation trademark*

[b] *TDK ferrite code*

(Source: Adapted from "Magnetic Materials: An Overview, Basic Concepts, Magnetic Measurements, Magnetostrictive Materials," by G.Y. Chin et al. In R. Bloor, M. Flemings, and S. Mahajan (Eds.), Encyclopedia of Advanced Materials, Vol. 1, 1994, p. 1424, Table 1. Copyright © 1994 Pergamon Press. Reprinted with permission of the editor.)

TABLE 19-5 ■ *Typical magnetic recording materials*[16]

	Particle Length μm	Aspect Ratio	Magnetization (B_r)		Coercivity (H_c)		Surface Area m^2/g	Curie temp. (T_c) °C
			Wb/m^2	emu/cc	kA/m	Oe		
γ-Fe_2O_3	0.20	5:1	0.44	350	22–34	420	15–30	600
Co-γ-Fe_2O_3	0.20	6:1	0.48	380	30–75	940	20–35	700
CrO_2	0.20	10:1	0.50	400	30–75	950	18–55	125
Fe	0.15	10:1	1.40[a]	1100[a]	56–176	2200	20–60	770
Barium Ferrite	0.05	0.02 μm thick	0.40	320	56–240	3000	20–25	350

[a] *For overcoated, stable particles use only 50 to 80% of these values due to reduced magnetic particle volume*

(Source: From The Complete Handbook of Magnetic Recording, Fourth Edition, by F. Jorgensen, p. 324, Table 11-1. Copyright © 1996 Reprinted by permission of The McGraw-Hill Companies.)