Materials Science and Engineering (BMEE209L)

by

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Content

- Module: 1 Fundamentals to Materials Engineering covers the following:
  - Importance of Materials Engineering
  - Engineering Materials Development
  - Materials Science/Materials Engineering
  - The Materials Tetrahedron
  - Classification of Materials
  - Importance of New Materials
  - Materials Selection Process
  - Engineering Requirements of Materials
  - Classification of Functional Materials

Importance of Materials Engineering

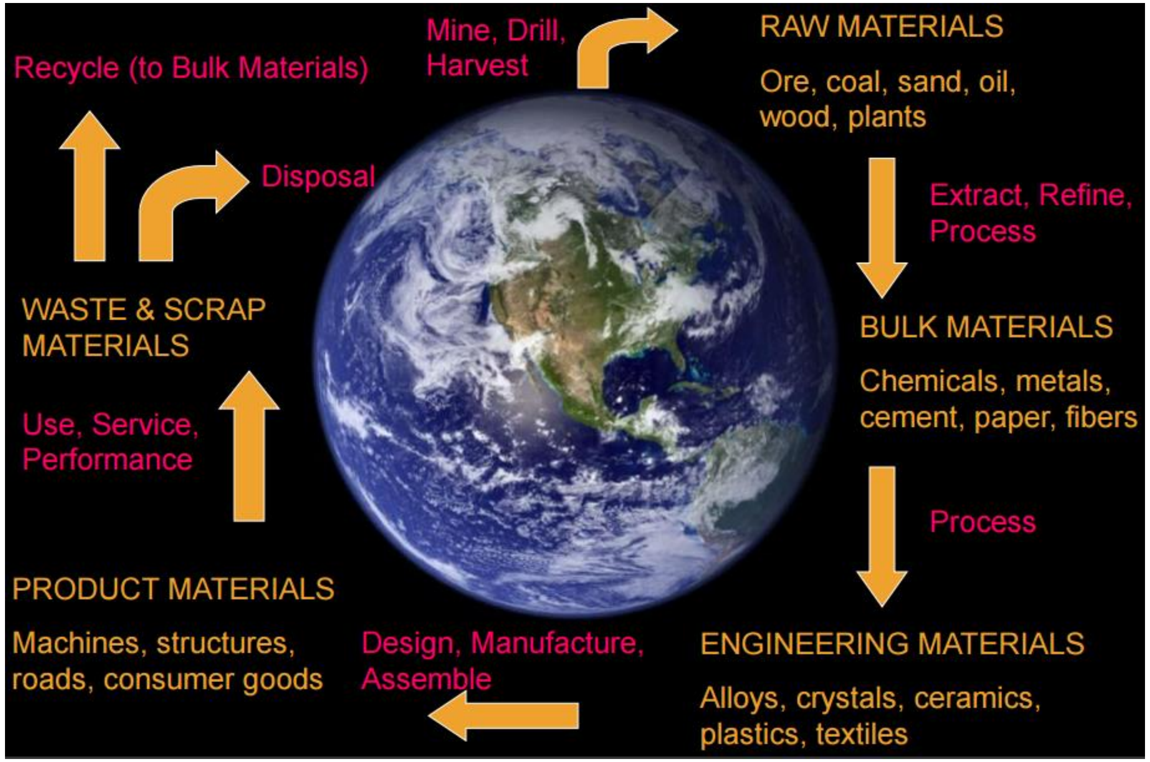
- Materials closely connected our culture.

- Development and advancement of societies are dependent on the available materials and their use.

- Early civilizations designated by level of materials development.

- Develop techniques to produce materials with superior qualities.

  (heat treatments and addition of other substances)



Materials Life-Cycle

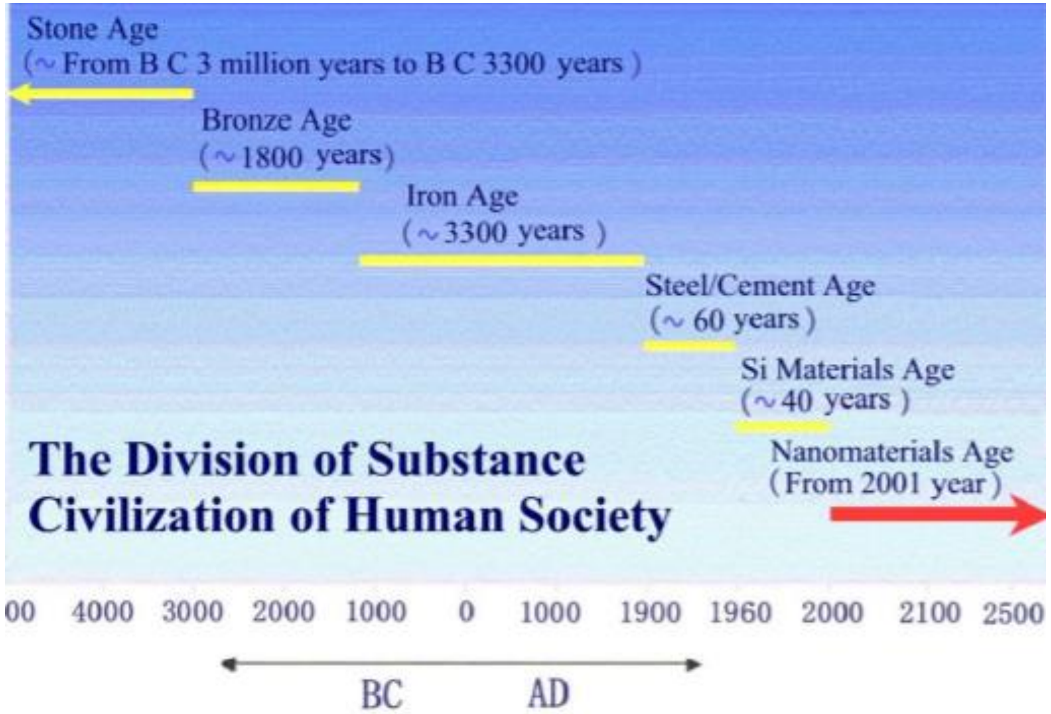
History of Materials

- Copper and iron were the first metals put to extensive use by early man.
- Copper mixed with tin called bronze was so widely used for many years that this period came to be known as the 'Bronze Age'.
- The increasing use of metals in day to day life aroused the interest of man in their properties and the sources from which they could be recovered. This gave birth to a new branch in chemistry called metallurgy.
- The science that deals with procedures used in extracting metals from their ores, purifying and alloying metals and creating useful objects from metals is called metallurgy.
- In other words, Metallurgy is also the practice of removing valuable metals from an ore and refining the extracted raw metals into a purer form.

Chronological List of Developments in the Use of Materials

Date	Development	Location
9000 B.C.	Earliest metal objects of wrought native copper	Near East
6500 B.C.	Earliest life-size statues, of plaster	Jordan
5000–3000 B.C.	Chalcolithic period: melting of copper; experimentation with smelting	Near East
3000–1500 B.C.	Bronze Age: arsenical copper and tin bronze alloys	Near East
3000–2500 B.C.	Lost-wax casting of small objects	Near East
2500 B.C.	Granulation of gold and silver and their alloys	Near East
2400–2200 B.C.	Copper statue of Pharaoh Pepi I	Egypt
2000 B.C.	Bronze Age	Far East
1500 B.C.	Iron Age (wrought iron)	Near East
700–600 B.C.	Etruscan dust granulation	Italy
600 B.C.	Cast iron	China
224 B.C.	Colossus of Rhodes destroyed	Greece
200–300 A.D.	Use of mercury in gilding (amalgam gilding)	Roman world
1200–1450 A.D.	Introduction of cast iron (exact date and place unknown)	Europe
Circa 1122 A.D.	Theophilus's On Divers Arts: the first monograph on metalworking written by a craftsman	Germany
1252 A.D.	Diabutsu (Great Buddha) cast at Kamakura	Japan
Circa 1400 A.D.	Great Bell of Beijing cast	China
16th century	Sand introduced as mold material	France
1709	Cast iron produced with coke as fuel, Coalbrookdale	England
1715	Boring mill or cannon developed	Switzerland
1735	Great Bell of the Kremlin cast	Russia
1740	Cast steel developed by Benjamin Huntsman	England
1779	Cast iron used as architectural material, Ironbridge Gorge	England
1826	Zinc statuary	France
1838	Electrodeposition of copper	Russia, England
1884	Electrolytic refining of aluminum	United States, France

Engineering Materials Development



- Materials play an important role in the development of technology and the evolution of modern civilization.
- Ancient civilizations have been named after the materials used in that period.
- During the Stone Age, people used only the materials found around them, such as stone, wood, and bone. They used these materials to make weapons to kill the animals for their food.
- During the Bronze Age, people were able to extract copper from its ore.
- During the Iron Age, the extraction of iron from its ores signaled another major development. Heat treatment processes were developed during this period.
- In the Steel Age, Bessemer and open hearth processes for the production of steel were developed. The general use of steel as a construction material started during this period.
- From 1950 onward, the era is named the Silicon Age. The development of silicon has led to the development of electronics, computers, and automation.
- It is clear from history that development of materials is important for development of civilization.

Occurrence of Metals

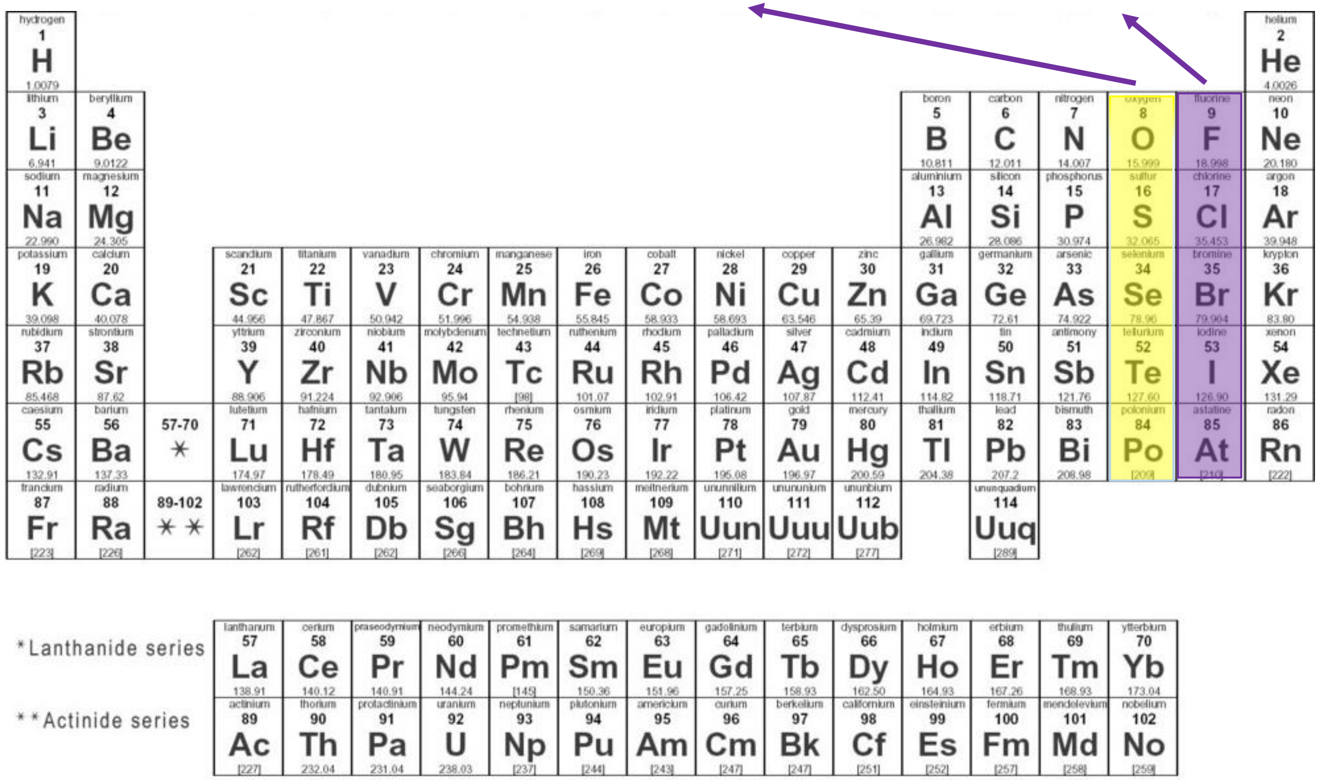
- Metals occur in nature in the free as well as in the combined states.

- The most unreactive metals i.e. which are not affected by air and water, like silver, gold and platinum are generally found in the free state.

- In other words, elements which have low chemical reactivity generally occur native or free or in metallic state and those which are chemically reactive or affected by air and water generally occur in combined state e.g. halogens, chalcogens.

Chalcogens
Oxygen Family
Group 16

Halogens
Fluorine Family
Group 17



Periodic Table

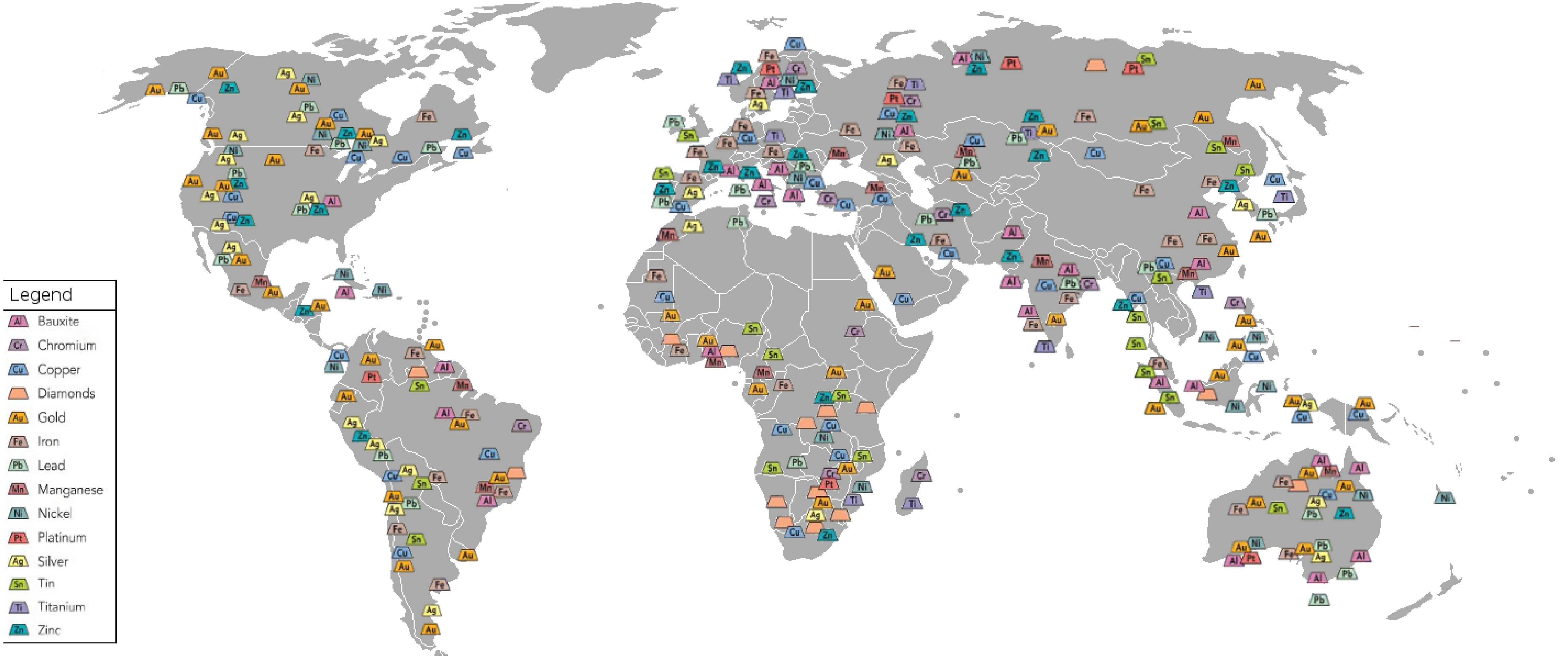
Common Occurrence of Metals

Type of ore	Elements or compounds
Carbonates	$CaCO_3$, $CaCO_3 \cdot MgCO_3$, $MgCO_3$, $FeCO_3$, $PbCO_3$, $BaCO_3$, $SrCO_3$, $ZnCO_3$, $MnCO_3$, $CuCO_3 \cdot Cu(OH)_2$, $2CuCO_3 \cdot Cu(OH)_2$, K_2CO_3, $(BiO)_2CO_3 \cdot H_2O$
Fluorides	CaF_2
Halides	$NaCl$, KCl, $AgCl$, $KCl \cdot MgCl_2 \cdot 6H_2O$, $NaCl$ and $MgCl_2$ in sea water
Native metals	Cu, Ag, Au, As, Sb, Bi, Pt (Os, Ir, Pd), Mn (nodules on ocean floor)
Oxides	Al_2O_3, Fe_2O_3, Fe_3O_4, SnO_2, MnO_2, TiO_2, $FeO \cdot Cr_2O_3$, $FeO \cdot WO_3$, Cu_2O, ZnO, ThO_2, Bi_2O_3, $(Fe, Mn)(Nb, Ta)_2O_6$
Phosphates	$LiF \cdot AlPO_4$, $Th_3(PO_4)_4 \cdot X$ (Re)(a) PO_4
Silicates	$Be_3AlSi_6O_{18}$, $ZrSiO_4$, $Sc_2Si_2O_7$, $NiSiO_3 \cdot XMgSiO_3$, $ThSiO_4$, $LiAlSi_2O_6$
Sulfates	$BaSO_4$, $SrSO_4$, $PbSO_4$, $CaSO_4 \cdot 2H_2O$, $CuSO_4 \cdot 2Cu(OH)_2$
Sulfides	Ag_2S, Cu_2S, CuS, PbS, ZnS, HgS, $FeS \cdot CuS$, FeS_2, Sb_2S_3, Bi_2S_3, MoS_2, NiS, CdS, $FeAs_2 \cdot FeS_2(Fe, Ni)_9$ $(S, Te)_8$, $(Tl, Pb)S$
Miscellaneous	$(Fe, Mn)WO_4$, $CaWO_4$, $(Co, Ni)As_2$, $(Co, Fe)As_2$, $NiSb$, $PtAs_2$, $(Cu, Tl, Ag)_2Se$

Important Metals Found in Minerals as Oxides, Sulfides, or Carbonates

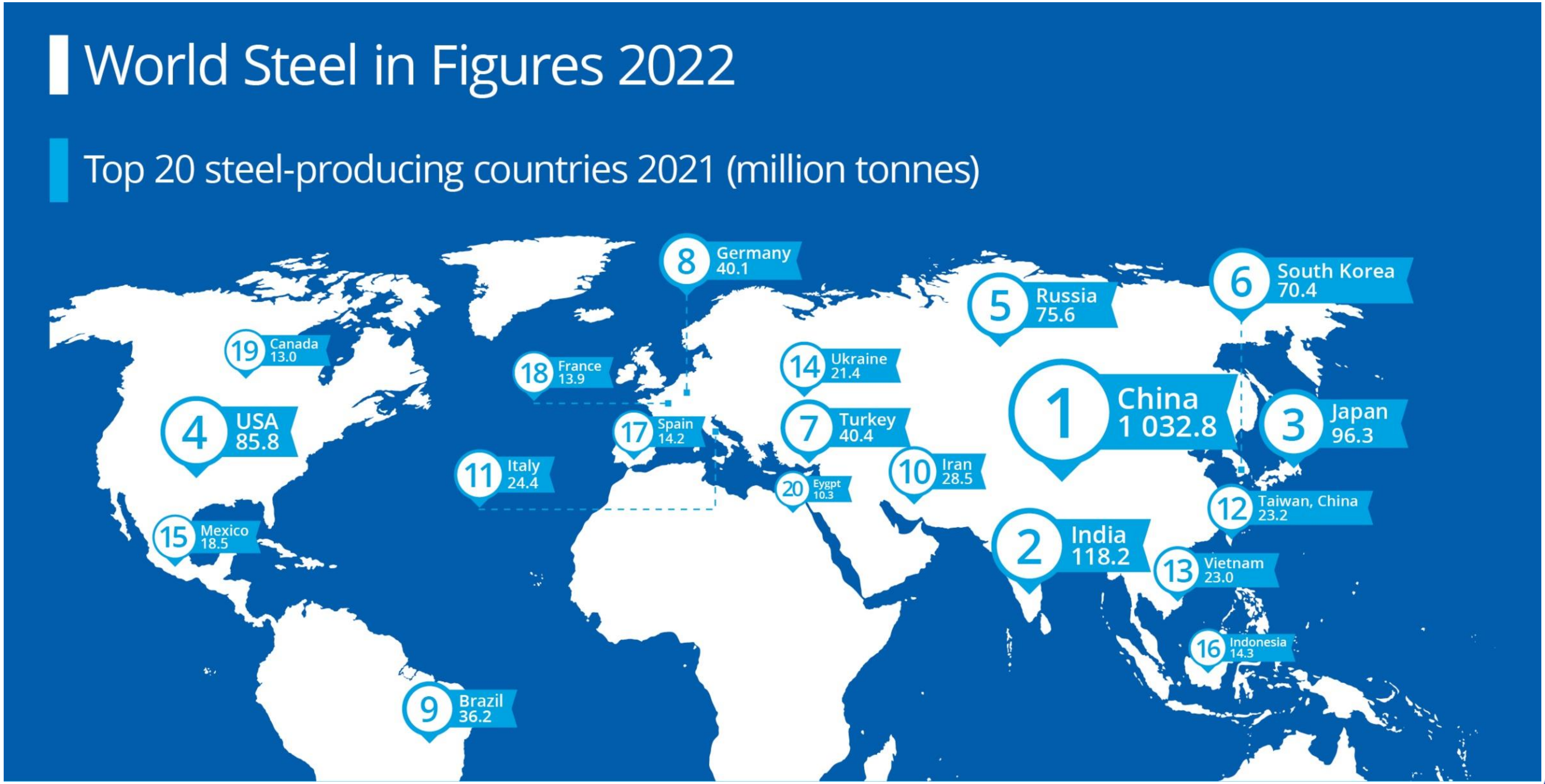
Metal	Mineral	Composition
Aluminum	Corundum	Al_2O_3
Chromium	Chromite	$FeCr_2O_4$
Copper	Chalcocite	Cu_2S
	Chalcopyrite	$CuFeS_2$
	Malachite	$Cu_2CO_3(OH)_2$
Iron	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
Lead	Galena	PbS
Manganese	Pyrolusite	MnO_2
Mercury	Cinnabar	HgS
Molybdenum	Molybdenite	MoS_2
Tin	Cassiterite	SnO_2
Titanium	Rutile	TiO_2
	Ilmenite	$FeTiO_3$
Zinc	Sphalerite	ZnS

Resources of Metal Containing Minerals (World)



- Earth Crust (Aluminum: 8.1%, Iron 5.1%, Calcium: 3.6%, Sodium: 2.8%, Potassium: 2.6%, Magnesium: 2.1%, Titanium: 2.1%, Manganese: 0.10%)
- Ocean water: (Na: 10500 g/ton, Mg: 1270 g/ton, Ca: 400 g/ton, K: 380 g/ton) ; Ocean nodules (Mn: 23.86%, Mg 1.66%, Al 2.86%, Fe 13.80%)
- Recycled scrap (at the end of metals' life)

Steel Producing Countries in World



General Properties and Structure of Metals

- Opaque- not transparent
- Good conductors of heat and electricity
- High malleability and ductility
- In the electron sea model, each metal atom releases its valence electrons to be shared by all the atoms in the crystal.
- The valence electrons occupy an energy band called the valence band that is delocalized over the entire solid.
- However, each metal has its own unique properties to be accounted for.

Materials Science/Materials Engineering

- Materials make modern life possible—from the polymers in the chair you're sitting on, the metal ball-point pen you're using, and the concrete that made the building you live or work in to the materials that make up streets and highways and the car you drive. All these items are products of materials science and technology (MST).
- Briefly defined, materials science is the study of "stuff".
- Materials science is the study of solid matter, inorganic and organic.
- Materials Science – Investigating relationships that exist between the structure and properties of materials.
- Materials Engineering – On the basis of these structure-property correlations, designing or engineering the structure of a material to produce a pre-determined set of properties.

Materials Science/Engineering—From Art to Science

- Materials science became a real science due to the development of modern analysis and imaging techniques.

- Modern analysis and imaging techniques become possible due to developments in the materials science.

- For example:

  - Art: Crushing, Grinding of the ores and minerals and their physical separation by washing etc.

  - Science: Atomic structures, Heat and Mass Transfer, Fluid Flow (Smelting and Reduction etc.).

  - Technology: Metal Fabrication, Deformation, and Casting etc.

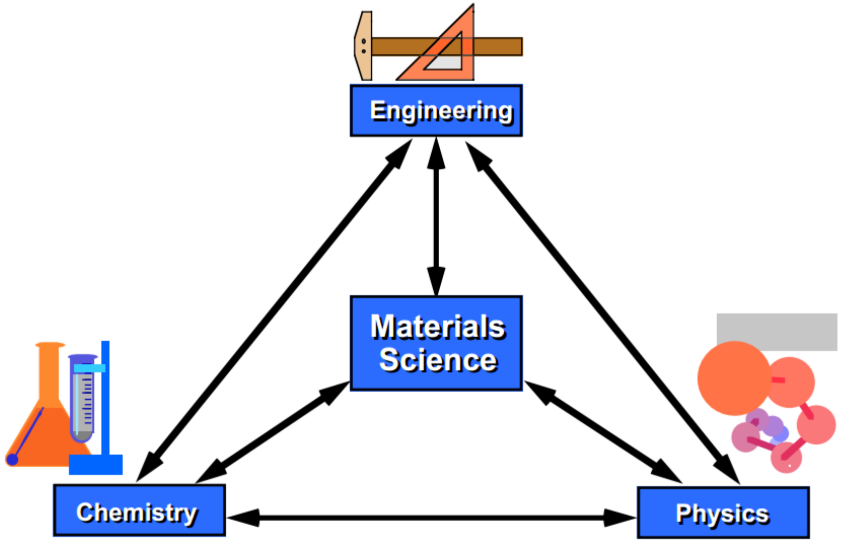
Materials Science/Engineering—A Multidisciplinary Approach

- The programme combines training in basic subjects in the field of material science with obtaining practical knowledge and skills in the use and study of different classes of engineering materials.

- This is a specialty in which engineers are prepared to create and use materials of our time.

- However you look at it, materials have become a scientific frontier that continues to develop new and improved ways for people to live and travel now and in the future.

- Materials science in our everyday lives:
  - Electronics revolution has provided onboard computers.
  - Development of new materials is in bio-medicine.
  - Materials that are used inside human bodies are such things as hip, knee, and finger joint replacements made from composite materials.

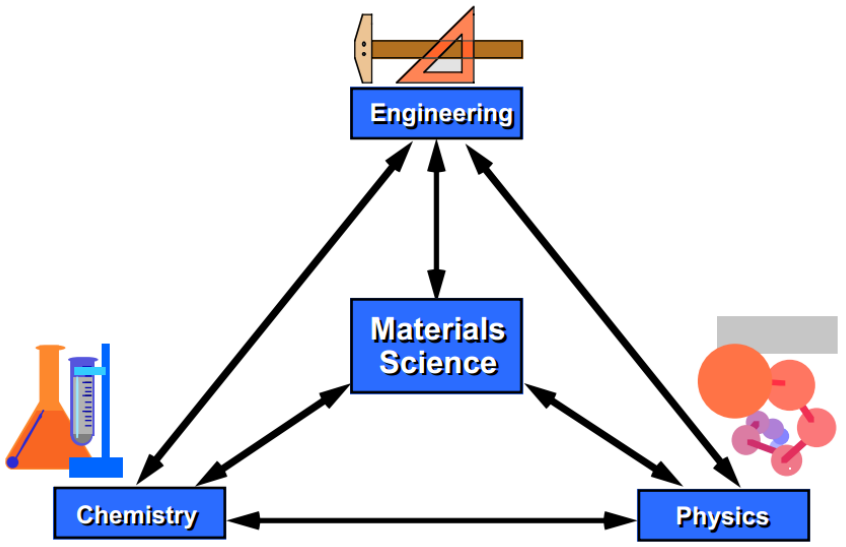


Materials Science/Engineering — A Multidisciplinary Approach

Contd…

- The program combines training in basic subjects in the field of material science with obtaining practical knowledge and skills in the use and study of different classes of engineering materials.

- The interdisciplinary field of materials science involves the discovery and design of new materials, with an emphasis on solids. The intellectual origins of materials science from the enlightenment, when researchers began to use analytical thinking from chemistry, physics, and engineering to understand ancient, phenomenological observations in metallurgy.



Materials Science/Engineering — A Multidisciplinary Approach

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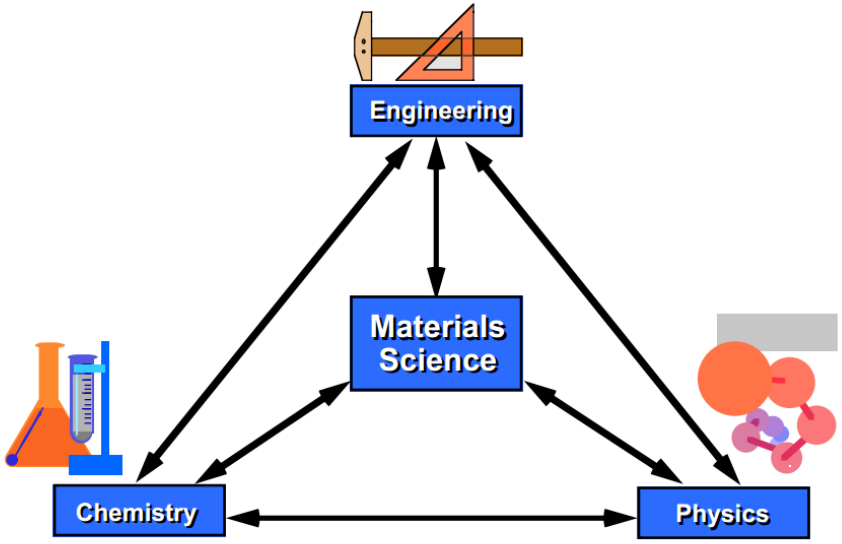
- **Physics** is the natural science that involves the study of matter, along with related concepts such as energy and force. The main goal of physics is to understand how it behaves.

- **Chemistry** is a branch of physical science that studies the composition, structure, properties and change of matter. Chemistry includes topics such as the properties of individual atoms, how atoms form chemical bonds to create chemical compounds, the interactions of substances through intermolecular forces, and the interactions between substances through chemical reaction to form different substances.

- **Engineering** is the application of mathematics, empirical evidence and scientific, economic, social, and practical knowledge in order to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, materials and processes.



Materials Science/Engineering — A Multidisciplinary Approach

The Materials Tetrahedron

- Engineering problem involves issues related to material selection.
- Understanding the behavior of materials, particularly structure-property correlation, will help selecting suitable materials for a particular application.
- To provide a basic understanding of the principles that determines the evolution of structures in metals and alloys during their processing and its relation with their properties & performance in service.
- A materials scientist has to consider four 'intertwined' concepts, which are schematically shown as the 'Materials Tetrahedron'.
- Each of these aspects is dependent on the others.

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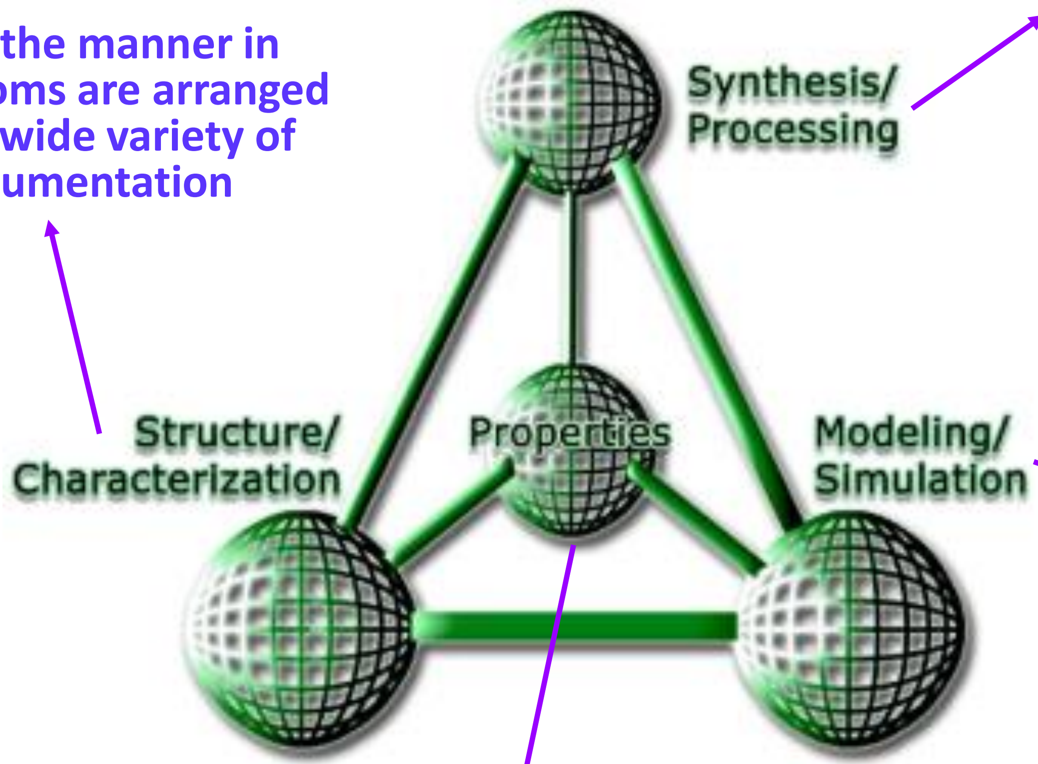
Studying the manner in which atoms are arranged using a wide variety of instrumentation

Developing new materials and modifying materials after or during their manufacture



How materials behave or interact with the environment such as how they conduct heat

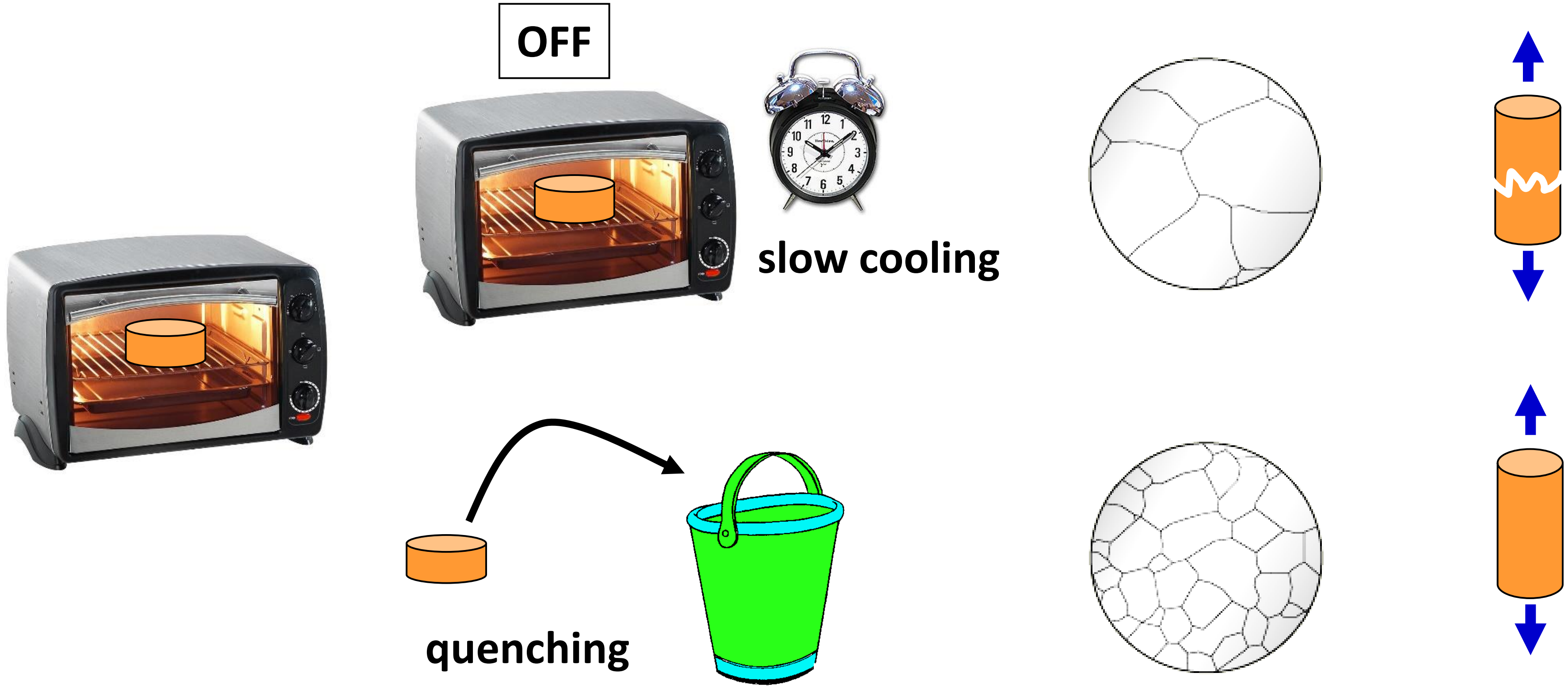
Using mathematical and computational tools to study and predict structure, properties, and processing

Performance Goal

Processing→Structure→Properties→Performance

Performance Goal: increased strength of a metallic material

Actually, crystals are NOT perfect. There are defects!
In metals, strength is determined by how easily defects can move!



Structure

STRUCTURE (length scale)

Sub-atomic	Atomic	Microscopic	Bulk
< 0.2 nm 1 nm = 10^{-9} m	0.2-10 nm	1-1000 μm 1 μm = 10^{-6} m	> 1 mm

- **Structure – Structure of a material usually relates to the arrangement of its internal components.**
- **Subatomic – Structure involves electrons within the individual atoms and interactions with their nuclei.**
- **Atomic level – structure encompasses the organization of atoms or molecules relative to one another.**
- **Microscopic – Which contains large groups of atoms that are normally agglomerated together.**
- **Macroscopic/Bulk – Viewable with the naked eye.**

Property

- A property is a material trait in terms of the kind and magnitude of response to a specific imposed stimulus. Properties are made independent of material shape and size.

- Example:

  - A specimen subjected to forces will experience deformation.

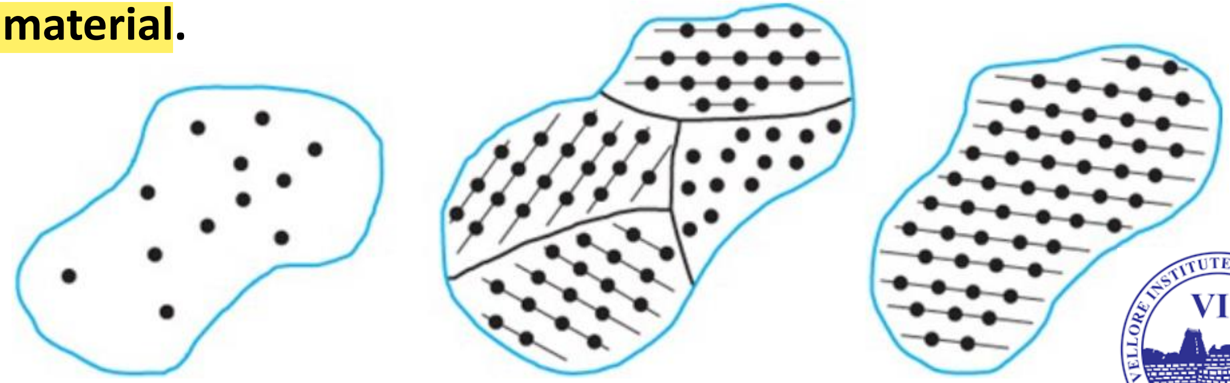
  - A polished metal surface will reflect light.

- Properties of solid materials may be grouped into six different categories:

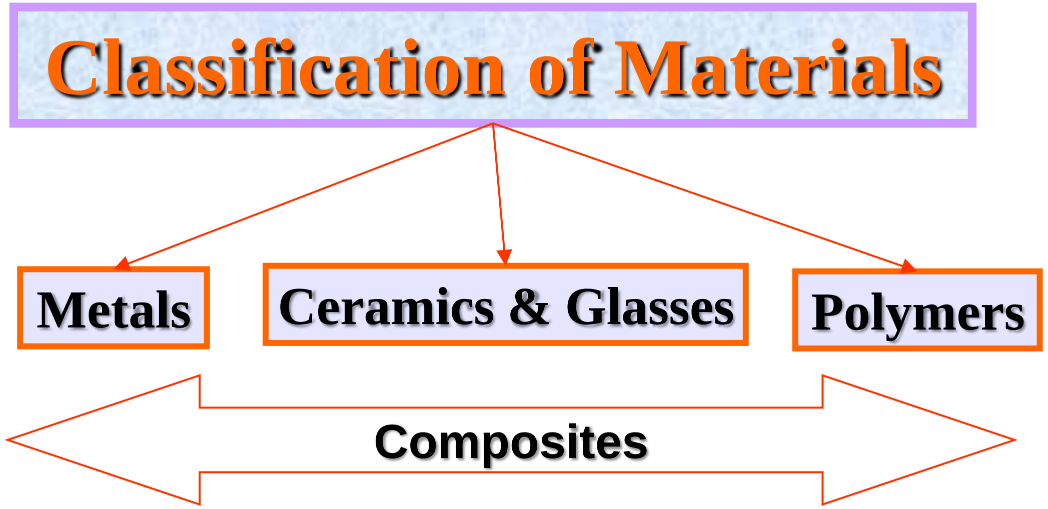
  - mechanical
  - electrical
  - thermal
  - magnetic
  - optical
  - deteriorative

Classification of Materials

- Engineering materials are classified using different methods.
- The traditional method is according to their nature into metals, ceramics, polymers and composites.
- The factors which form the basis of various systems of classifications of materials in material science and engineering are:
  - The chemical composition of the material
  - The mode of the occurrence of the material in the nature
  - The refining and the manufacturing process to which the material is subjected to prior to acquiring the required properties
  - The atomic and crystalline structure of material
    - Crystalline material is comprised of one or many crystals and in each crystal, atoms or ions show a long-range periodic arrangement.
    - Non-crystalline material (Amorphous), where the materials atoms do not have a long-range order.
    - Single crystal is a crystalline material is made of only one crystal (there are no grain boundaries).
    - Grains are the crystals in a polycrystalline material.
    - Polycrystalline material is a material comprised of many crystals (as opposed to a single-crystal material that has only one crystal).
  - The industrial and technical use of the material



Common Type of Materials



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- Common type of engineering materials are metals, ceramics, and polymers and various types of composites of these.

- A composite is a combination of two or more materials which gives a certain benefit to at least one property → A comprehensive classification is given in the next slide. The term Hybrid is a superset of composites.

- The type of atomic entities (ion, molecule etc.) differ from one class to another, which in turn gives each class a broad 'flavor' of properties.

  - Metals are usually ductile and ceramics are usually hard and brittle.
  - Polymers have a poor tolerance to heat, while ceramics can withstand high temperatures.
  - Metals are opaque (in bulk), while silicate glasses are transparent/translucent.
  - Metals are usually good conductors of heat and electricity, while ceramics are poor in this aspect.
  - If you heat semi-conductors their electrical conductivity will increase, while for metals it will decrease.
  - Ceramics are more resistant to harsh environments as compared to metals.

- Biomaterials are a special class of materials which are compatible with the body of an organism (biocompatible). Certain metals, ceramics, polymers etc. can be used as biomaterials.

Bonding and structure are key factors in determining the properties of materials!!!

Diamond is poor electrical conductor but a good thermal conductor!!!

Metals

- Materials in this group are composed of one or more metallic elements (such as iron, aluminum, copper, titanium, gold, and nickel), and often also nonmetallic elements (for example, carbon, nitrogen, and oxygen) in relatively small amounts.
- Atoms in metals and their alloys are arranged in a very orderly manner.
- In comparison to the ceramics and polymers, are relatively dense.
- Mechanical Property — relatively stiff and strong, ductile (i.e., capable of large amounts of deformation without fracture), and are resistant to fracture.
- Metallic materials have large numbers of non localized electrons; that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons.
- Example, metals are extremely good conductors of electricity, and heat, and are not transparent to visible light; a polished metal surface has a lustrous appearance.
- Some of the metals (viz., Fe, Co, and Ni) have desirable magnetic properties.

Ceramics

- Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides.
- Examples — aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2),silicon carbide (SiC), silicon nitride (Si_3N_4).
- Examples of traditional ceramics — clay minerals (i.e., porcelain), cement, and glass.
- Relatively stiff and strong — stiff nesses and strengths are comparable to those of the metals , very hard, extremely brittle (lack ductility), highly susceptible to fracture.
- Thermal and electrical Properties — Insulate to the passage of heat and electricity low electrical conductivities and are more resistant to high temperatures.
- Optical characteristics — Ceramics may be transparent, translucent, or opaque.

Polymers

- Carbon-based compounds.
- Chain of H–C molecules. Each repeat unit of H–C is a monomer e.g. ethylene (C_2H_4), polyethylene –(–CH_2–CH_2)n.

- Polymers include the familiar plastic and rubber materials.
- Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (viz. O, N, and Si).
- They have very large molecular structures, often chain-like in nature that have a backbone of carbon atoms. Some of the common and familiar polymers are polyethylene (PE), nylon, poly (vinyl chloride)(PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber.

- Low densities, not as stiff nor as strong as ceramics and metals.
- Extremely ductile and pliable (i.e., plastic).
- Relatively inert chemically and unreactive in a large number of environments.

- Tendency to soften and/or decompose at modest temperatures, which, in some instances, limits their use.
- Low electrical conductivities and are non-magnetic.

Composites

- A composite is composed of two (or more) individual materials, which come from the categories discussed above — viz., metals, ceramics, and polymers.

- Objective — to achieve a combination of properties that is not displayed by any single material

- Examples:

  - Cemented carbides (WC with Co binder)
  - Plastic molding compounds containing fillers
  - Rubber mixed with carbon black
  - Wood (a natural composite as distinguished from a synthesized composite)

Classification of Materials

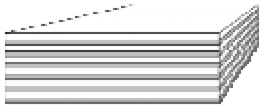
Materials

- Monolithic
  - Metals (& Alloys)
  - Ceramics & Glasses
  - Polymers (& Elastomers)
- Hybrids
  - Composite
  - Sandwich
  - Lattice
  - Segment

Monolith is a monument or natural feature consisting of a single massive stone or rock

a natural or synthetic polymer having elastic properties, e.g. rubber

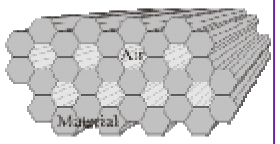
Glass is a non-crystalline amorphous solid that is often transparent and has practical, technological, and decorative usage e.g. window panes



Hybrids are designed to improve certain properties of monolithic materials

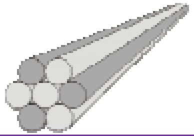
Composites: have two (or more) solid components; usually one is a matrix and other is a reinforcement

Sandwich structures: have a material on the surface (one or more sides) of a core material



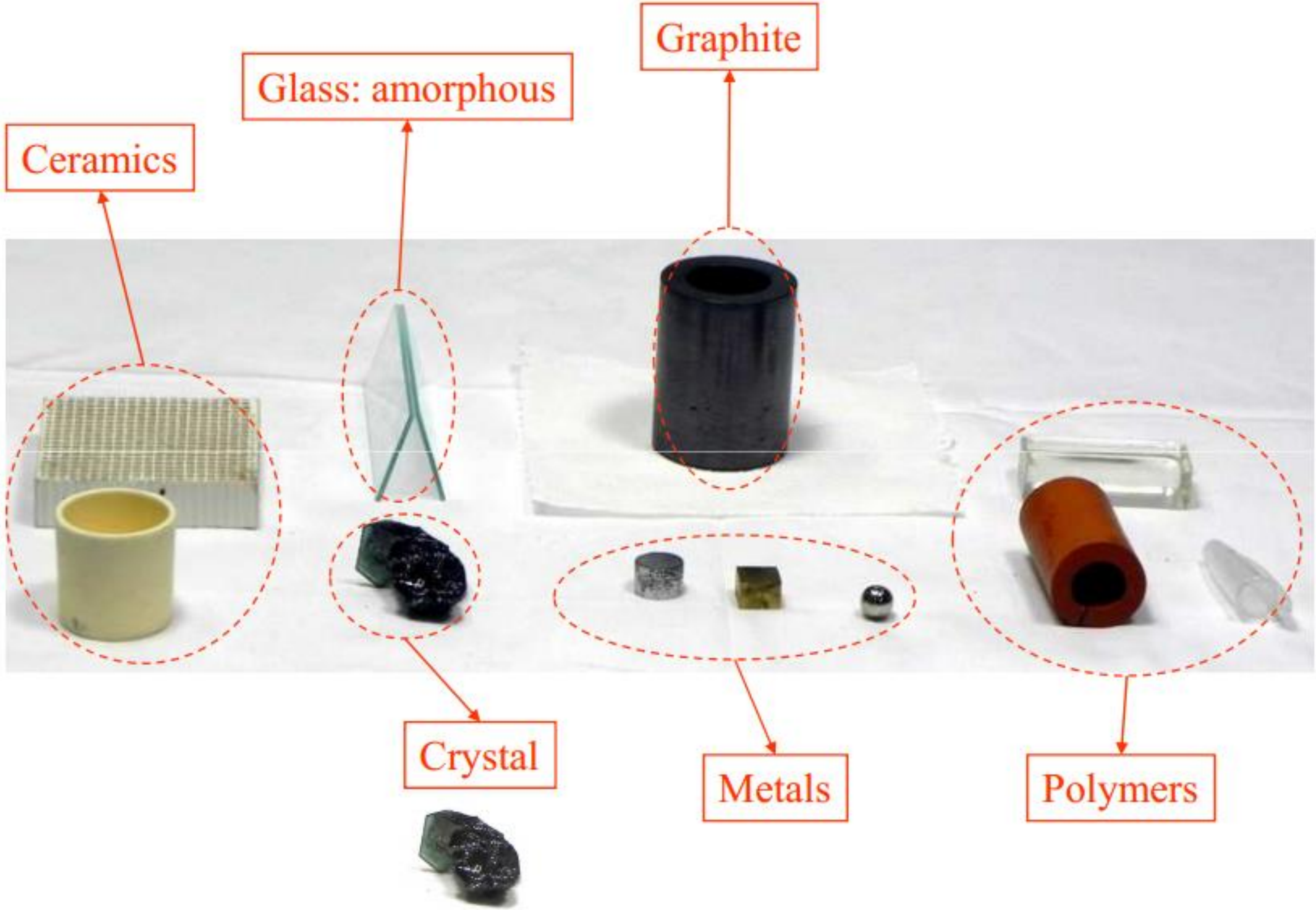
Lattice Structures: typically a combination of material and space (e.g. metallic or ceramic forms, aerogels etc.)

Aerogel is a synthetic porous ultralight material derived from a gel, in which the liquid component of the gel has been replaced with a gas



Segmented Structures: are divided in 1D, 2D or 3D (may consist of one or more materials)

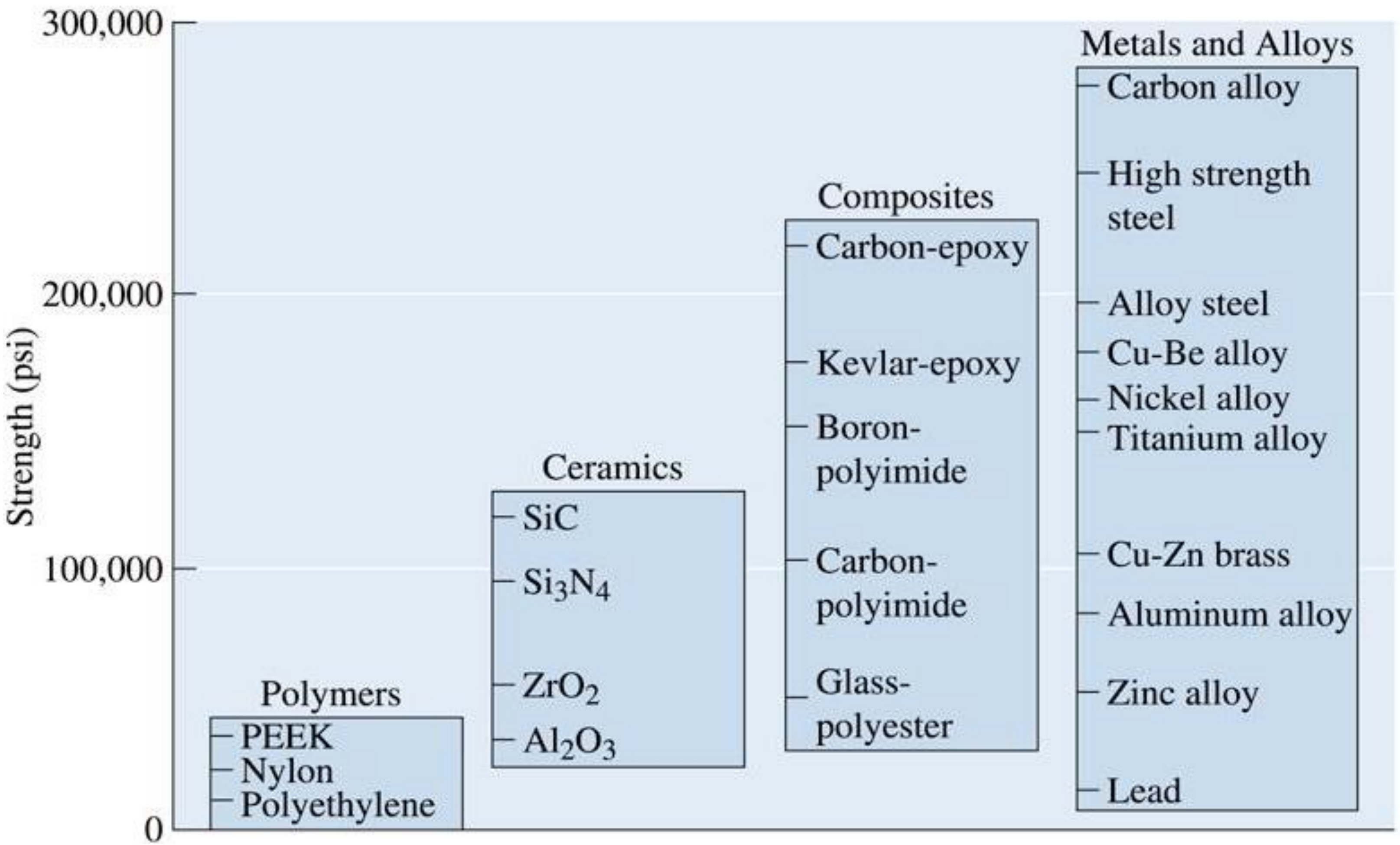
Common Materials with Various Viewpoints



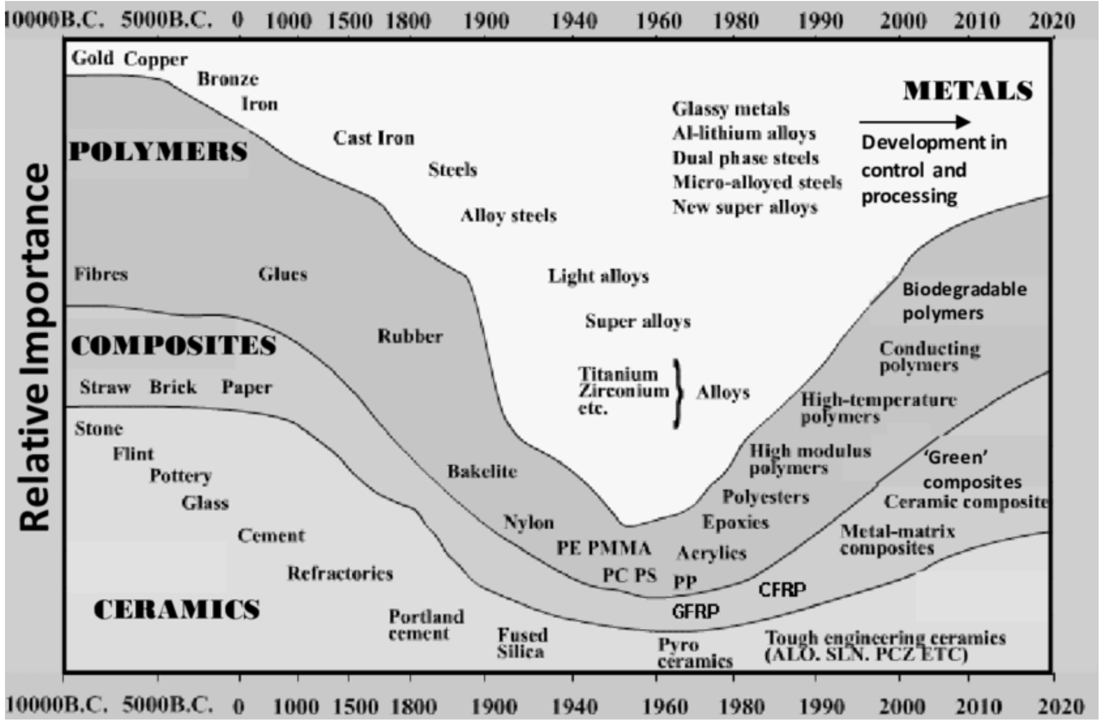
Classes of Property

Economic	Price and Availability, Recyclability
General Physical	Density
Mechanical	Modulus, Yield and Tensile strength, Hardness, Fracture strength, Fatigue strength, Creep strength, Damping
Thermal	Thermal conductivity, Specific Heat
Electric & Magnetic	Resistivity, Dielectric constant, Magnetic permeability
Environmental interactions	Oxidation, corrosion and wear
Production	Ease of manufacturer, joining, finishing
Aesthetic (Appearance)	Colour, Texture, Feel.

Strengths of Various Materials



Importance of New Materials



- ❑ There is a need to develop new materials for modern technological applications.
- ❑ They should have high performance efficiency and reliability.
- ❑ They should be light in weight and show a combination of properties.
- ❑ It should be possible to use them at the extreme environments, such as high temperature, high pressure, low temperature, low pressure, and highly corrosive.
- ❑ Over the years, so many new materials have been developed to meet technological requirements.
- ❑ Sometimes, it may not possible to meet stringent property requirements by using a single material.
- ❑ Hence, a combination of materials was thought of and thus composite materials have evolved. It is possible to get the best properties of constituents from a composite material.
- ❑ Predictions suggest that the demand for composites will continue to increase steadily. In the last 50 years, there has been a rapid increase in the production of synthetic composites, especially the fiber-reinforced polymer (FRP) composites.

Advanced Materials

- Materials that are utilized in high-technology (or high-tech) applications are sometimes termed advanced materials.

- Examples:-

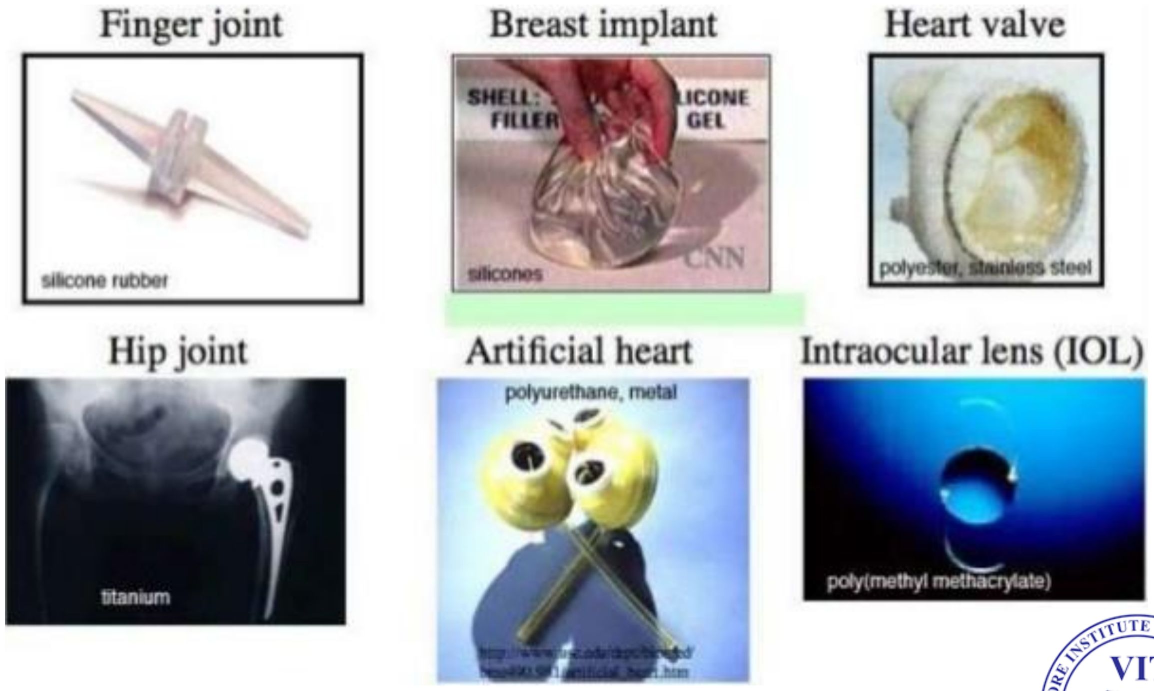
  - Include electronic equipment (camcorders, CD/DVD players, etc.), computers, fiber-optic systems, spacecraft, aircraft, and military rocketry, liquid crystal displays (LCDs), and fiber optics.

  - These advanced materials may be typically traditional materials types (e.g., metals, ceramics, polymers) whose properties have been enhanced, and also newly developed, high-performance materials.

  - Advanced materials include semiconductors, biomaterials, and what we may term materials of the future.

Biomaterials

- **Biomaterials are employed in components implanted into the human body for replacement of diseased or damaged body parts.**
- **These materials must not produce toxic substances and must be compatible with body tissues (i.e., must not cause adverse biological reactions).**
- **All of the above materials — metals, ceramics, polymers, composites, and semiconductors — may be used as biomaterials.**
- **Example — Titanium and its alloy, Co-Cr alloy, stainless steel, zirconia, hydroxylapatite (HA), TiO_2 etc.**



Semiconductors

- Semiconductors have electrical properties that are intermediate between the electrical conductors (viz. metals and metal alloys) and insulators (viz. ceramics and polymers).

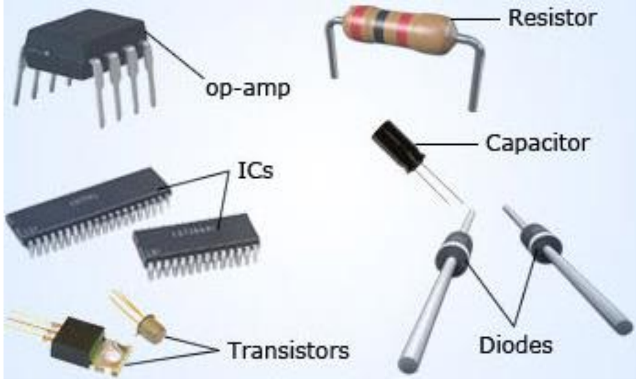
- The electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, for which the concentrations may be controlled over very small spatial regions.

- Semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries (not to mention our lives) over the past three decades.

- There are two types of semiconductors.

  - Single crystal semiconductor — Germanium (Ge), Selenium (Se), and Silicon (Si) have a repetitive crystal structure.

  - Compound semiconductor — Gallium Arsenide (GaAs), Cadmium Sulfide (CdS), are constructed of two or more semiconductor materials of different atomic structures.



Materials Selection Process

- Applied scientists or engineers must make material choices.
- Materials Selection
  - Pick Application and determine required Properties
  - Properties: Mechanical, electrical, thermal, magnetic, optical, deteriorative
  - Properties- Identify candidate material
  - Material: Structure, composition
  - Material- Identify required processing
  - Processing: Changes structure and overall shape

    Example: casting, sintering, vapor deposition, doping forming, joining, annealing.

- Materials Selection
  - in-service performance
  - deterioration
  - economics

BUT...really, everyone makes material choices!

aluminum

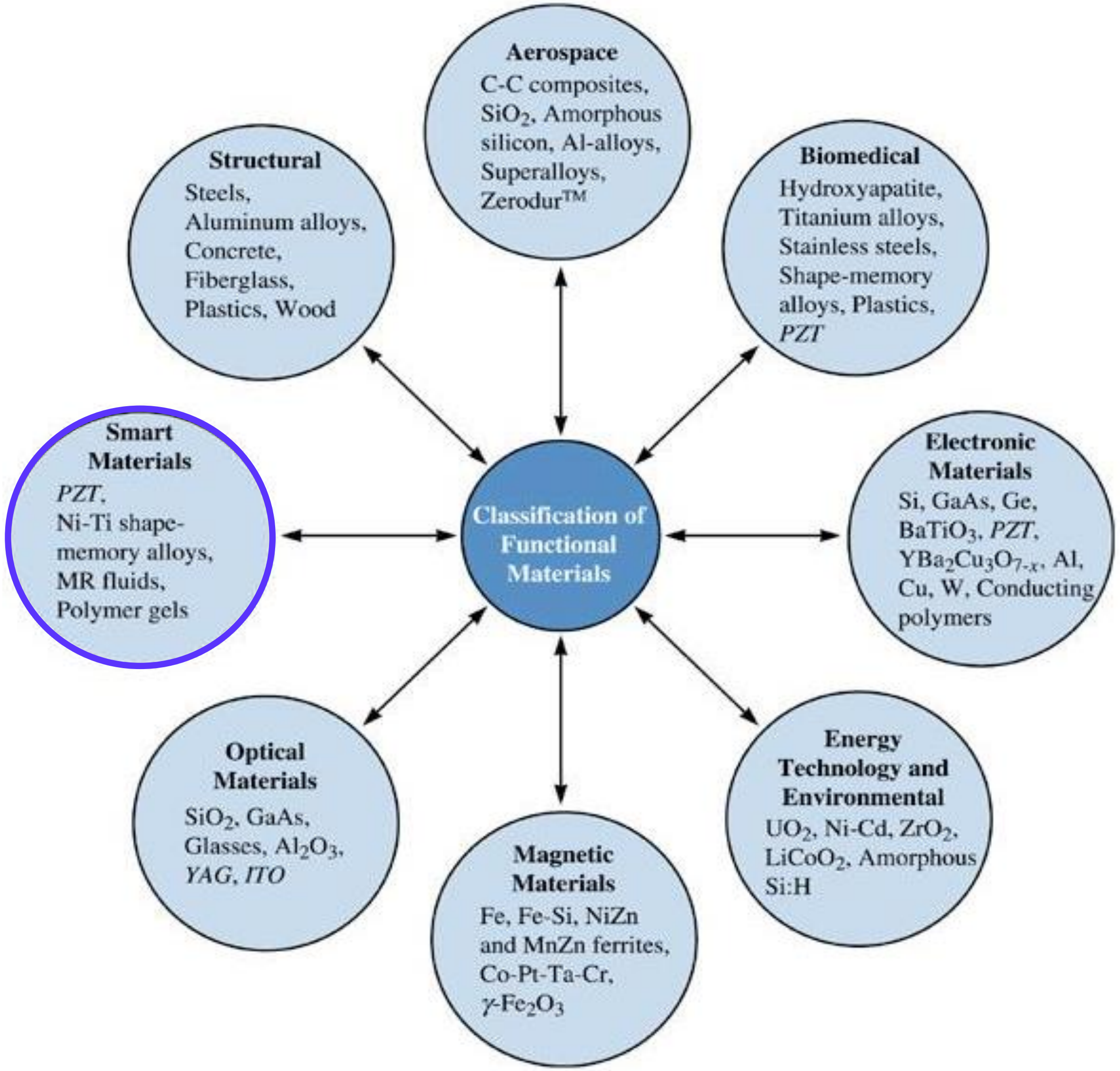
glass

plastic

Engineering Requirements of Materials

- Engineering requirements of a material means as what is expected from the material so that the same can be successfully used for making engineering components.
- The main engineering requirements of material fall under three categories.
  - Fabrication Requirements means that the material should be able to get shaped easily. That means materials have good machinability, ductility, castability, heat treatability, and weldability etc.
  - Service Requirements imply that the material selected for the purpose must stand up into service condition and it relates themselves with material's proper strength, wear resistance, and corrosion resistance, etc.
  - Economic Requirements demand that the engineering part should be made with minimum overall cost and minimum overall cost may be achieved by proper selection of both technical and marketing variables.

Classification of Functional Materials



- **Functional classification of materials**
  - **Notice that metals, plastics, and ceramics occur in different categories.**
  - **A limited number of examples in each category is provided.**

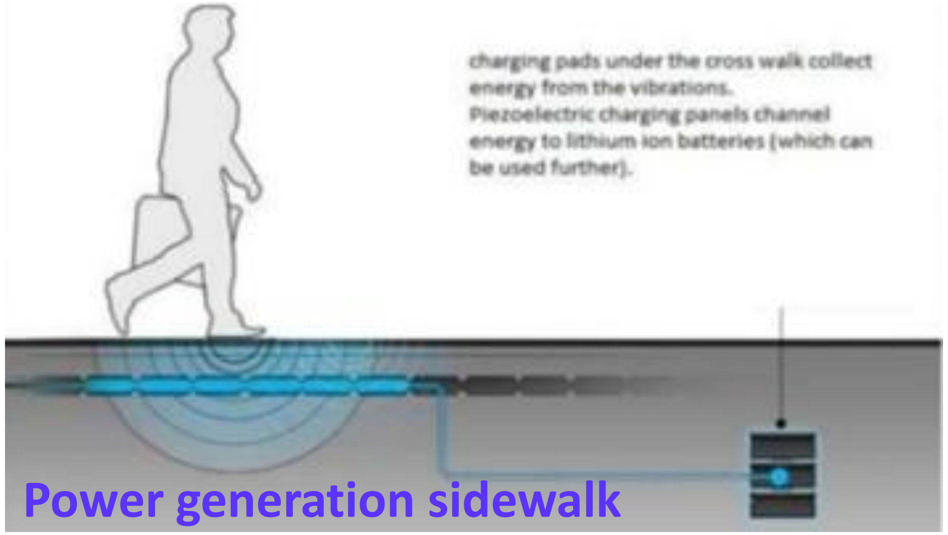
Piezoelectric Materials

Piezoelectric Materials

Crystals which acquire a charge when compressed, twisted or distorted and vice versa

NATURAL	SYNTHETIC
Quartz	Lead zirconate titanate (PZT)
Rochelle Salt	Zinc oxide (ZnO)
Topaz	Barium titanate ($BaTiO_3$)
Sucrose	Gallium orthophosphate ($GaPO_4$)
Tendon	Potassium niobate ($KNbO_3$)
Silk	Lead titanate ($PbTiO_3$)
Enamel	Lithium tantalate ($LiTaO_3$)
Dentin	Langasite ($La_3Ga_5SiO_{14}$)
DNA	Sodium tungstate (Na_2WO_3)

Piezoelectric Materials—Applications



Power generation sidewalk

- Vibrations caused from machines in the gym.
- At workplaces, piezoelectric crystal are laid in the chairs for storing energy.
- Utilizing the vibrations in the vehicle like clutches, gears etc.

Gyms and workplaces

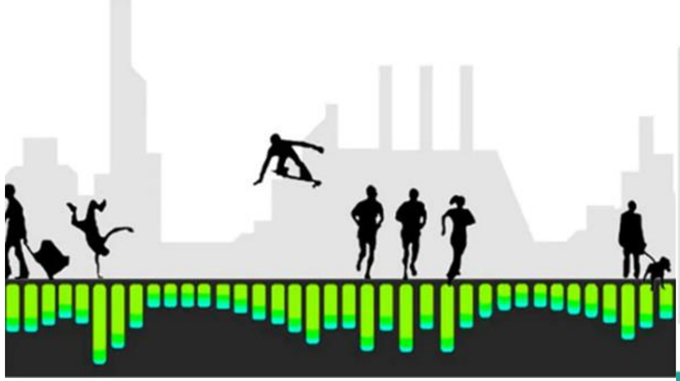
- Crystals laid down under keys of mobile unit and keyboard.
- For every key pressed vibrations are created.
- These vibrations can be used for charging purposes.

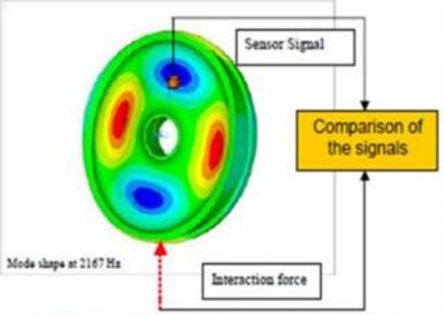
Mobile keypads and keyboards

Converse of Piezoelectric effect is used in Quartz watches

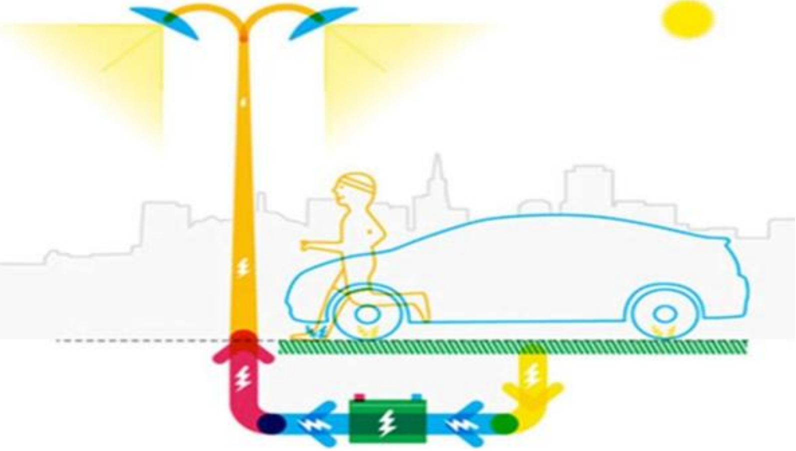
Quartz watches

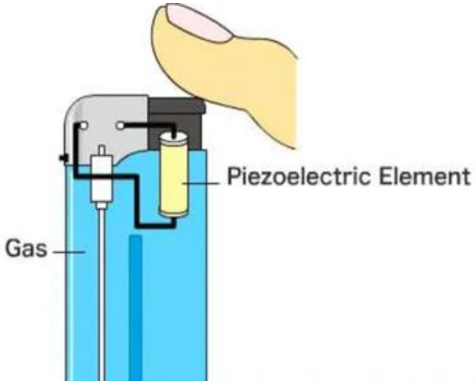
Contd…



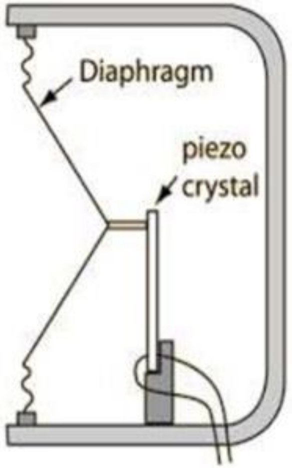


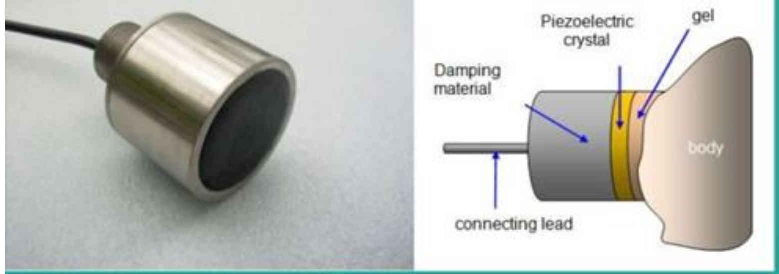
To detect wear in train wheels by detecting the change in vibration behavior of the entire wheel by generating mode shapes





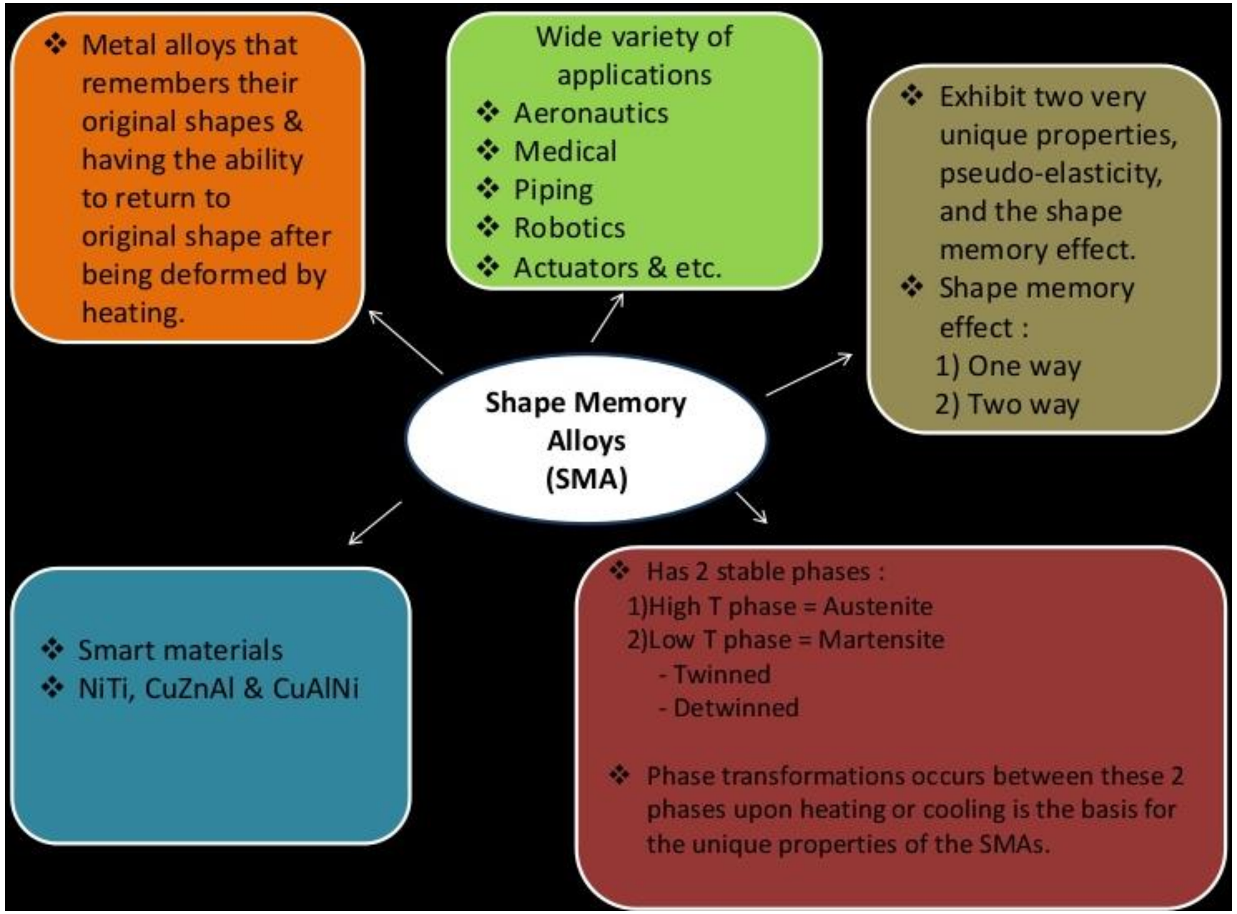
Piezoelectric Microphone
- sound sensor
- sound waves bend the crystal
- creates a changing voltage.



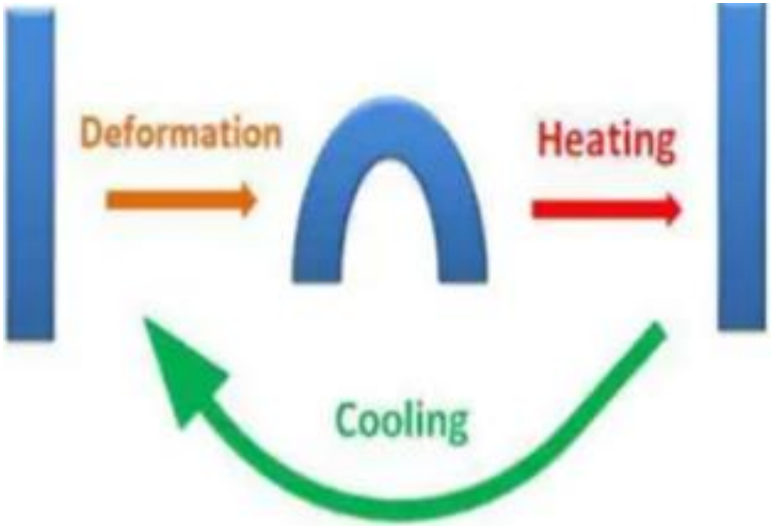


Used in ultrasonic transducers
- medical ultrasound imaging
- Non Destructive Tests in constructions

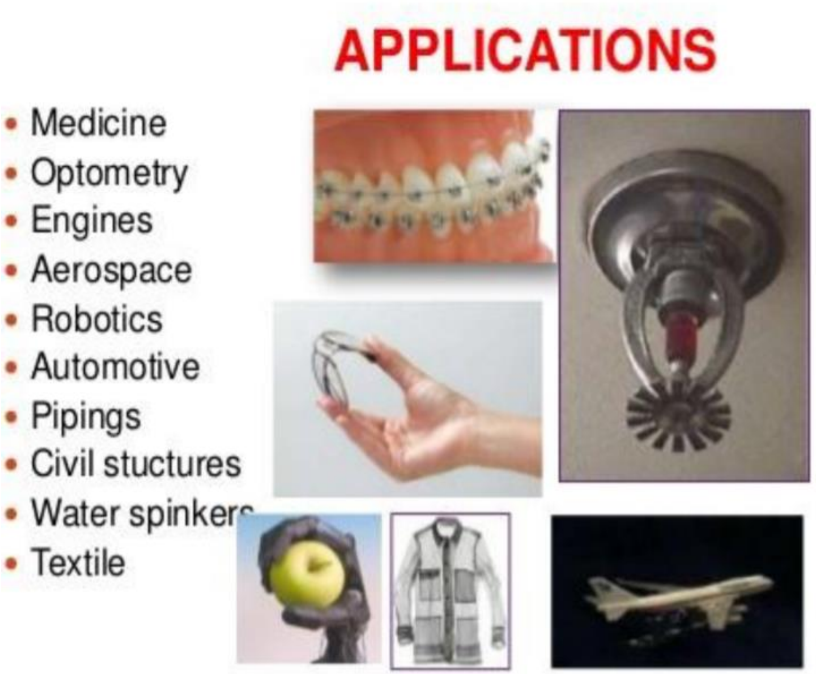
Shape Memory Alloys

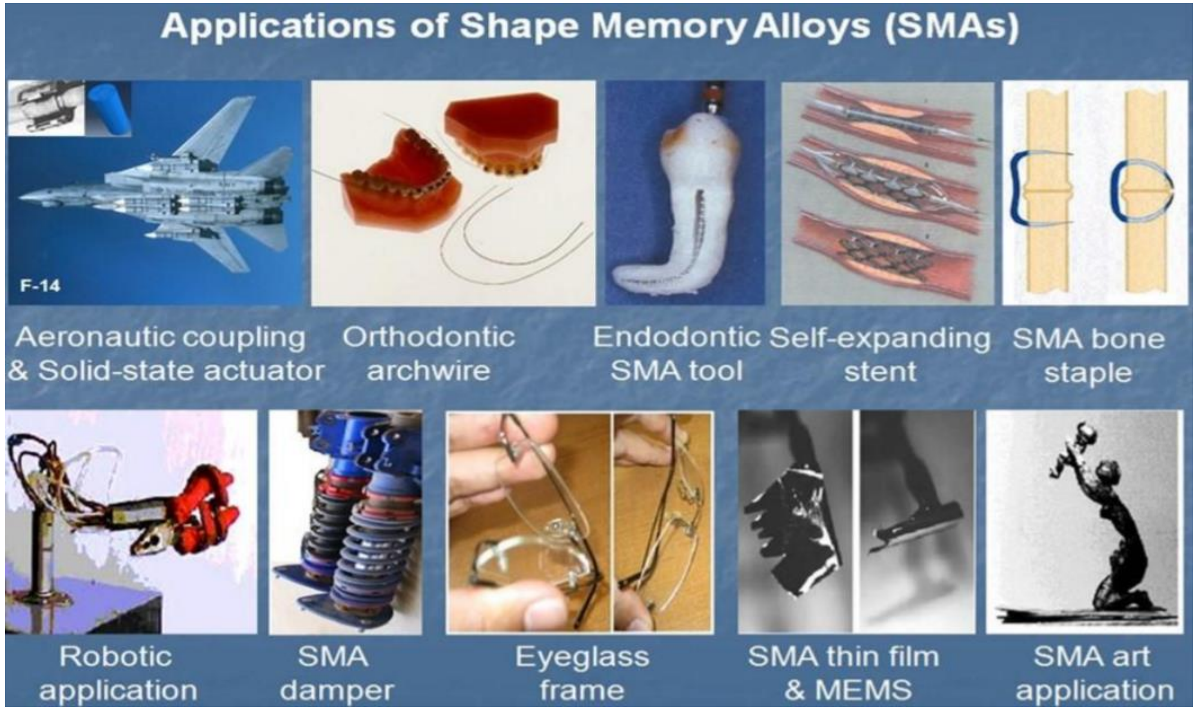


- Shape memory alloy is an alloy and it is one type of smart materials.
- SMAs are materials that remember their original shape.
- It deformed, they recover their original shape upon heating.
- They can take large stresses without undergoing permanent deformation.
- They can be formed into various shapes like bars, wires, plates and rings, thus serving various functions.



Shape Memory Alloys—Applications



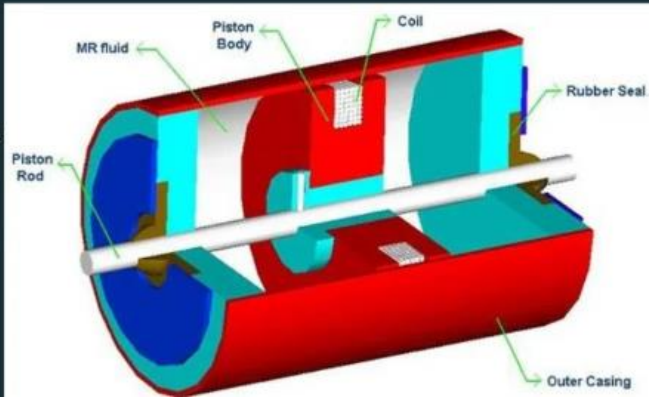


Magnetorheological (MR) Fluids

- These are liquids that change their properties when we apply a magnetic field to them.
- When the magnet is in place the MR Fluid turns into solid.
- When the magnet is removed the solid instantly reverts to liquid
- Soft magnetic material in a carrier oil.
  - Silicon oil or even corn syrup is mixed with the MRF to prevent rust.
  - Typical MR fluid contains 20-40% by volume of relatively pure, soft iron particles.
- Rheology or to the phenomena of flowing matter
- Is type of rheological fluids whose yield stress can be varied by an applied magnetic field.
- A typical MR fluid consists of micron sized magnetizable iron/ferrous particles suspended in a base fluid like silicone oil or water.

- **Vehicle Suspension Dampers**

- The MR damper has a built-in MR valve across which the MR fluid is forced. The piston of the MR damper acts as an electromagnet with the required number of coils to produce the appropriate magnetic field. Also the MR damper has a run-through shaft to avoid an accumulator.



Polymer Gels

- Polymer gel is a water-swollen, and cross-linked polymeric network produced by the simple reaction of one or more monomers.

OR

- Polymer gel is a polymeric material that exhibits the ability to swell and retain a significant fraction of water within its structure, but will not dissolve in water.

OR

- Polymer gels are macromolecular structure constructed of a cross linked water insoluble polymeric network that has capacity to absorb large amount of water.

- The ability of polymer gels to absorb water arises from hydrophilic functional groups attached to the polymeric backbone, while their resistance to dissolution arises from cross-links between network chains.
- After the absorption of water these gels can expand up to 1000 times in volume.