The CERN Accelerator School

Introduction to Engineering Materials

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INMA
INSTITUTO DE NANOCIENCIA
Y MATERIALES DE ARAGÓN

Outline

- Introduction: purpose and scope
- Classification of Materials
- Structure of Matter: Microscopic vs Macroscopic properties
  - Atomic bonding
  - Crystalline structures
  - Defects and dislocations
  - Phase diagrams and transformations
- Deterioration
- Applications in Accelerators

Introduction

Materials: Past, Present and Future

Introduction

- **Materials Science**

INVESTIGATION

Structure ⟷ Properties

- **Materials Engineering**

DESIGN/ENGINEER

Structure ➡ Properties

⇩

Engineering Materials

Accelerator Applications and technological challenges

Introduction

MATERIAL SELECTION

Enormous range of engineering materials

- In-service conditions
  - Required properties: mechanical, thermal, chemical, electrical, …
- Deterioration during operation
- Cost: material + fabrication

Knowledge of structure-property relationships and processing techniques helps with the choice

Processing → Structure → Properties → Performance

Introduction

Properties of Solid Materials:	**Stimuli**
• Mechanical (elastic modulus, strength)	Load, Force
• Thermal (heat capacity, thermal conductivity)	Heat
• Electrical (conductivity, dielectric constant)	Electric Field
• Magnetic	Magnetic Field
• Optical	Light
• Deteriorative	Chemical

Many Properties depend on microstructure

Classification of Materials

Engineering Materials classification (SOLID MATERIALS)

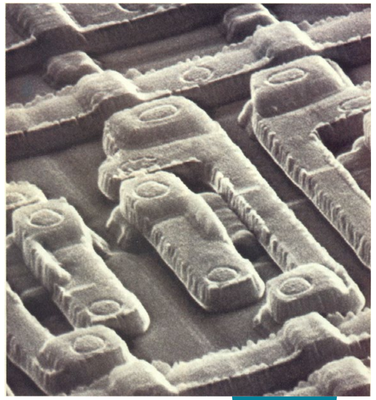
There are more than 50,000 commercially available materials

3 –**Basic groups** (based on atomic structure)

- **Metals and alloys**
  - Steel, aluminum, etc.
- **Polymers**
  - Polyethylene, polystyrene, nylon, epoxies, etc.
- **Ceramics and glasses**
  - Alumina, silica, silicon carbide, etc.

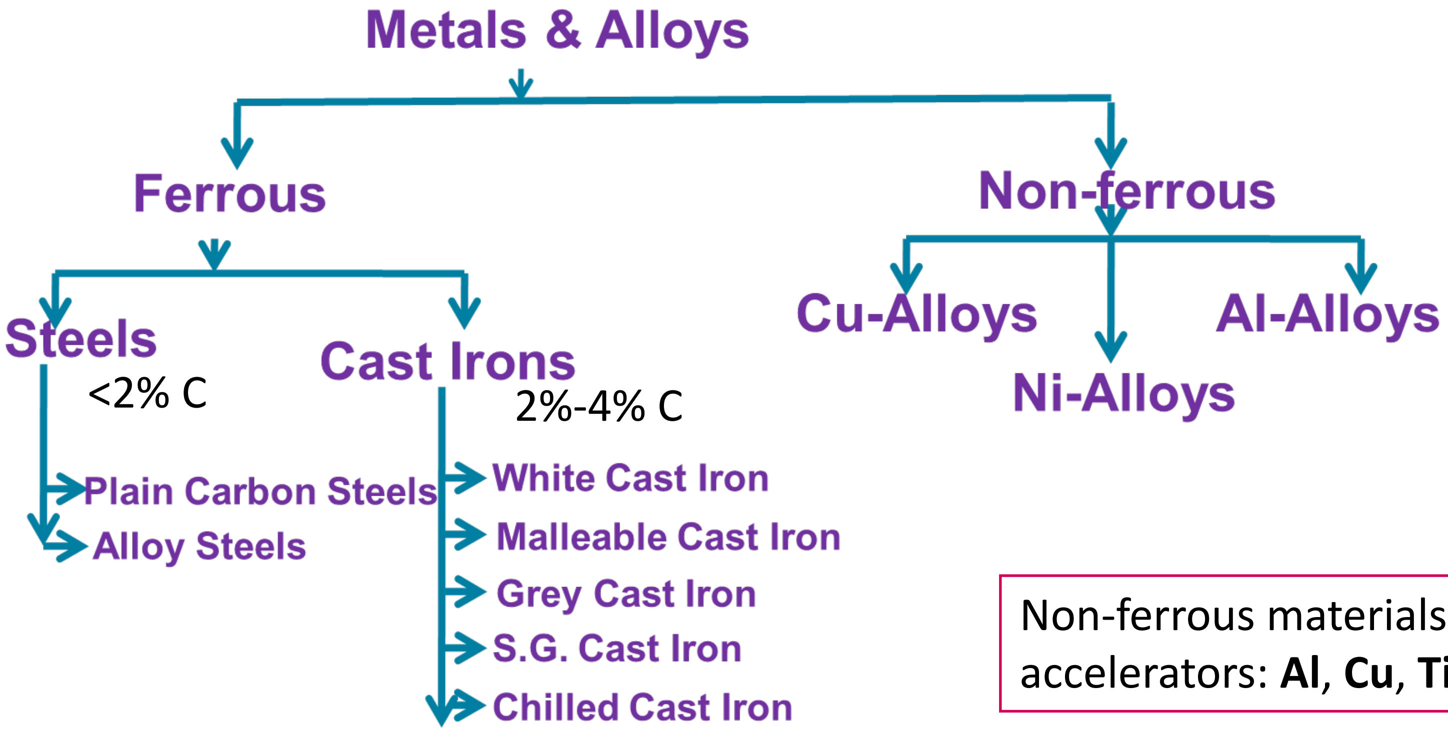
3 –**Additional groups** (based on atomic structure)

- **Composite materials**
  - Fiberglass, carbon fiber reinforced polymers, etc.
- **Semiconductors**
- **Biomaterials and Natural materials**
  - Wood, leather, silk, bone



Microelectronic Devices are Complex Composite Structures

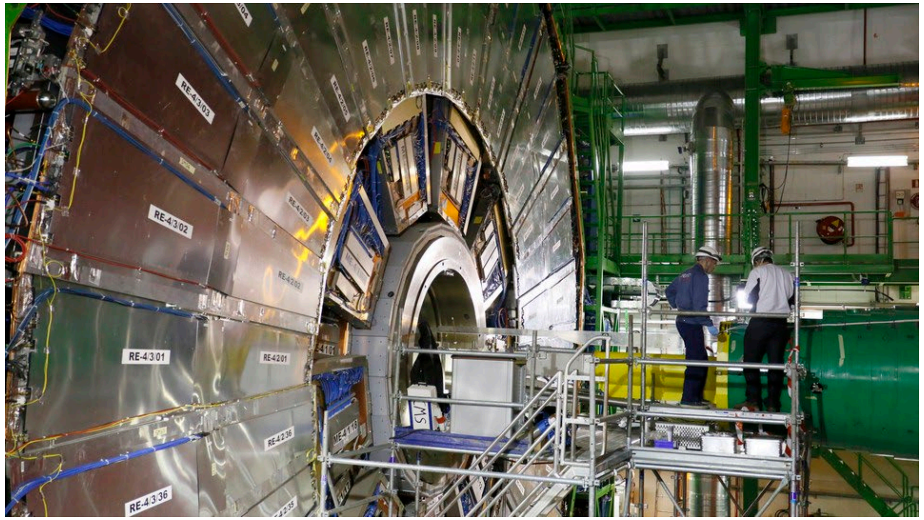
Classification of Materials: Metals & Alloys

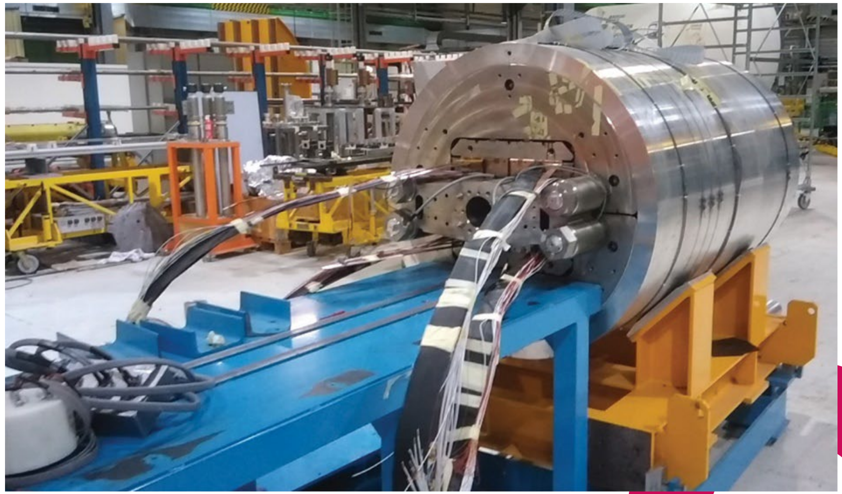


Metals & Alloys

- **Ferrous**
  - **Steels** <2% C
    - **Plain Carbon Steels**
    - **Alloy Steels**
  - **Cast Irons** 2%-4% C
    - **White Cast Iron**
    - **Malleable Cast Iron**
    - **Grey Cast Iron**
    - **S.G. Cast Iron**
    - **Chilled Cast Iron**
- **Non-ferrous**
  - **Cu-Alloys**
  - **Ni-Alloys**
  - **Al-Alloys**

Non-ferrous materials for accelerators: **Al**, **Cu**, **Ti**, **Nb**





Al alloys and **Ti** alloys for vacuum applications

Ti alloys are used for cryogenic applications (helium tanks)

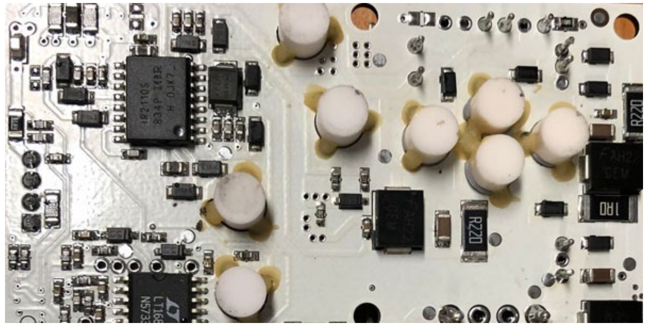
Highly pure **Nb** is as superconductor used for radiofrequency SC cavities

Classification of Materials: Ceramics

Ceramics

Metal Oxides **Nitrides** **Carbides**

- **Alumina**
- **Beryllia**
- **Zirconia**
- **Glass**
- **Glass Ceramics**



LVPS of the ATLAS detector

Advanced ceramics, such as Silicon Carbide, **SiC**, are commonly used in particle accelerators to dissipate heat effectively

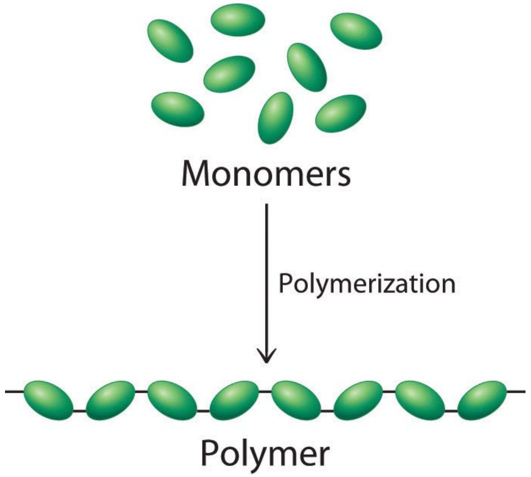
Ceramic chamber

Feedthrough

Ceramics defined as any inorganic non metallic material.
(inorganic substances do not contain C or its compounds)

Classification of Materials: POLYMERS

The word polymer means ‘many(poly) units(mers)’



- **Thermosoftening plastic or Thermoplastic**

Moldable above a specific temp and solidifies upon cooling.

may be reshaped by heating Temperature.

Fluorocarbons (Teflon), polyamides (Nylon), polyethylene,

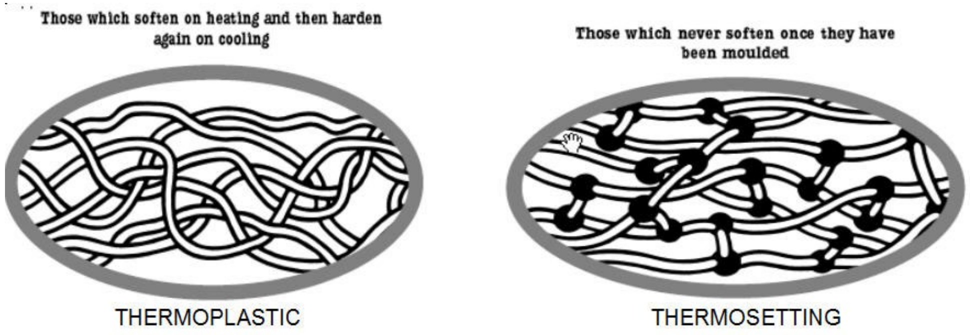
Polyester (PET), …

- **Thermosetting polymers** have their chains cross linked by covalent bonds.

Cross links between the chains form a 3D solid structure that cannot be changed.

Epoxies (araldite)

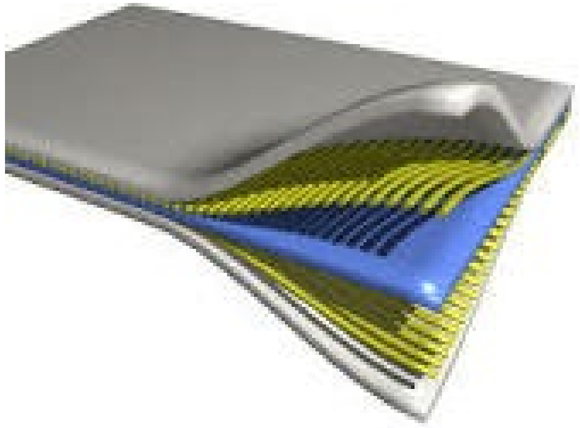
- **Elastomers,** rubber, neoprene, silicones
- Fiber polymers (lycra)

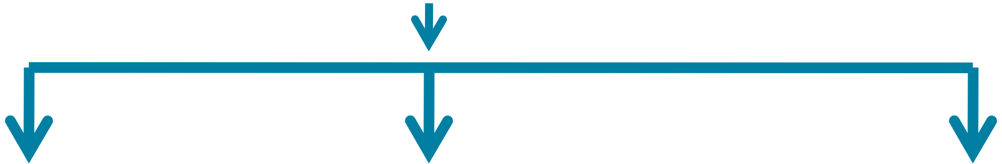


Radiation tests elastomeric O-rings

Classification of Materials: COMPOSITES

Composite materials are made from two or more constituent materials with combined characteristics different from the individual components.



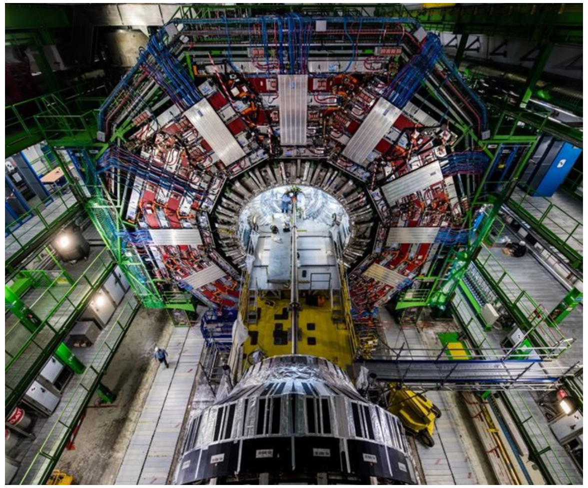


Composites

Laminar

Particle Reinforced

Fibre Reinforced



High-modulus unidirectional carbon fiber

Carbon fiber profiles in the high-precision structures that support the silicon tracker modules - CMS (CERN)

Carbon fiber prototype tube part of the “High-Luminosity LHC upgrade of the CMS detector.

Photo provided by Dr. Andreas Jung

Structure of Matter: Microscopic vs Macroscopic properties

Arrangement of internal components

Level of structure

MACROSCOPIC
> 10^{-4} m

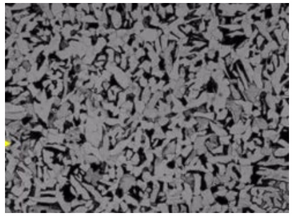
MICROSCOPIC
0.1-100 10^{-6} m

NANOSTRUCTURE
1-100 10^{-9} m

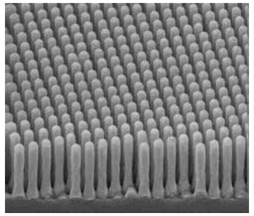
ATOMIC, MOLECULAR
1-10 10^{-10} m

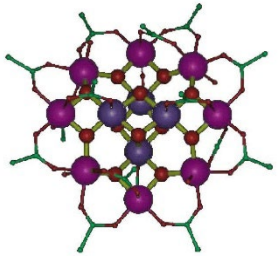
SUB-ATOMIC

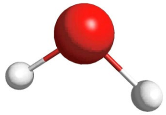
Porosity
cracks

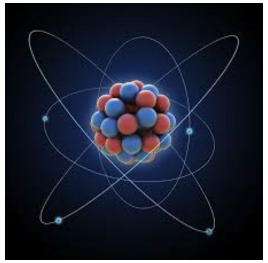


Grains,
inclusions

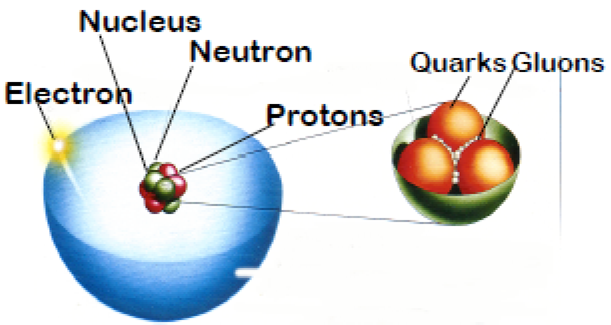






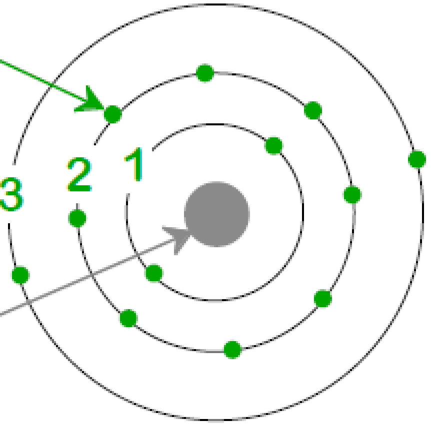


Structure of Matter: Sub-Atomic level - Elements



BOHR ATOM

orbital electrons:
n = principal
quantum number



Nucleus: Z = # protons

= 1 for hydrogen to 94 for plutonium

Atomic mass A ≈ Z + N N = # neutrons

- Most elements: Electron configuration not stable.

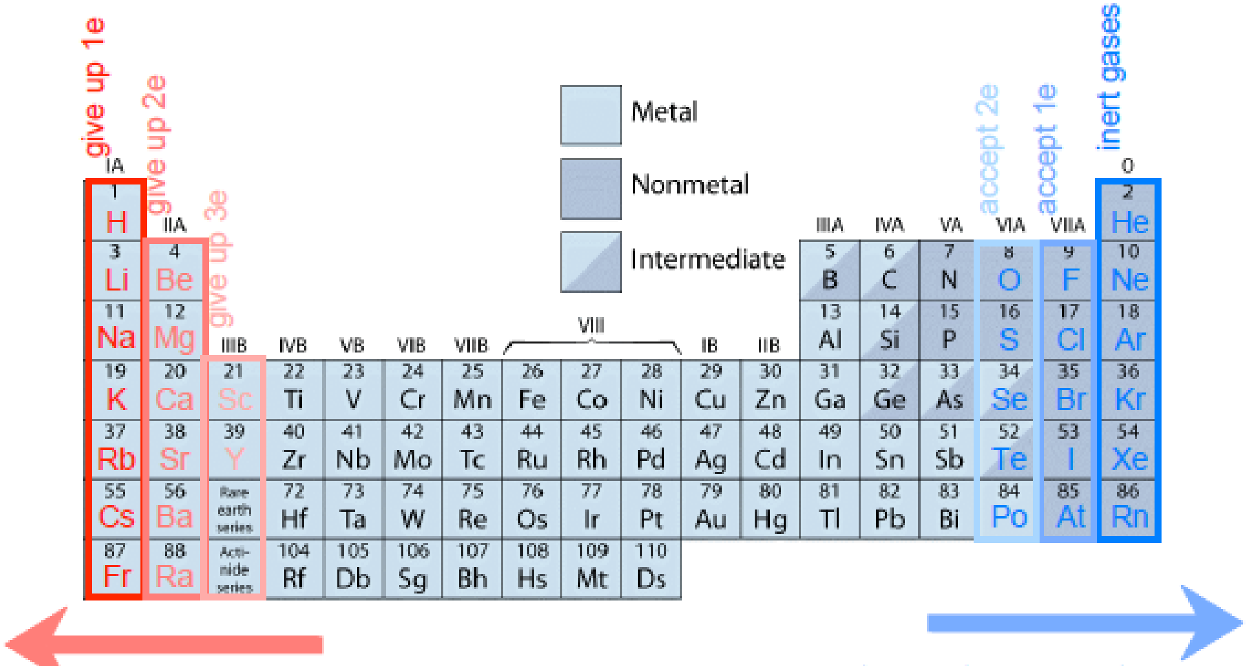
Element	Atomic #	Electron configuration
Hydrogen	1	$1s^1$
Helium	2	$1s^2$ (stable)
Lithium	3	$1s^2 2s^1$
Beryllium	4	$1s^2 2s^2$
Boron	5	$1s^2 2s^2 2p^1$
Carbon	6	$1s^2 2s^2 2p^2$
...		...
Neon	10	$1s^2 2s^2 2p^6$ (stable)
Sodium	11	$1s^2 2s^2 2p^6 3s^1$
Magnesium	12	$1s^2 2s^2 2p^6 3s^2$
Aluminum	13	$1s^2 2s^2 2p^6 3s^2 3p^1$
...		...
Argon	18	$1s^2 2s^2 2p^6 3s^2 3p^6$ (stable)
...	...	...
Krypton	36	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$ (stable)

- Why? Valence (outer) shell usually not filled completely.

Adapted from Table 2.2, *Callister 7e.*

Structure of Matter: Sub-Atomic level - Elements

- Columns: Similar Valence Structure



Electropositive elements: Readily give up electrons to become + ions.

Electronegative elements: Readily acquire electrons to become - ions.

Table 4. PERIODIC TABLE OF ELEMENTS IN METALLIC MATERIALS

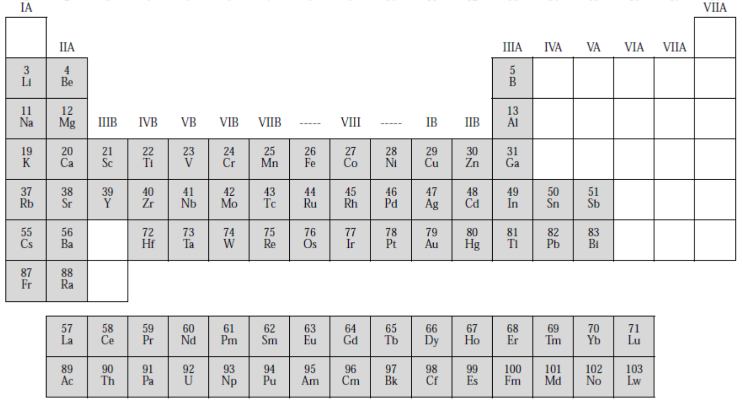


Table 5. PERIODIC TABLE OF ELEMENTS IN CERAMIC MATERIALS

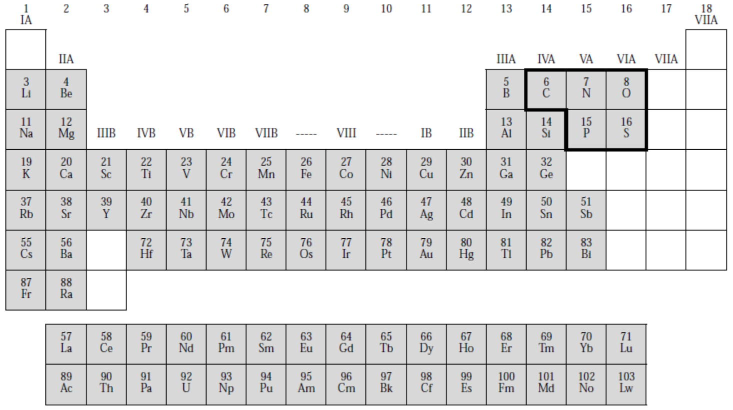


Table 6. PERIODIC TABLE OF ELEMENTS IN POLYMERIC MATERIALS

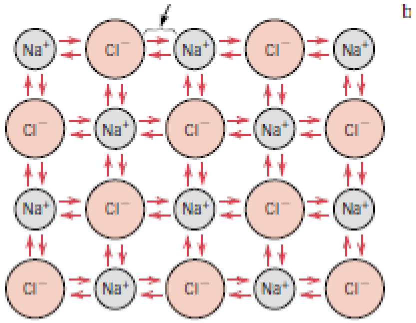
Periodic Table of Elements in Materials

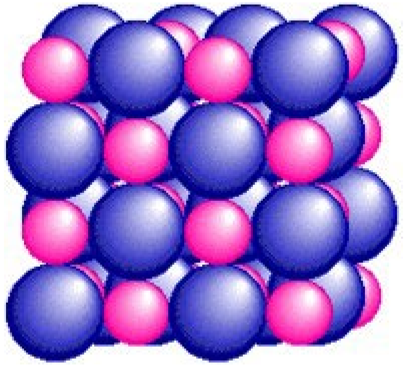
Structure of Matter: Atomic level - Bonding

PRIMARY INTERATOMIC BONDS

Ionic Bonding

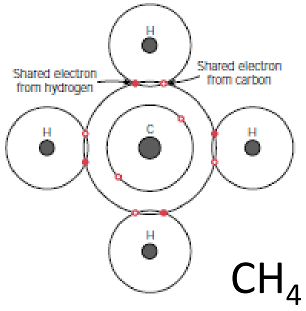
Metallic and nonmetallic elements
High bonding energy and Non directional
Ionic materials are hard, brittle, electrically and thermal insulators
Predominant in **ceramic materials**



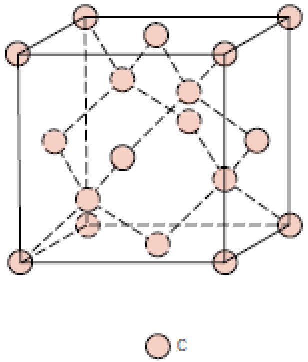


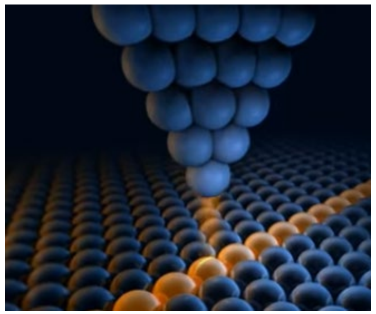
Covalent Bonding

Directional along the electron sharing atoms
Elemental solids located on the right of the periodic table: C, Si, Ge, GaAs, SiC..
Weak (bismuth, melts 270ºC) or strong (diamond, 3550ºC)
Polymeric materials



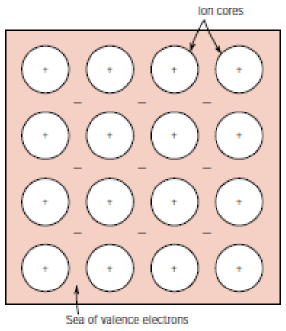
CH_4



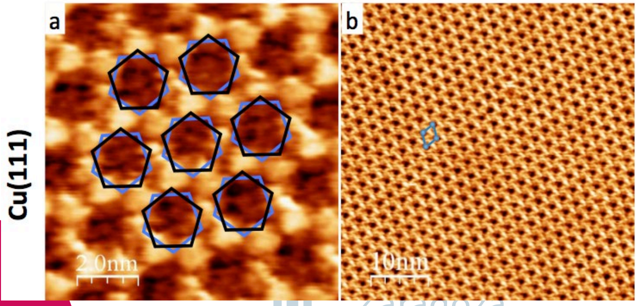


Metallic Bonding

Metals and their alloys
Non directional, Ion cores and electron cloud of valence electrons
Weak (Hg, melts -39ºC) or strong (tungsten, 3410ºC)
Good conductors of electricity and heat
Ductile



Cr_{10} monolayers UHV-evaporated on Cu(111)

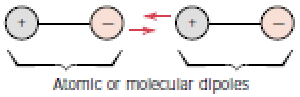


DOI: 10.1002/admi.202300146

Structure of Matter: Atomic level - Bonding

SECONDARY INTERATOMIC BONDS

Van der Waals Bonding

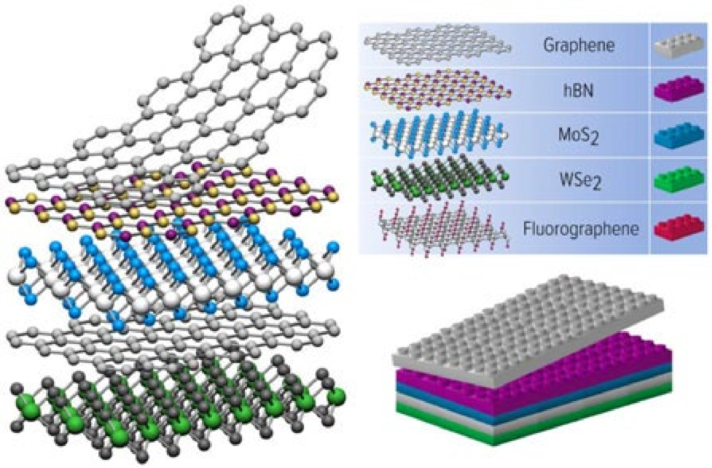


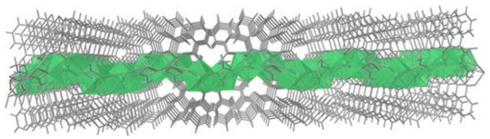
Always present

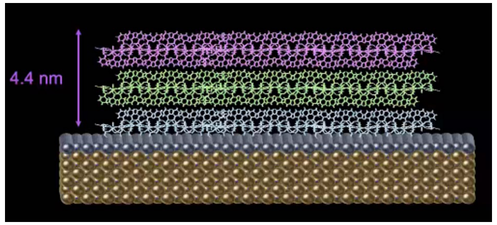
Evidenced in inert gases, in molecular structures

Induced dipoles and permanent dipoles

Van der Waals Materials: Graphene, 2D materials





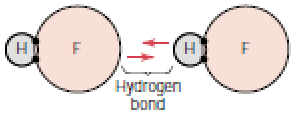


https://doi.org/10.1002/anie.202100507

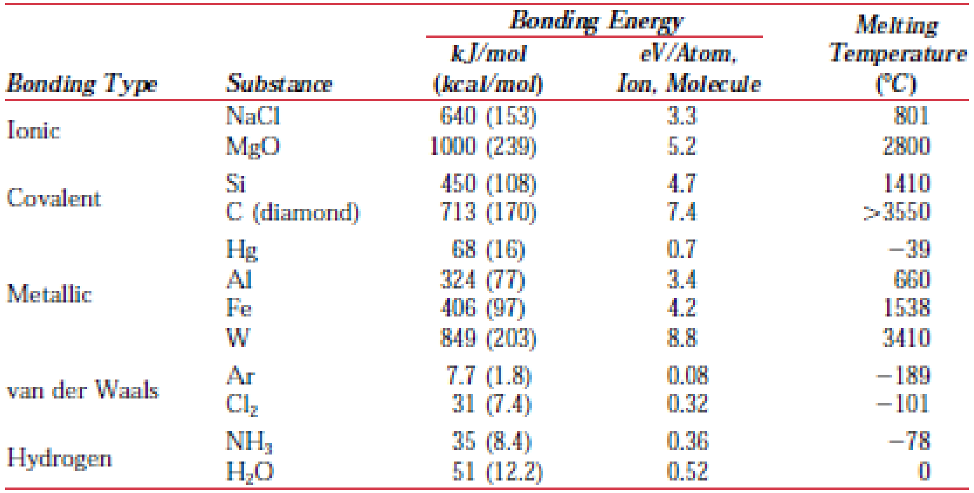
Hydrogen Bonding

Special case of polar molecule bonding

Relatively strong, increasing melting and boiling temperatures



Secondary bonds are very importantn in the properties of **polymers**



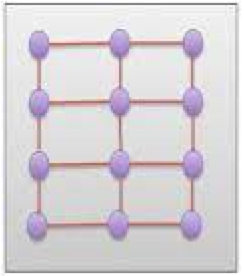
Bonding Type	*Substance*	*Bonding Energy* *kJ/mol (kcal/mol)*	*eV/Atom, Ion, Molecule*	*Melting Temperature (°C)*
Ionic	NaCl	640 (153)	3.3	801
	MgO	1000 (239)	5.2	2800
Covalent	Si	450 (108)	4.7	1410
	C (diamond)	713 (170)	7.4	>3550
Metallic	Hg	68 (16)	0.7	−39
	Al	324 (77)	3.4	660
	Fe	406 (97)	4.2	1538
	W	849 (203)	8.8	3410
van der Waals	Ar	7.7 (1.8)	0.08	−189
	Cl_2	31 (7.4)	0.32	−101
Hydrogen	NH_3	35 (8.4)	0.36	−78
	H_2O	51 (12.2)	0.52	0

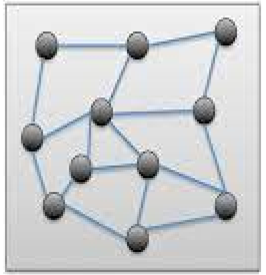
Structure of Matter: Crystal Structure

The properties of some materials are directly related to their crystal structures

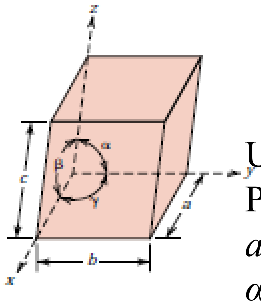
A **crystalline** material is one in which the atoms are situated in a repeating or periodic array over large atomic distances (long-range order). Each atom is bonded to its nearest-neighbor atoms.
The **unit cell** is the basic structural unit or building block.
All metals, many ceramic materials, and certain polymers form crystalline structures under normal solidification conditions.

In **amorphous** or non-crystalline materials, long-range atomic order is absent. (glass, paraffin,…)
(not fully understood). They have interesting properties like high mechanic strength and corrosion resistance.
Meltglass: Melt Spinning of Metals



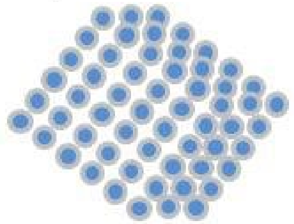


Amorphous Solid



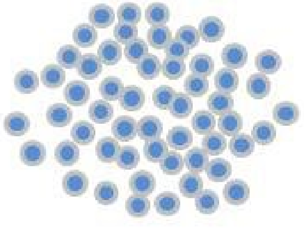
Unit cell geometry
Parameters:
$a, b, c,$
α, β, γ

Crystalline solid

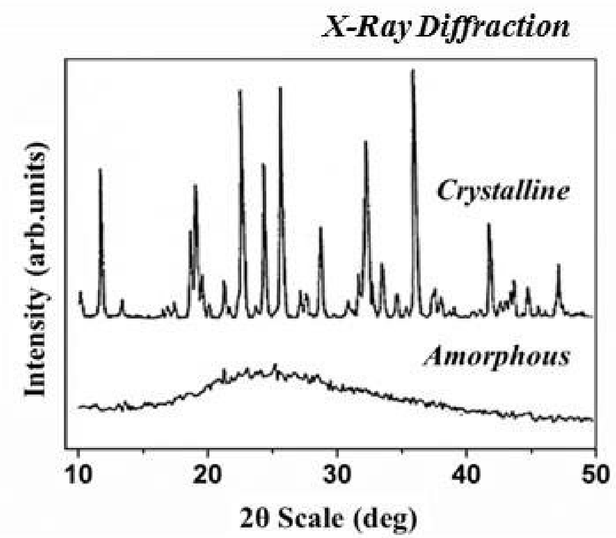


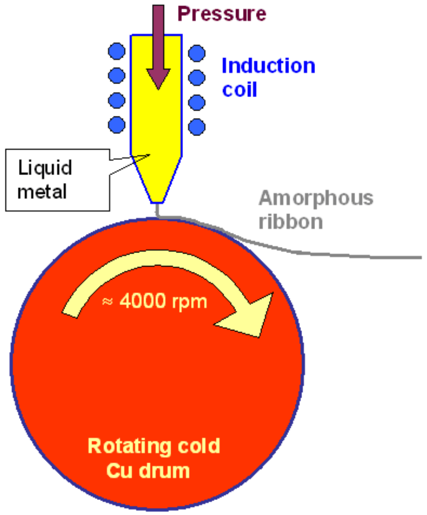
Long range ordering

Amorphous solid



No long range ordering

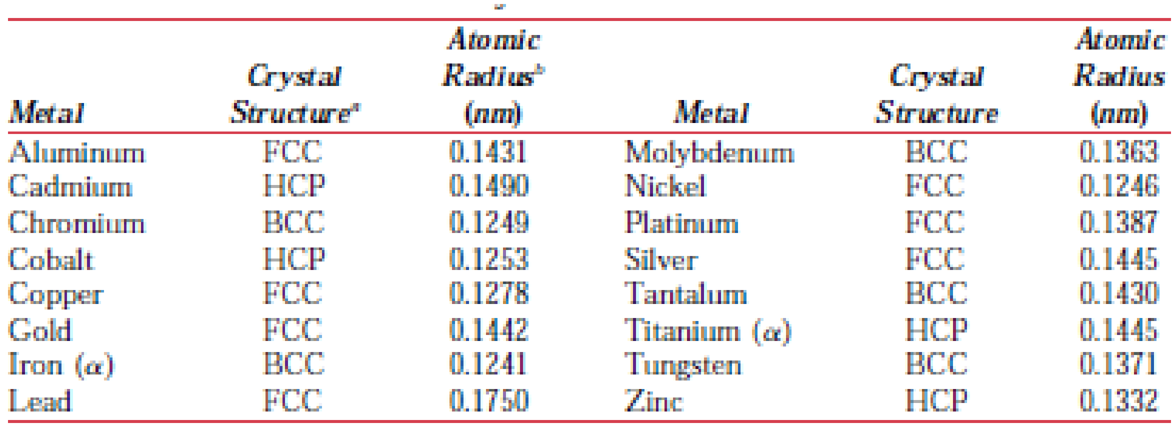




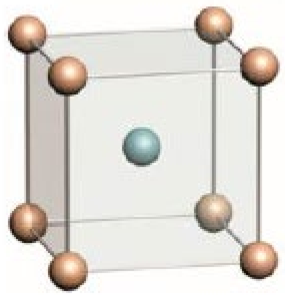
Structure of Matter: Crystal Structure

Metallic Crystal Structures:

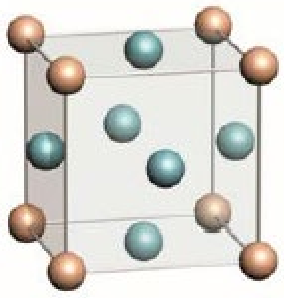
Non directional in nature: dense atomic packings
Most of the common metals have these crystal structures: BCC FCC HCP



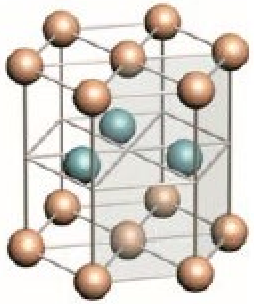
Metal	Crystal Structure[a]	Atomic Radius[b] (nm)	Metal	Crystal Structure	Atomic Radius (nm)
Aluminum	FCC	0.1431	Molybdenum	BCC	0.1363
Cadmium	HCP	0.1490	Nickel	FCC	0.1246
Chromium	BCC	0.1249	Platinum	FCC	0.1387
Cobalt	HCP	0.1253	Silver	FCC	0.1445
Copper	FCC	0.1278	Tantalum	BCC	0.1430
Gold	FCC	0.1442	Titanium (α)	HCP	0.1445
Iron (α)	BCC	0.1241	Tungsten	BCC	0.1371
Lead	FCC	0.1750	Zinc	HCP	0.1332



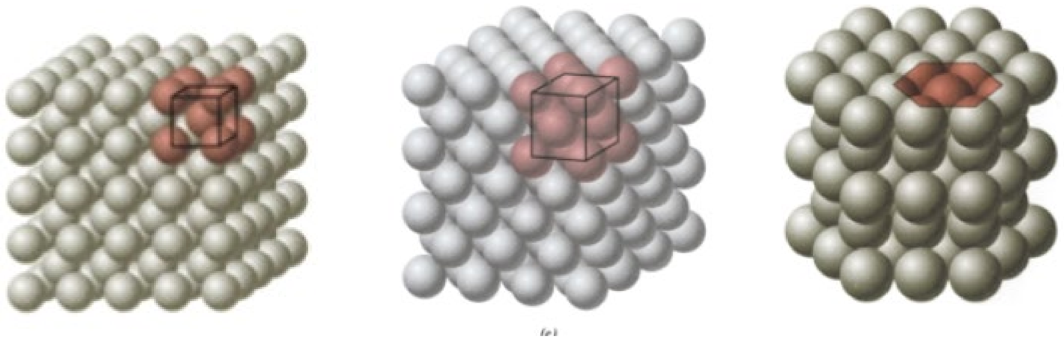
Body-centered cubic (BCC)



face-centered cubic (FCC)



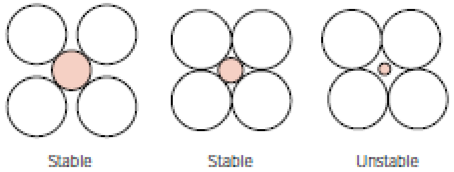
Hexagonal Close-Packed (HCP)



Structure of Matter: Crystal Structure

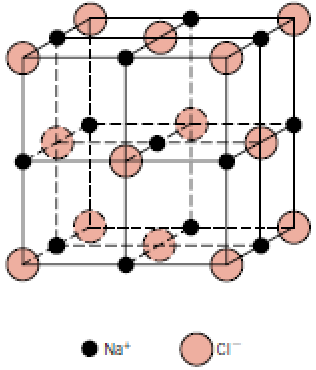
Ceramic Crystal Structures:

2 or more elements: complex
Bonding ionic-covalent



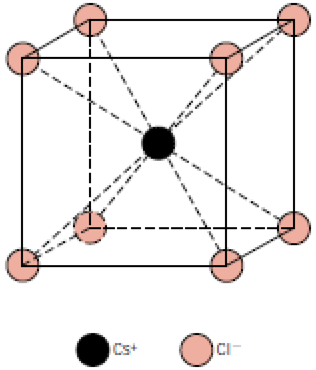
Stability when anions coordinating with a cation are **all in contact** with the cation.
For a specific cn there is a critical or minimum r_C/r_A

AX-Type (A cation, X anion)

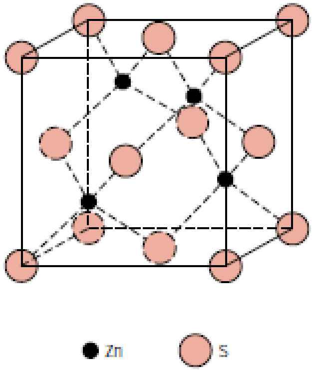


NaCl, MgO, MnS, LiF, FeO

cn=6
two interpenetrating FCC lattices

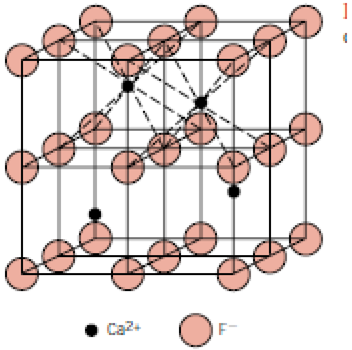


CsCl,
cn=8



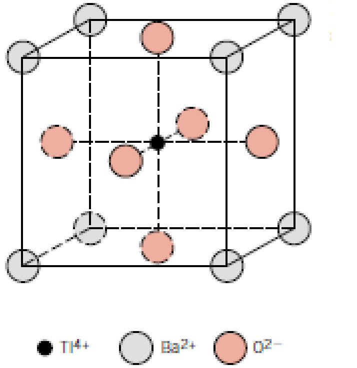
ZnS, ZnTe, SiC
cn=4

A_mX_p-Type Fluorite



CaF_2, (similar to CsCl)
cn=8

$A_mB_nX_p$-Type Perovskyte

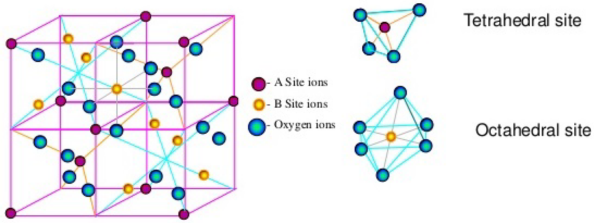


$BaTiO_3$ (Ba^{2+}, Ti^{4+}, O^{2-})
$SrZrO_3$, $SrSnO_3$
cn=8

$A_mB_nX_p$-Type Spinel, Inverse Spinel

Normal: $(A^{II})^T(B^{III})_2{}^O O_4$
$MgAl_2O_4$ (Mg^{2+}, Al^{3+}, O^{2-})

Crystal structure of Spinel Ferrite



Inverse: $(B^{III})^T(A^{II}B^{III})^O O_4$
Fe_3O_4 (ferrite), $CoFe_2O_4$, $NiFe_2O_4$

cn = coordination number

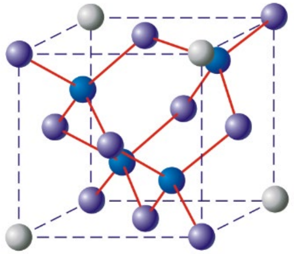
Structure of Matter: Crystal Structure

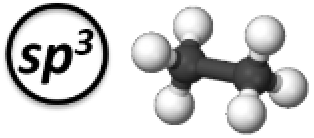
Polymorphism is the ability of solid material to exist in more than one form or crystal structure.

Carbon allotropic forms:

Carbon is capable of forming many allotropes (structurally different forms of the same element)

Diamond
3D structure (sp^3 bonding)

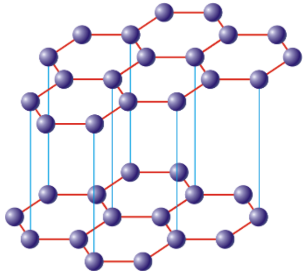


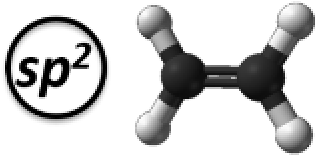


Diamond is a metastable phase degrading to graphite: Diamonds do not last for ever!

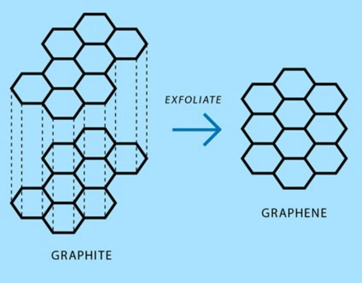
Graphite
3D structure (sp^2 bonding)

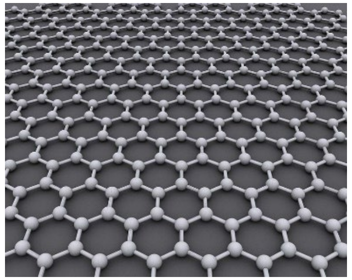
AI



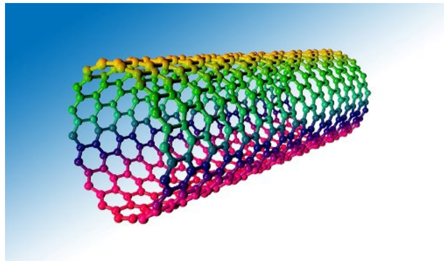


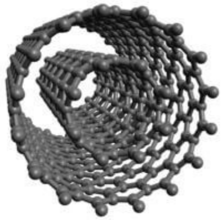
Graphene
2D structure



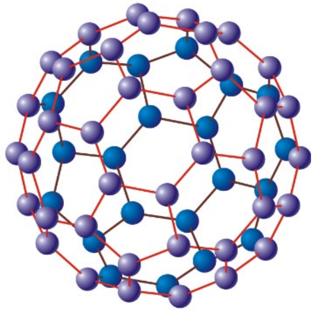


Carbon Nanotubes
1D structure



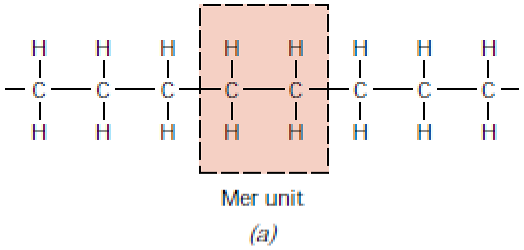


C_{60} Fullerene
0D structure

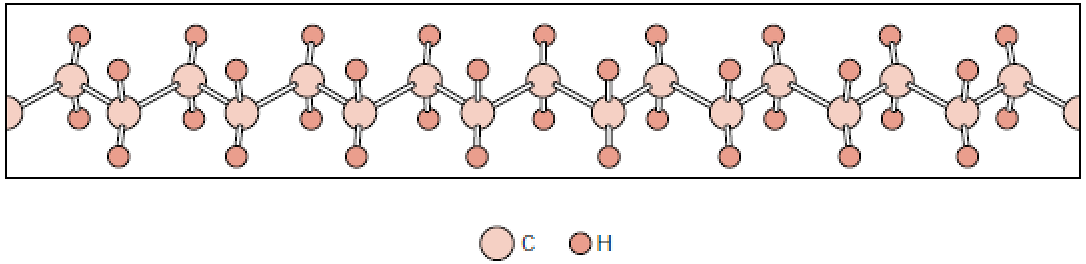


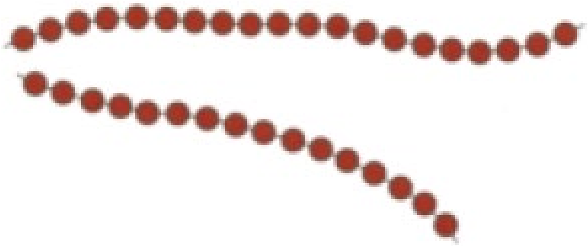
Structure of Matter: Crystal Structure

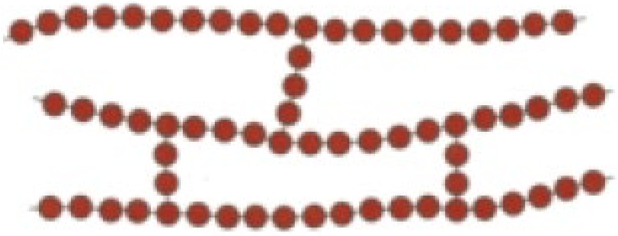
Polymers: many organic materials are hydrocarbons



Strong covalent bonds in each molecule
Weak hydrogen and van der Waals bonds between molecules
⇓
low melting and boiling points







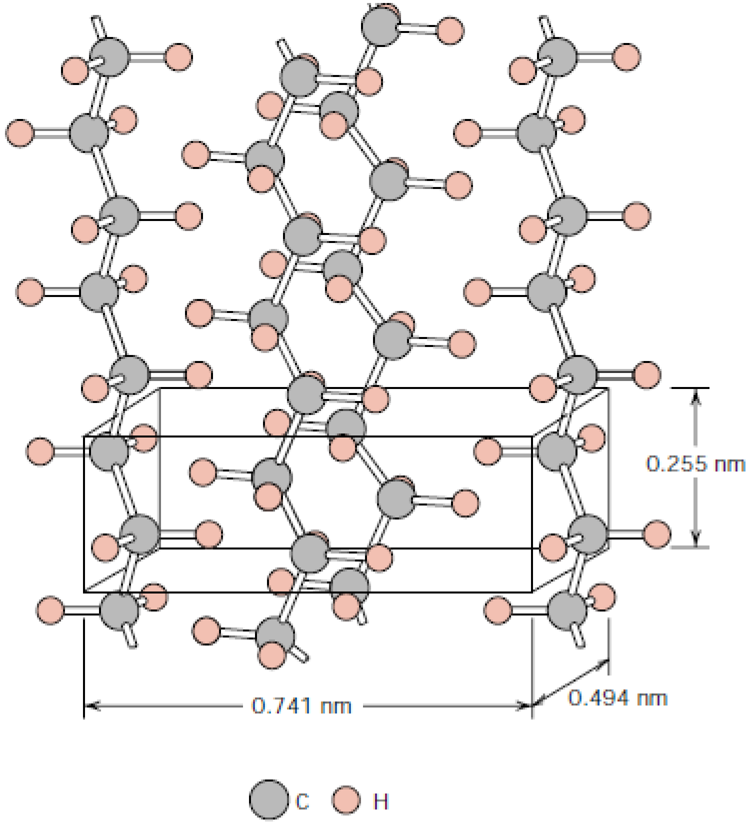
Linear polymers: mer units in single chains.
extensive van der Waals and hydrogen bonding between the chains
Flexible

In **crosslinked polymers,** adjacent linear chains are joined by covalent bonds
Can form networks
Harder and stronger, and have better dimensional stability

Structure of Matter: Crystal Structure

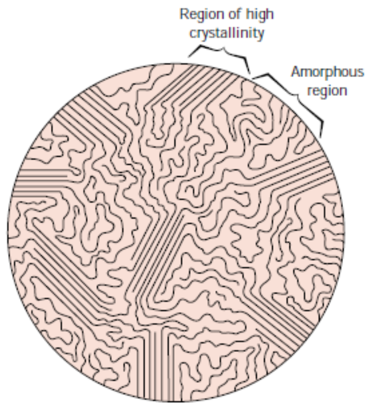
Polymers:

Many bulk polymers that are crystallized from a melt form **spherulites**



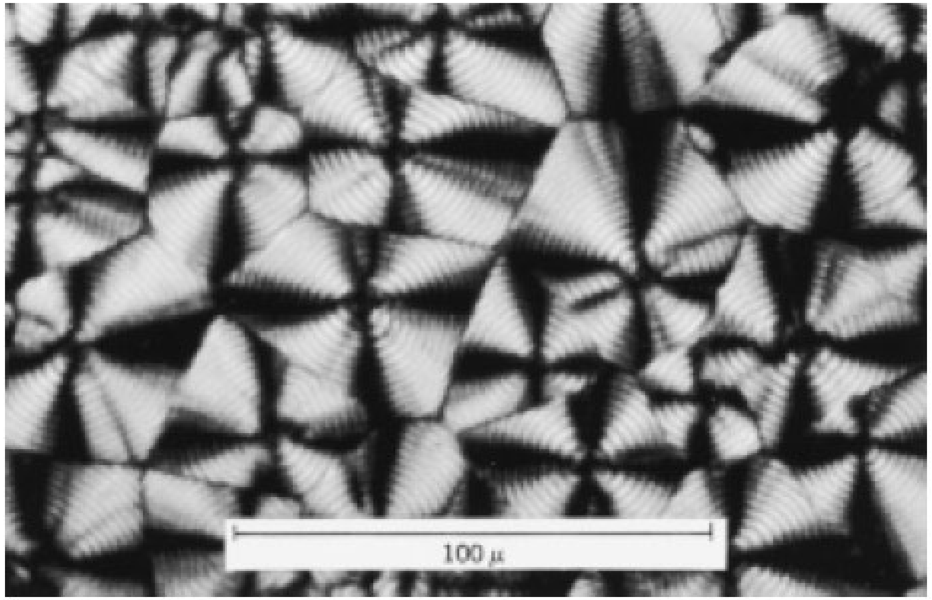
Arrangement of molecular chains in a unit cell for polyethylene. (Adapted from C. W. Bunn, *Chemical Crystallography*, Oxford University Press, Oxford, 1945, p. 233.)

$(-CH_2-CH_2-)_n$



semicrystalline polymer, showing both crystalline and amorphous regions. (From H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*. Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

A transmission photomicrograph (using cross-polarized light) showing the spherulite structure of polyethylene. Linear boundaries form between adjacent spherulites, and within each spherulite appears a Maltese cross. 525×. (Courtesy F. P. Price, General Electric Company.)

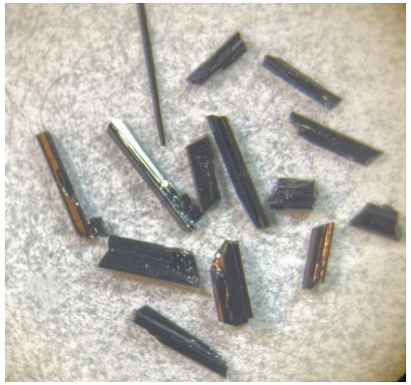


The degree of crystallinity may range from completely amorphous to almost entirely (up to about 95%) crystalline

Structure of Matter: Microstructure

Single Cristal:

crystalline solid, where the periodic and repeated arrangement of atoms is perfect or extends throughout the entirety of the specimen



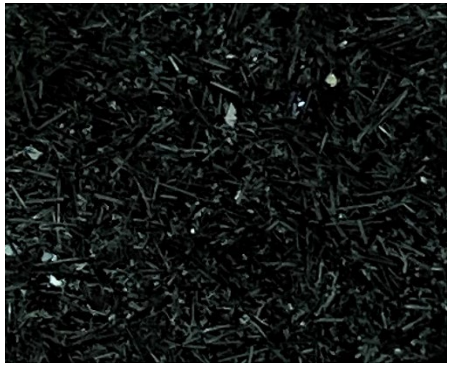
Co_3BO_5 Needles

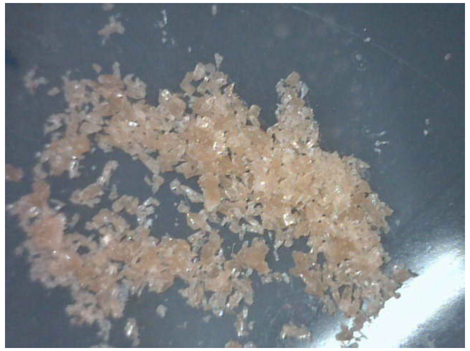
a = 9.2963(2) Å
b = 11.948(2) Å
c = 2.9737(6) Å

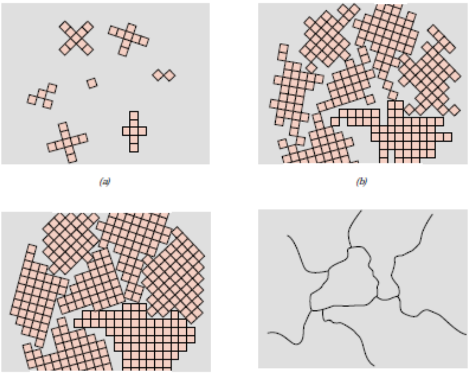
Anisotropic Physical Properties

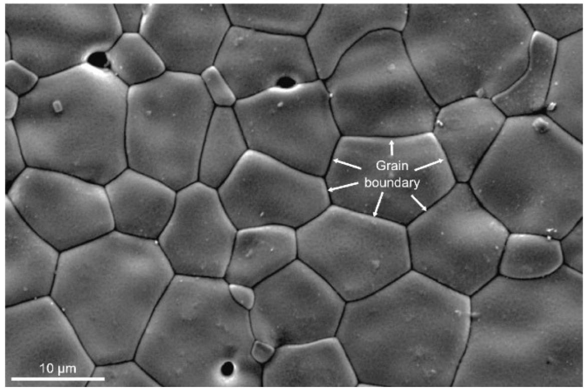
Polycrystalline material:

Most crystalline solids are composed of a collection of many small crystals or **grains**





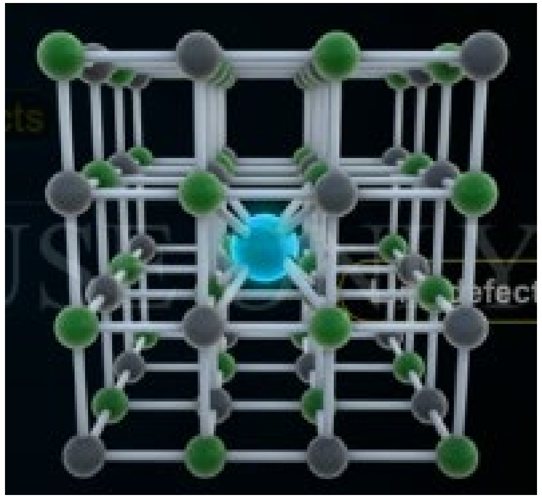




A measured property represents some average of the directional values, unless grains have a preferential crystallographic orientation (texture)

Structure of Matter: Imperfections in Solids

The perfect imperfection

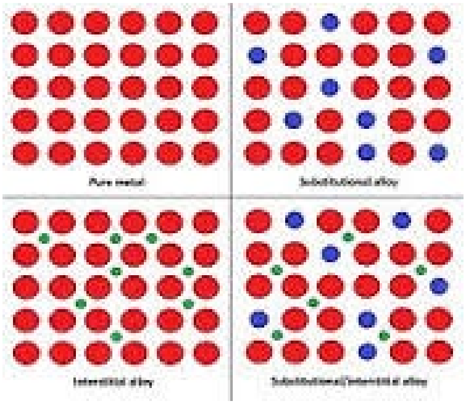


Presence of impurities: foreign atoms

A pure metal consisting of only one type of atom does not exist
Metals to a purity of 99.9999% have 10^{22} to 10^{23} impurities/m^3

Most familiar metals are **alloys,** in which impurity atoms have been added intentionally to impart specific characteristics to the material.

Improved mechanical strength and corrosion resistance by alloying.



- Sterling silver is a 92.5% silver–7.5% copper alloy.

In normal ambient environments, pure silver is highly corrosion resistant, but also very soft.
Alloying with copper enhances mechanical strength without depreciating corrosion resistance

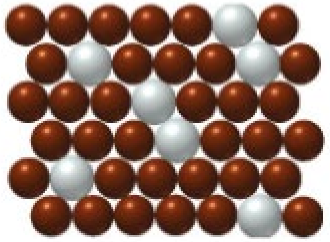
- The presence of carbon in iron significantly increases its strength and hardness, resulting in the creation of **steel**
- Adding chromium to steel makes it resistant to corrosion

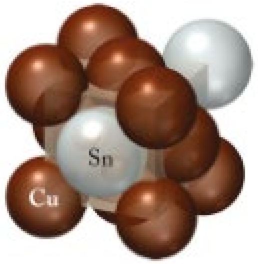
BRONZE: 80% Cu + 20% Sn

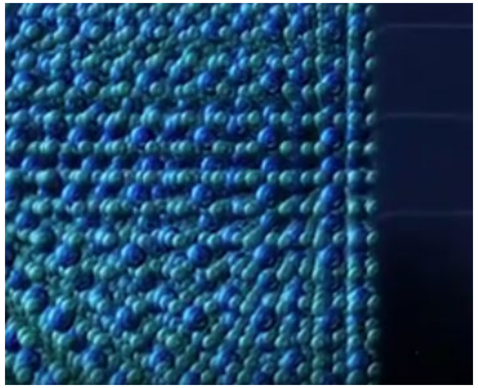
Bronze is a substitutional alloy **FCC structure**

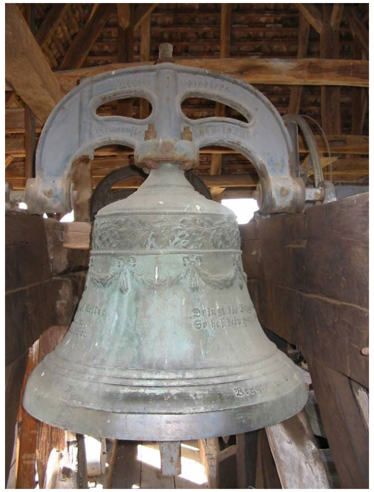
The different size of tin atoms changes the structure and gives bronze many of its properties

Larger Sn atoms restrict the movement of Cu, making the material harder









bell metal: most important quality is to maintain resonance when struck and to produce attractive sound that vibrates like a string.

Tin has a unique low dampening quality. As more tin is added into the material composition, the resonance vibrates for longer lengths of time.

Structure of Matter: Imperfections in Solids

Structural imperfections or crystallographic defects:

Type
Concentration
Behaviour of imperfections

- Mechanical strength
- Thermal properties
- Electronic properties

- **Point defects:** localized disturbances confined to one or two atomic sites. **Vacancies**, **interstitials**, and substitutional defects.

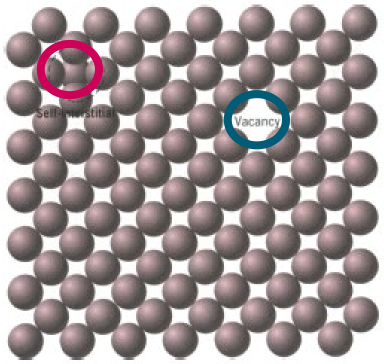
- **Line defects**, or **dislocations**, significantly affect the mechanical properties of materials and come in two forms: edge dislocations and screw dislocations.

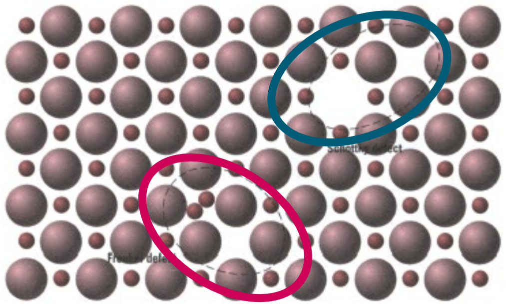
- **Surface imperfections** include **grain boundaries**, twin boundaries, and stacking faults, disrupting the ideal geometrical arrangement over a significant region of the crystal.

Understanding, controlling, and manipulating imperfections are fundamental in technological applications.

Structure of Matter: Imperfections in Solids

Point defects:

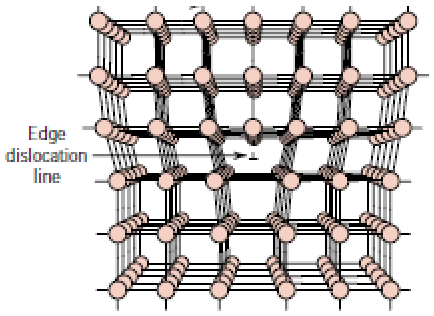


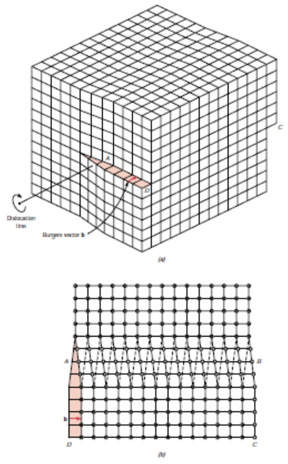


Impurity point defects are found in solid solutions, of which there are two types: **substitutional** and **interstitial.**

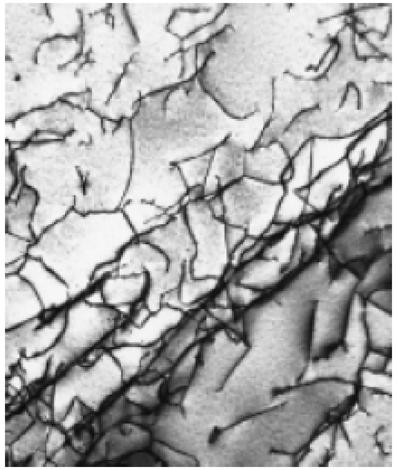
Materials of all types are often heat treated to improve their properties. The phenomena that occur during a heat treatment almost always involve atomic diffusion.

Linear defects:





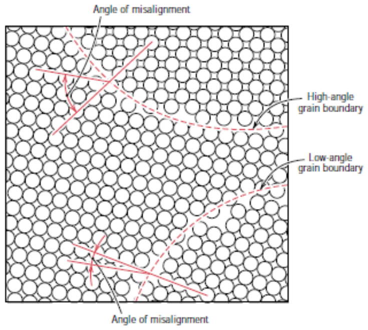
Edge dislocation; it is a linear defect that centers around the line that is defined along the end of the extra half-plane of atoms

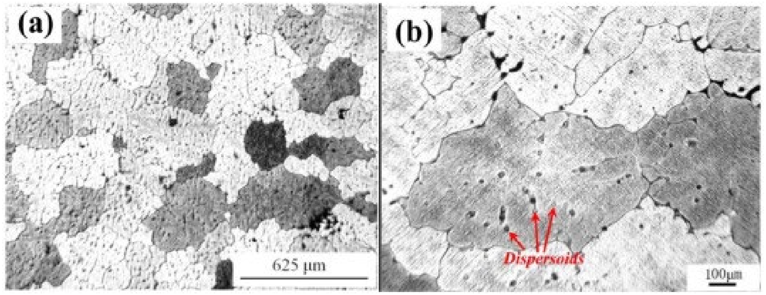


micrograph of a titanium alloy in which the dark lines are dislocations. 51,450×. (Courtesy of M. R. Plichta, Michigan Technological University.)

Structure of Matter: Imperfections in Solids

2D Interfacial defects: grain boundaries





Congchang Xu at al. A detailed investigation on the grain structure evolution of AA7005 aluminum alloy during hot deformation, Materials Characterization, 171,2021,110801, https://doi.org/10.1016/j.matchar.2020.110801.

A material with small grains is harder and stronger than one that is coarse grained.
It has a greater total grain boundary area to impede dislocation motion

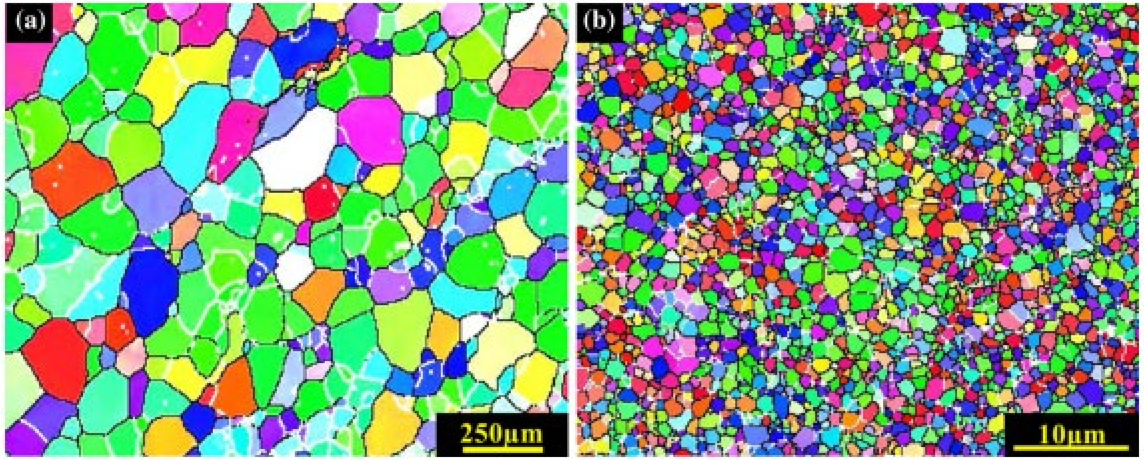
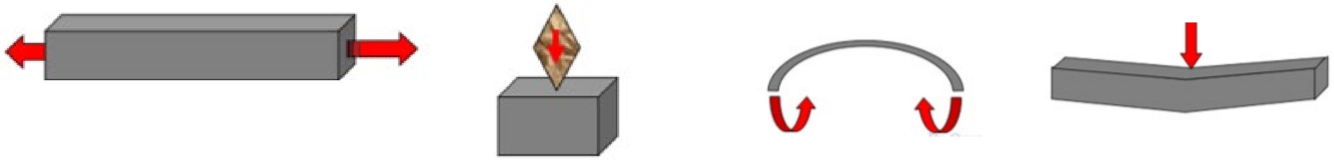


Figure shows electron backscatter diffraction (EBSD) maps of Al–0.2Sc–0.1Zr alloy before and after ACEF (accumulative continuous extrusion forming). Left shows that the grains in raw material rod were coarse and the **grain size was significantly refined from 100 μm to 800 nm**

Ren-Guo Guan, Di Tie. A Review on Grain Refinement of Aluminum Alloys: Progresses, Challenges and Prospects[J]. Acta Metallurgica Sinica(English Letters), 2017, 30(5): 409-432 https://doi.org/10.1007/s40195-017-0565-8

Structure of Matter: Mechanical Properties

Important mechanical properties are related to a deformation to an applied load or force: **strength**, **hardness**, **ductility**, and **stiffness**.

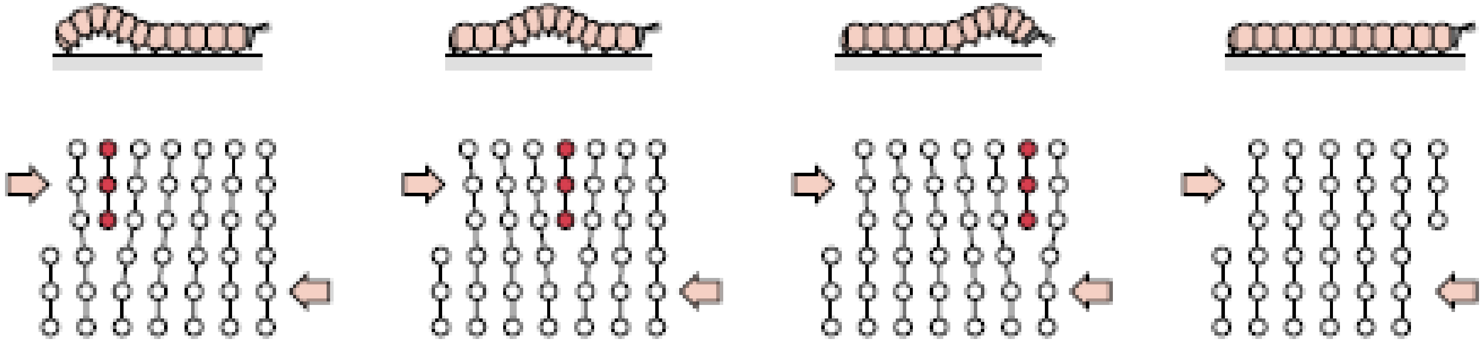


For most metallic materials, elastic deformation persists only to strains of about 0.005. As the material is deformed beyond this point, plastic deformation occurs.

From an atomic perspective:

Plastic deformation corresponds to the **breaking of bonds** with original atom neighbors and then reforming bonds with new neighbors.

Permanent deformation for metals is accomplished by means of a process called slip, which **involves the motion of dislocations**



Structure of Matter: Mechanical Properties

For crystalline ceramics

plastic deformation occurs by the motion of dislocations, but mobility is very restricted

↓

hardness and brittleness of these materials is partially due to the **difficulty of dislocation motion**.

- ✓ Bonding is predominantly ionic restricting the slip by electrostatic repulsion.
- ✓ For ceramics in which the bonding is highly covalent, slip is also difficult: covalent bonds are relatively strong; limited numbers of slip systems; and complex dislocation structures.

dislocation density

10^3 mm^{-2} carefully solidified metal crystals

$10^9 – 10^{10}$ mm^{-2} For heavily deformed metals $\xrightarrow[\text{Heat treating}]{}$ $10^5 – 10^6$ mm^{-2}

$10^2 – 10^4$ mm^{-2} for ceramic materials

Structure of Matter: Phase Diagrams and transformations

Carbon steels account for 90% of total steel production

the microstructure that develops depends on both the carbon content and heat treatment.

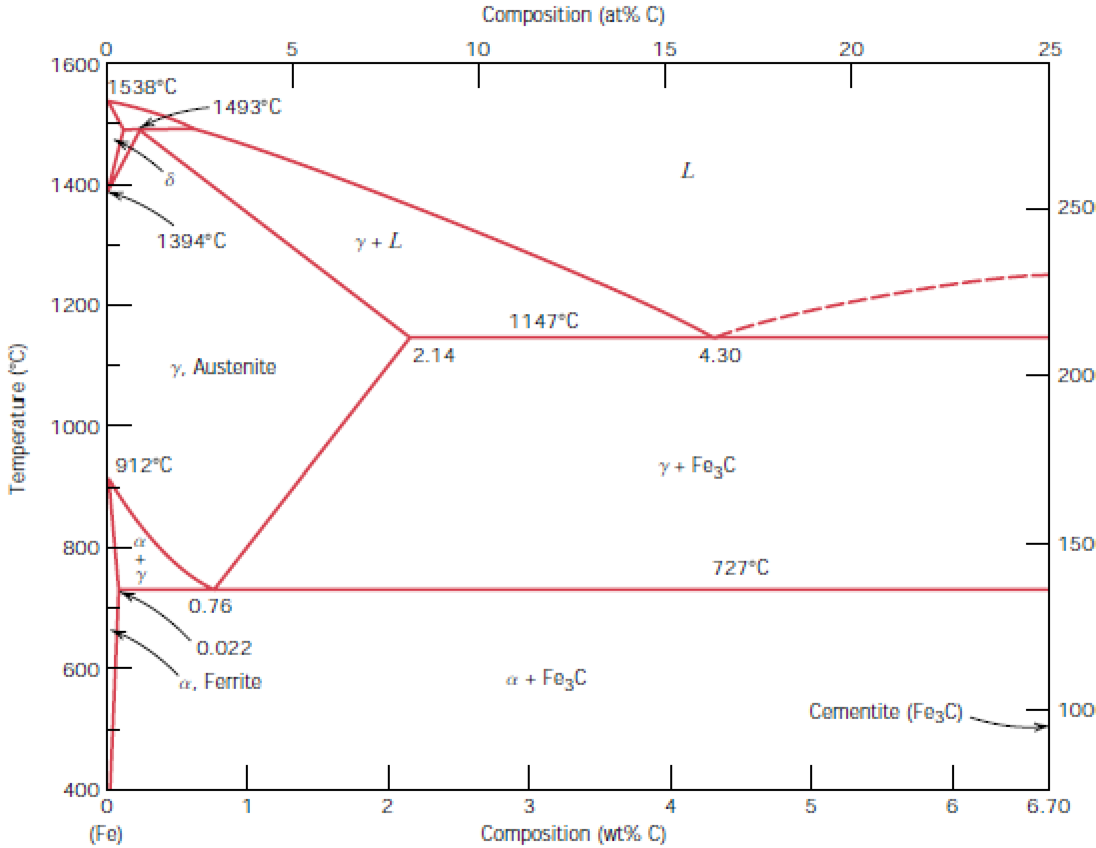


FIGURE 10.26 The iron–iron carbide phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)

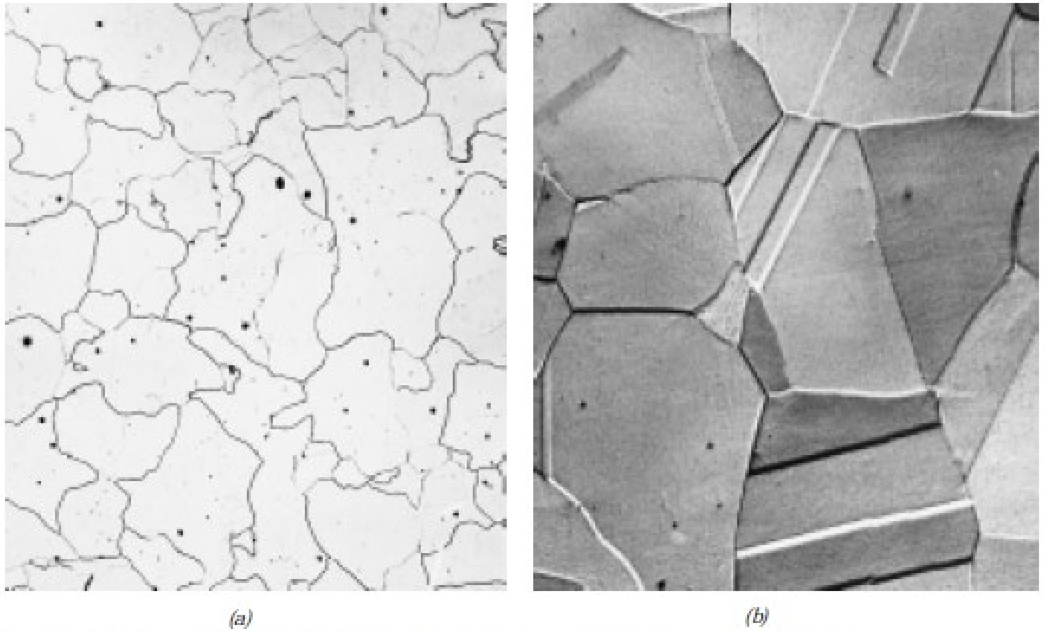


FIGURE 10.27 Photomicrographs of (*a*) α ferrite (90×) and (*b*) austenite (325×). (Copyright 1971 by United States Steel Corporation.)

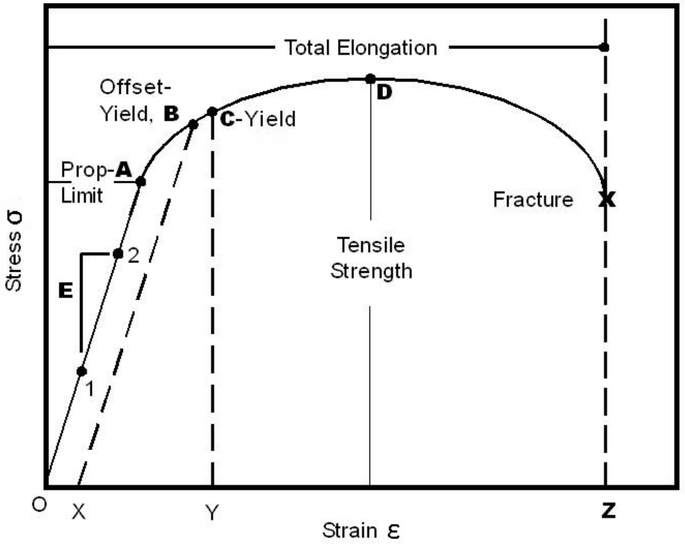
Cold working of some steels can induce the austenite (FCC) -to-martensite (BCT) transition.

Structure of Matter: Phase Diagrams and transformations

STRENGTHENING of Metals

The ability of a metal to plastically deform depends on the ability of dislocations to move.

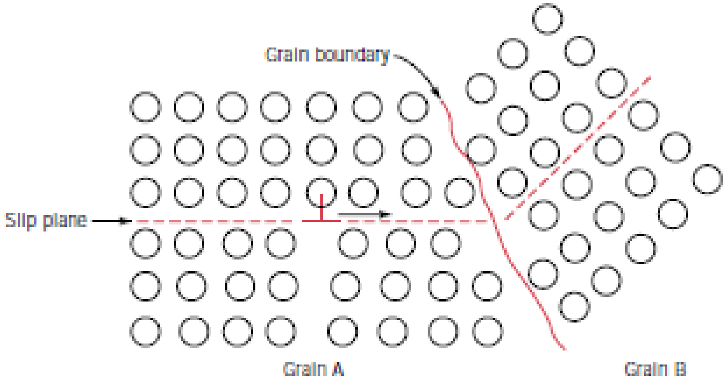
Since **hardness and strength** (both yield and tensile) are related to the ease with which plastic deformation can be made to occur, by reducing the mobility of dislocations, the mechanical strength may be enhanced



restricting or hindering dislocation motion renders a material harder and stronger

strengthening mechanisms for single phase metals

- grain size reduction
- solid-solution alloying
- Strain hardening: cold working (plastic deformations)



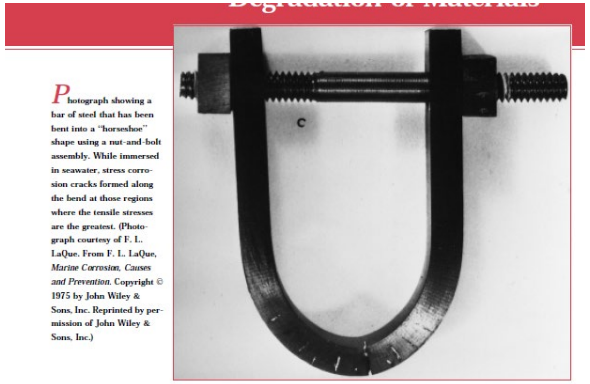
Corrosion and Degradation of Materials

Destruction of materials by means other than straight mechanical.

Corrosion may be defined as the destruction of a **metal** or an alloy because of chemical or electrochemical reaction with its surrounding environment or medium.

Corrosion is a natural phenomena : it is extractive metallurgy in reverse

- All of the metals found in compound form (ore) in nature (except noble metals, Au, Pt).
- Pure metals are meta stable. Metals are electropositive.



Photograph showing a bar of steel that has been bent into a "horseshoe" shape using a nut-and-bolt assembly. While immersed in seawater, stress corrosion cracks formed along the bend at those regions where the tensile stresses are the greatest. (Photograph courtesy of F. L. LaQue. From F. L. LaQue, *Marine Corrosion, Causes and Prevention.* Copyright © 1975 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

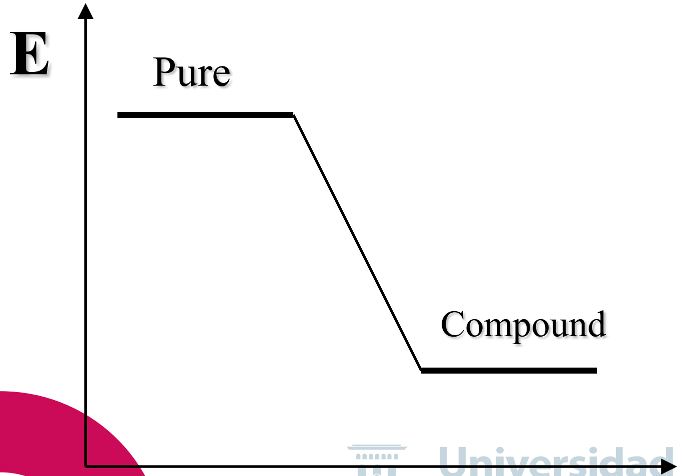
Most metal alloys experience corrosion and are also biodegradable

Energy (+e) $\xrightarrow{\hspace{3em}}$ Pure Metal

REDUCTION

$$M \longrightarrow M^{+} + e$$

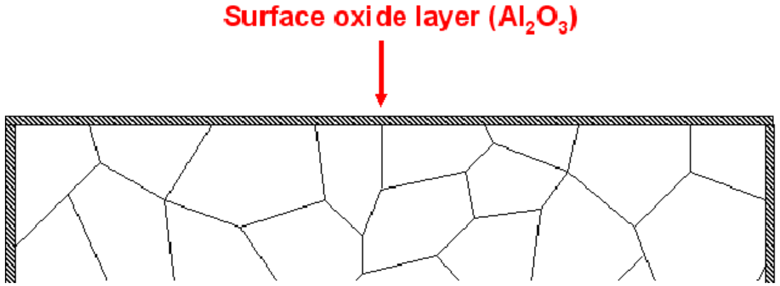
OXIDATION

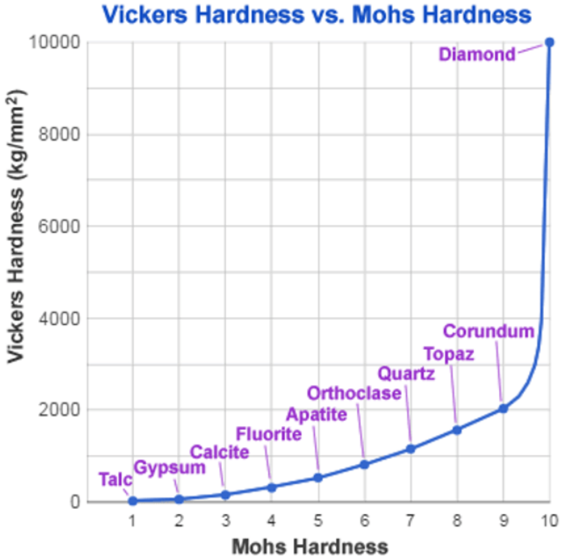


Corrosion and Degradation of Materials

Aluminium reacts very quickly to oxygen, creating a thin layer of aluminium oxide on its outer surface, which stops more oxygen from reaching the metal, so protecting it being ‘corrosion resistant’ by nature

Alpha alumina (corundum) Al_2O_3





Al the most abundant metal on Earth, constituting over 8 % of the Earth’s crust

Main source of aluminium is the sedimentary rock, bauxite

It wasn’t until towards the end of the 19th century that aluminium was produced at an industrial scale

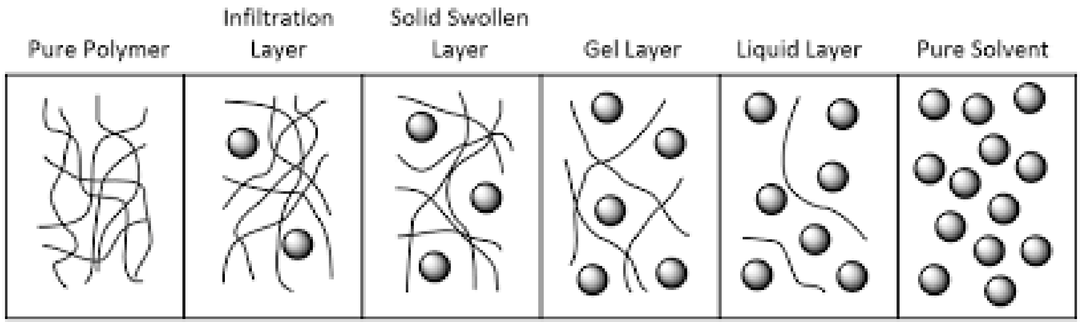
Corrosion and Degradation of Materials

Ceramic materials are highly resistant to corrosion. Frequently used at high *T* and corrosive environments.

Ceramics: Chemical reaction

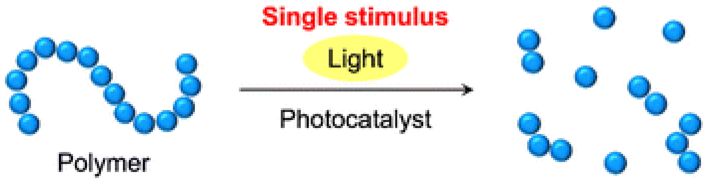
- Corrosion
- Oxidation of non-oxide ceramics

Polymeric degradation is physiochemical: it involves physical and chemical phenomena



Dissolution: small solute molecules fit into and occupy positions among the polymer molecules.

Decomposition: covalent bond rupture, as a result of heat energy, chemical reactions, and radiation, reducing mechanical integrity.



Corrosion and Degradation of Materials

In order to define the strength of an engineering material for a corrosion based design it is essential to define the nature of the environments affecting the material over time.

Material factor

Bulk chemical composition

Microstructure

Grain boundary composition

Surface condition

Stress Factor

Mean, max stress,…

Environment Factor

chemistry

conductivity

Thermodynamics

Equilibrium, stability

Kinetics

Time dependent factors and processes

Sometimes the degradation behavior of a material for some application is ignored, with adverse consequences

Corrosion and Degradation of Materials

Reduce the corrosion of metals

1. Selection of a more **corrosion resistant** alloy
2. Use **coatings** to act as a barrier between metal and environment: metal (cadmium, chromium, nickel, aluminum and zinc.) and/or paint coatings – most common approach.
3. Avoid having dissimilar metals in contact with each other: galvanic corrosion
4. Minimize defects on the metal **surface**: grinding or polishing marks, mill roll marks, nonmetallic inclusions, oxides, grain boundaries, nicks, and scratches are high energy sites which can drive corrosion reactions.
5. Minimize residual salts and chemical impurities on the metal surface. Metal processing or the cleaning and pretreatment steps prior to applying a coating can leave undesirable contaminants on the surface. These impurities contribute to corrosion.

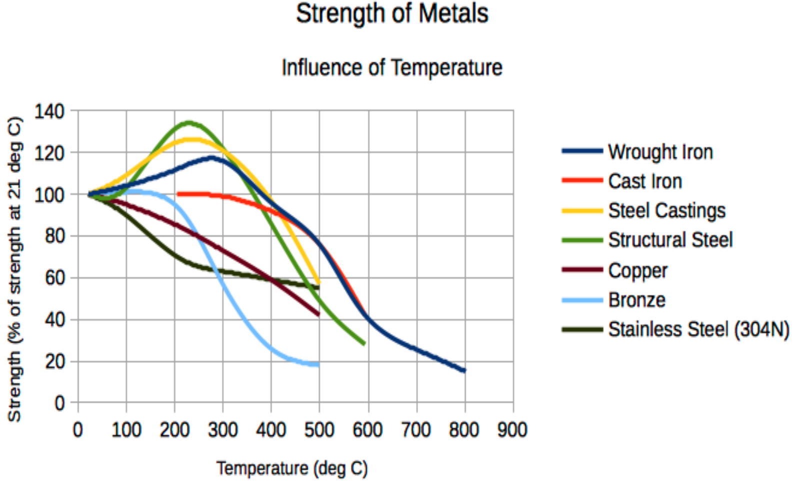
Applications in Accelerators

Environmental conditions for particle accelerators are very different from industrial environment

- Cryogenic *T*'s
- ultra high vacuum (10^{-11} mbar)
- high *H*
- high radiation
- high *T* and high strain rate

Application-specific assessment procedures

CERN specifications for materials



Materials properties change with *T* and *H*, and suppliers do not usually test them in these **extreme conditions**

Failure may occur because many properties are related to time and energy *T*-dependent processes and this may affect their performance .

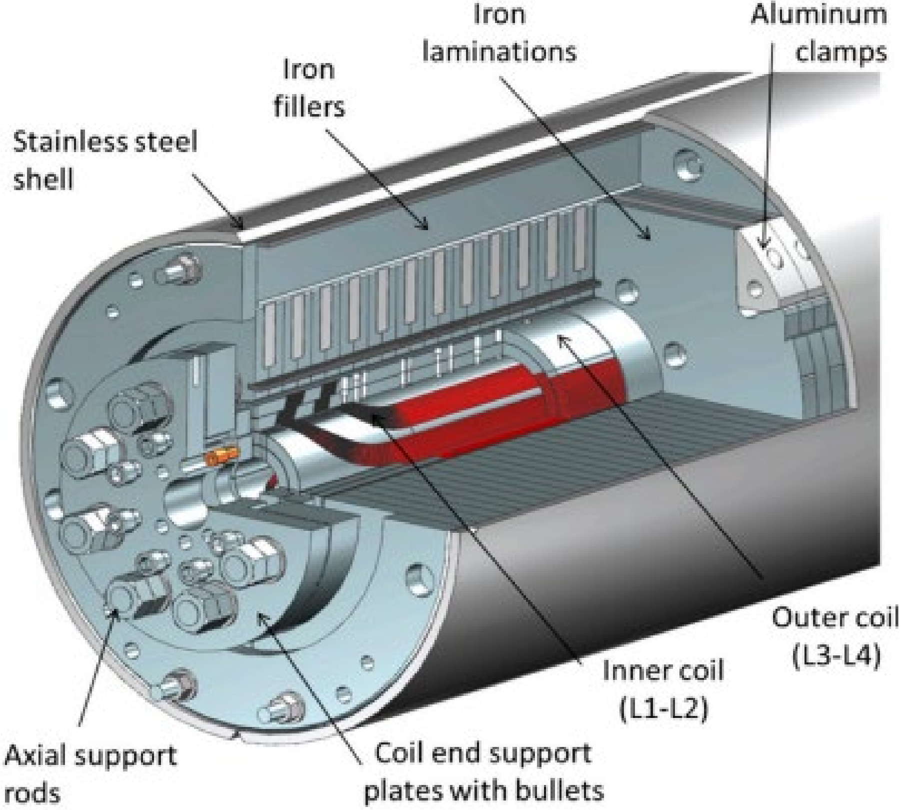
All physical properties are *T* dependent: not only thermal, and electric, but also magnetic, and mechanical.

Going beyond the frontiers of high-energy particle physics

new and more powerful accelerators
increasing demands on the materials used for the accelerating structures: intense radiofrequency fields, great radiation dose, higher magnetic fields…

Applications in Accelerators

Superconducting Magnets R&D



Front. Phys., 27 June 2022
Sec. Radiation Detectors and Imaging
Volume 10 - 2022 | https://doi.org/10.3389/fphy.2022.920520

NEW CHALLENGES

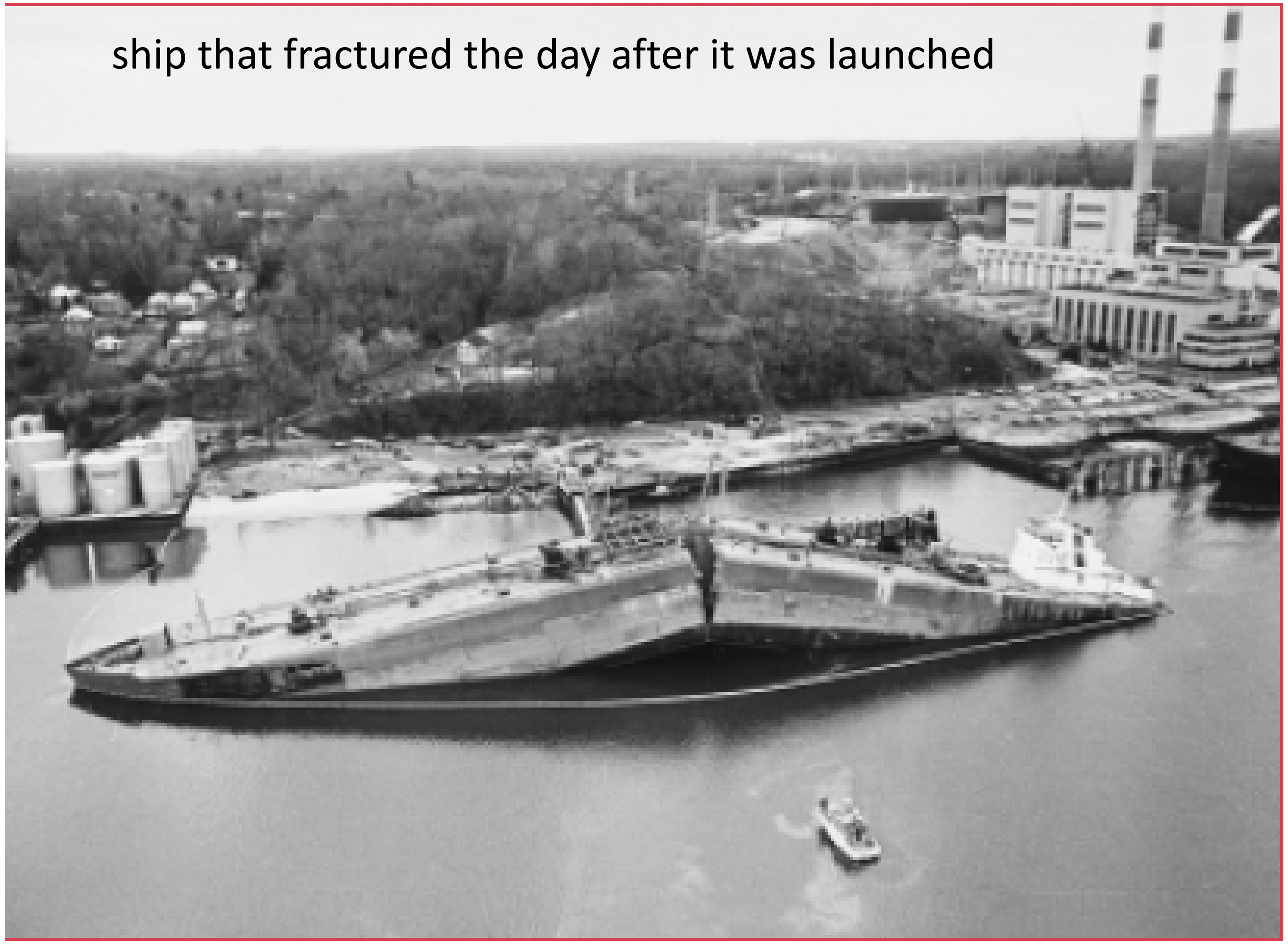
- Superconducting magnets with operational parameters well beyond current state-of-the-art

  prototype Nb_3Sn magnet has reached 14.5 T

- RF Technology

NEW OPORTUNITIES

Composite advanced materials
Amorphous materials
Polycrystalline materials
Additive manufacturing
Coatings
…



An oil tanker that fractured in a brittle manner by crack propagation around its girth. (Photography by Neal Boenzi. Reprinted with permission from The New York Times.)

Failure: How is this possible?

- ➢ Improper materials selection
- ➢ Materials processing
- ➢ Inadequate design of the components
- ➢ Misuse (fatigue)

Research field of fracture mechanics

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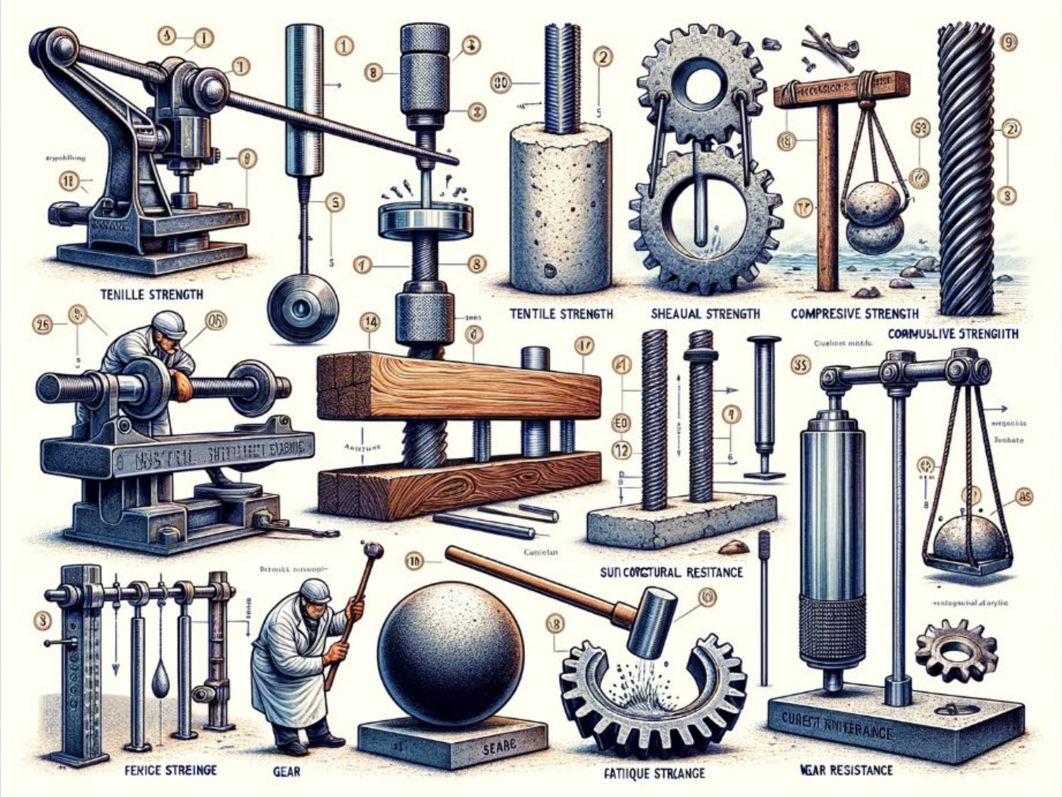
Online Resources:

- http://ocw.mit.edu/courses/materials-science-and-engineering/
- http://www.istl.org/02-spring/internet.html

The CERN Accelerator School

MATERIALS



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Thank you for your attention

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