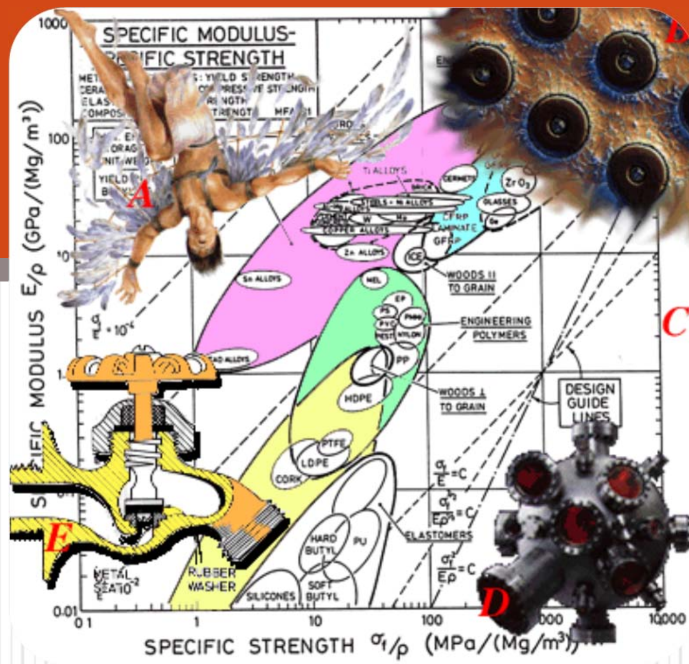
An Introduction to materials Science and Engineering

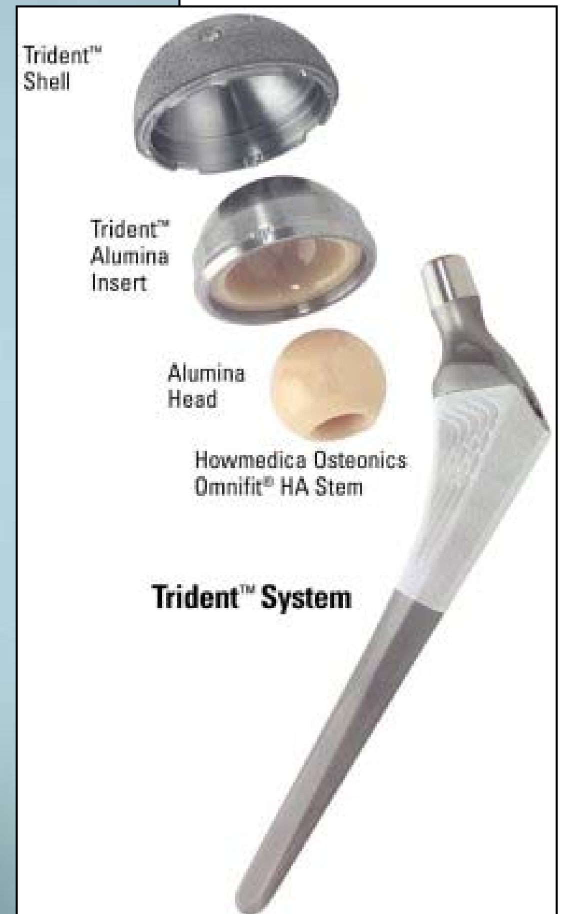


By: Kamran Khodaparasti
Tehran, Oct. 2012
kkhodaparasti@yahoo.com

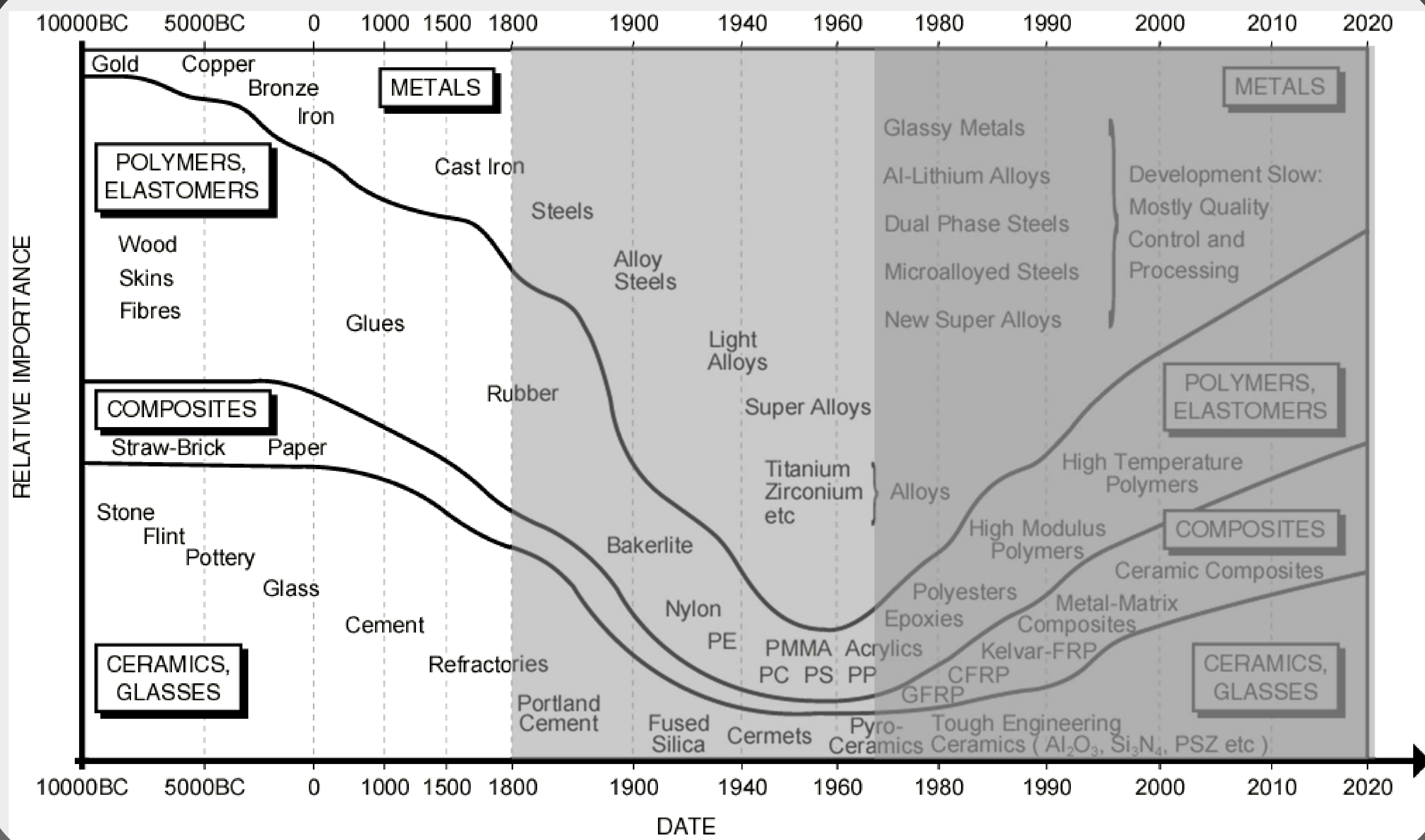

Materials Have Defined History
• Stone Age
• Bronze Age
• Iron Age
• Silicon Age ?

Discovery of "new" materials has shaped history

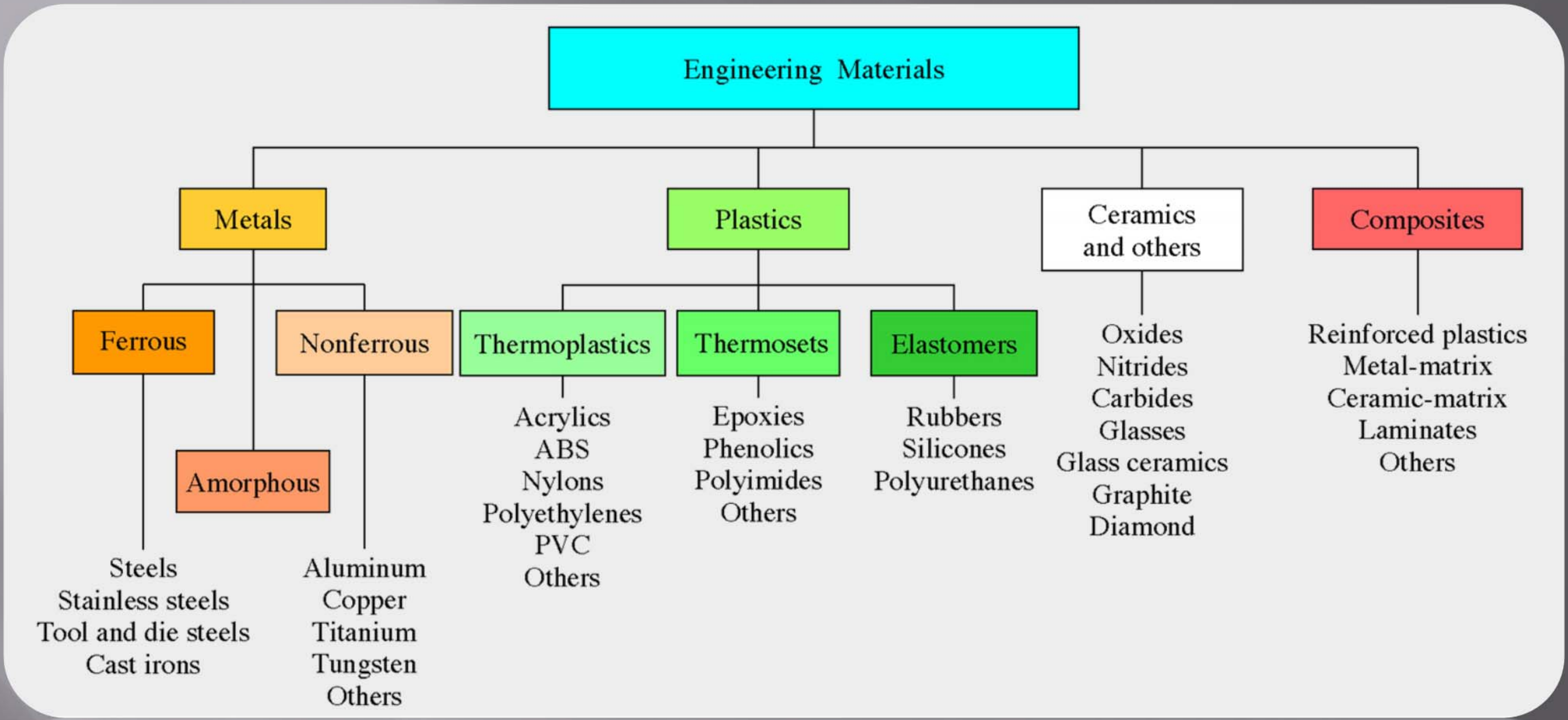

Without materials, there is no engineering.


Trident™ Shell
Trident™ Alumina Insert
Alumina Head
Howmedica Osteonics Omnifit® HA Stem
Trident™ System

The evolution of materials



Major classes of materials

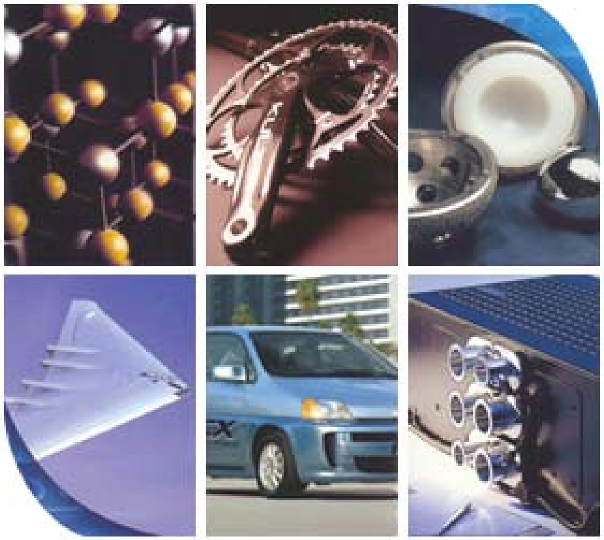


- Material → matter: Physical substance having mass and occupying space, as distinct from mind and spirit.
- Materials are...

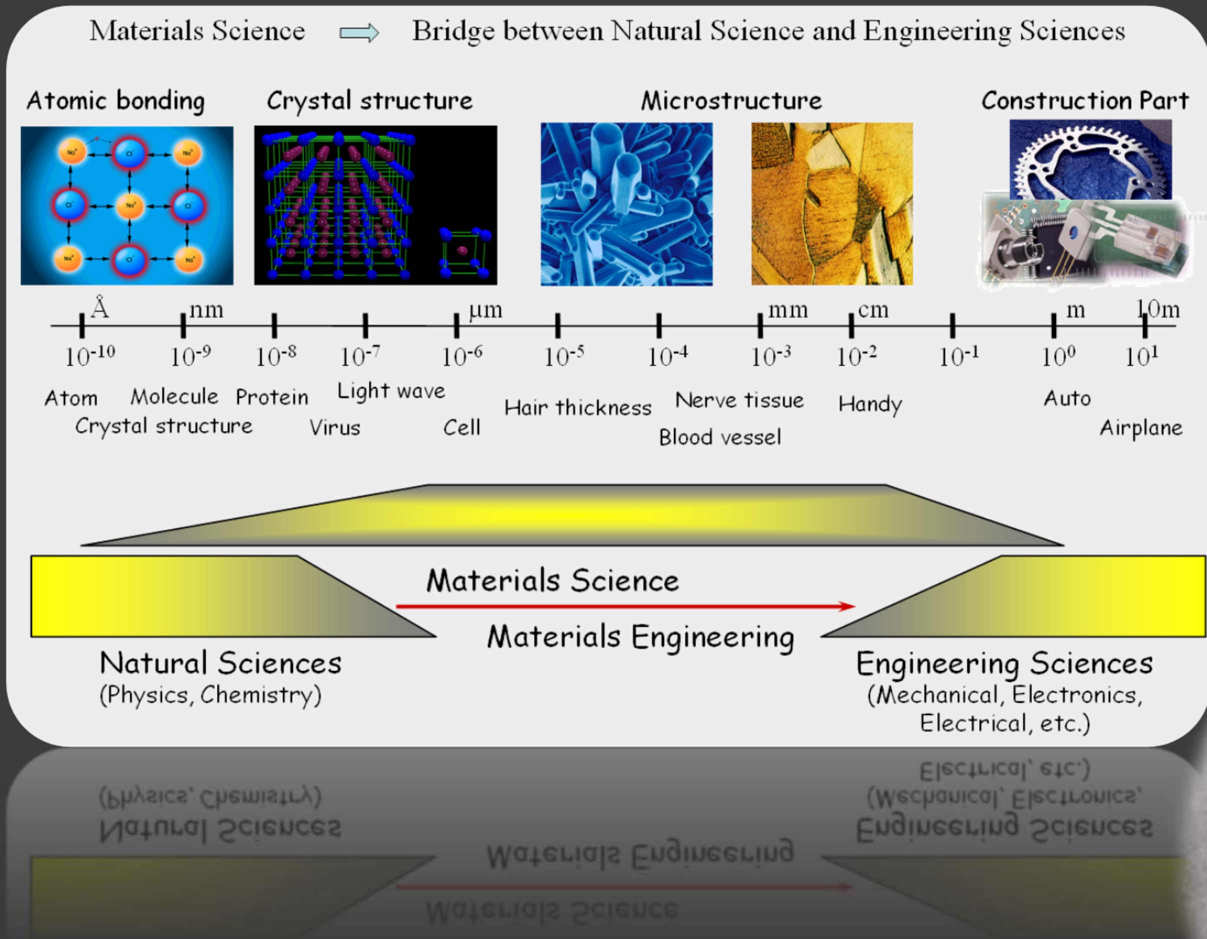
engineered structures...not blackboxes!

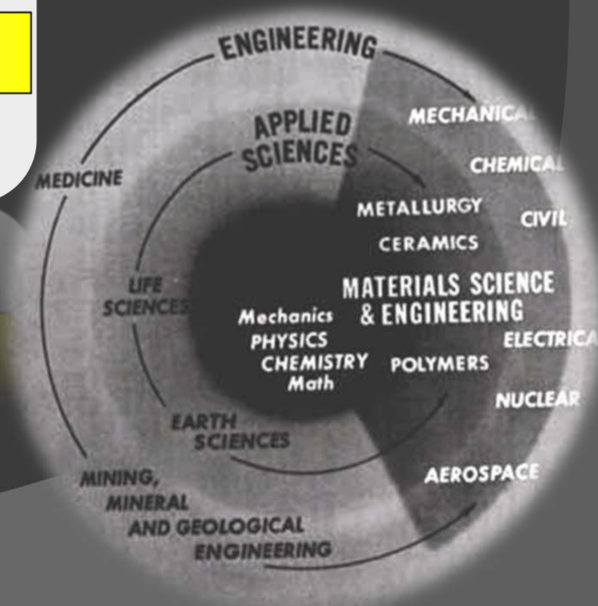
Materials engineering has its foundation in chemistry and physics

Materials are 'alive' with internal activity and tremendous driving forces.

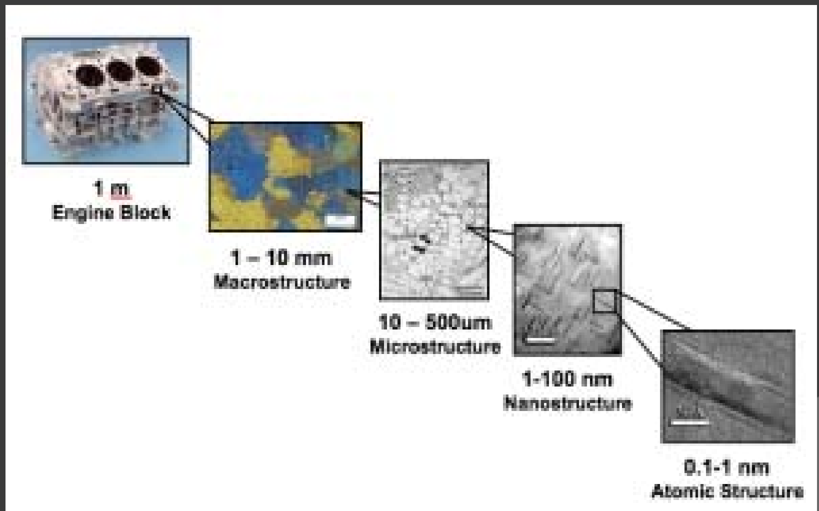


Materials Science and Engineering (MSE)

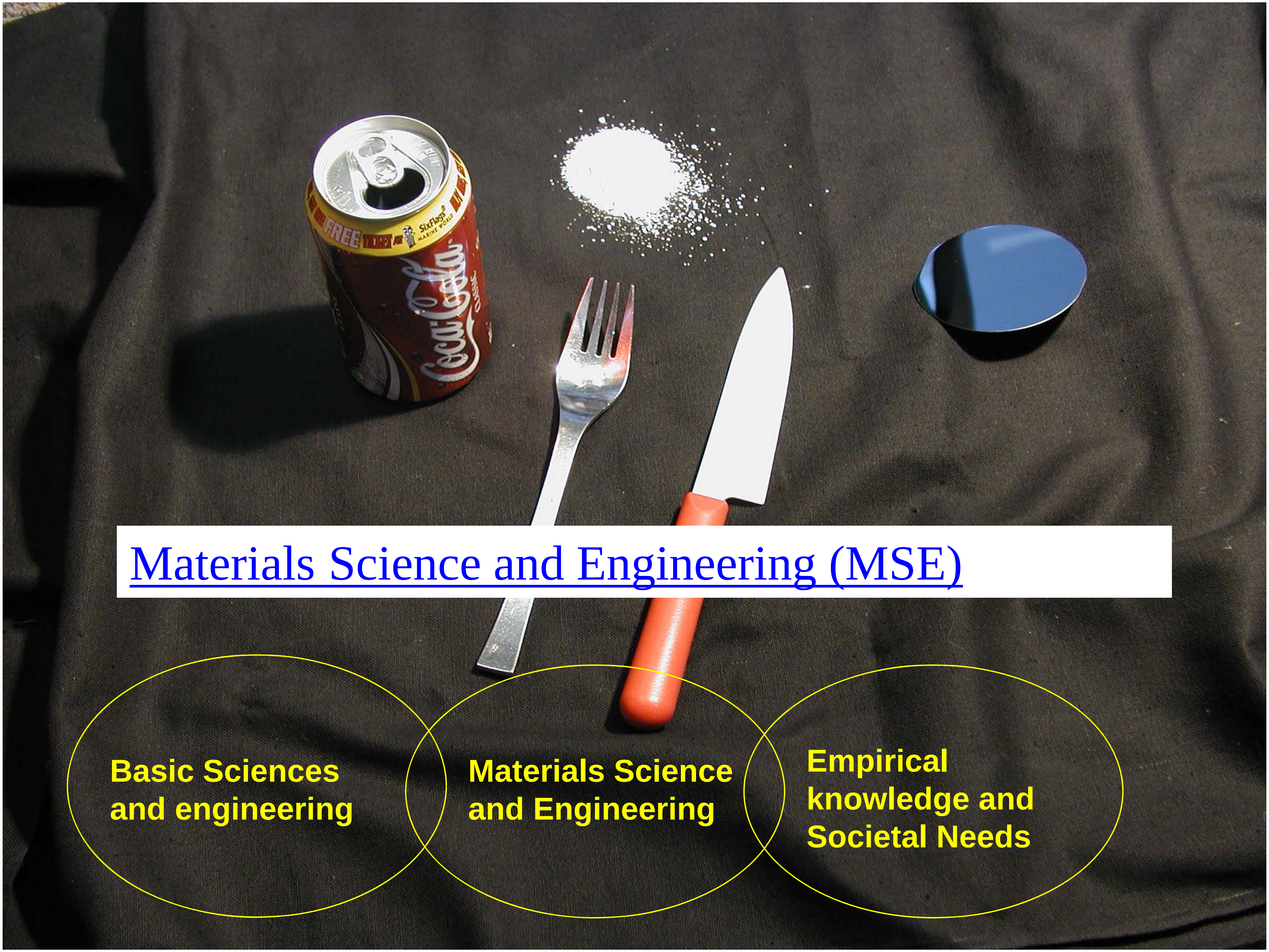




- A material can be viewed at different magnification levels revealing important features, as illustrated in this example of an aluminum alloy casting for an automotive engine block. At each level, or length scale, the features can be changed by variations in the alloy composition or manufacturing processes. These features combine to influence the properties in unique and complex ways. For example, the stress at which a material starts to deform, known as the yield strength, is affected by the atomic structure as well as microstructural features at the nanolevel and at the microstructural level.



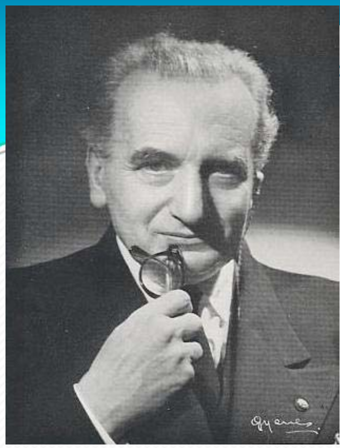
Materials Science and Engineering (MSE)



Basic Sciences and engineering

Materials Science and Engineering

Empirical knowledge and Societal Needs



Scientist vs. Engineer

" A scientist discovers which exist, an engineer creates what has never been."

-Von Karman

- Scientists explore what is.
- Scientist try to improve their understanding of nature.
- Their objective is knowledge.

- Engineers create what has never been.
- Engineers apply knowledge for the benefit of society.
- Their objective is a device, structure, or process.

- Engineers *develop* concepts, ideas & theories, & then transform them into *realities* in order to meet *needs*. They couple their understanding of science & mathematics with "engineering sense."

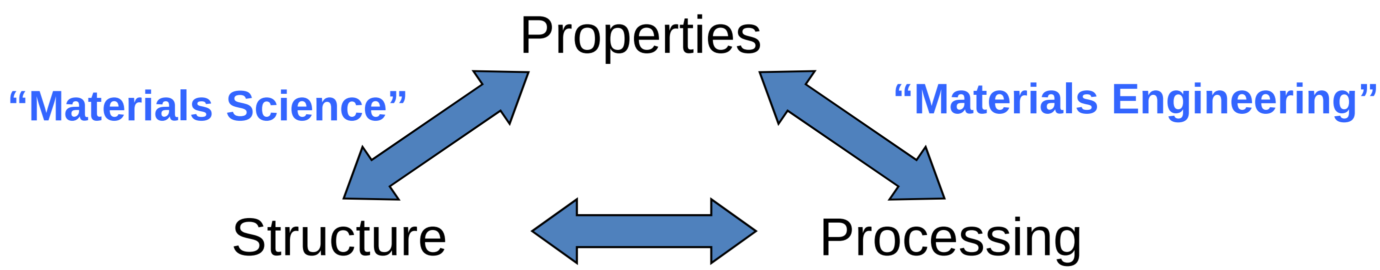
<u>Materials engineers</u> ***design*** *materials with outstanding properties to enable technological advancement in all engineering disciplines.*

<u>Materials scientists</u> ***explore*** *how material properties arise from composition and structure, and provide the basis for materials engineering.*

Materials Scientists and Engineers bring interesting science together with practical applications.

Materials Science and Engineering (MSE)

- A branch of science & engineering that deals with the inter-play between structure, properties and processing of materials



- Materials Science: investigates relationship between materials' structure & properties

- Materials Engineering: On the basis of materials science, designing and/or engineering the materials' structure to produce desired properties

systematic study, not trial & error

not trial & error

Trial and error managed to double the strength of aluminum alloys since the Wright brothers' time, but it took **80 years**

More than 160,000 engineering materials exist today, and most are mixes of between six and 10 different elements. These materials can have different properties at various scales, from that of the atom, up to the microstructure, to the end product, whether that's a laptop battery, solar cell or car door. It's challenging for the field to predict how each different combination of elements will behave at each of these levels

.

It takes between 10 and 20 years to develop a new material—an advanced metal alloy, for example, that can be used in lighter cars, trucks and airplanes.

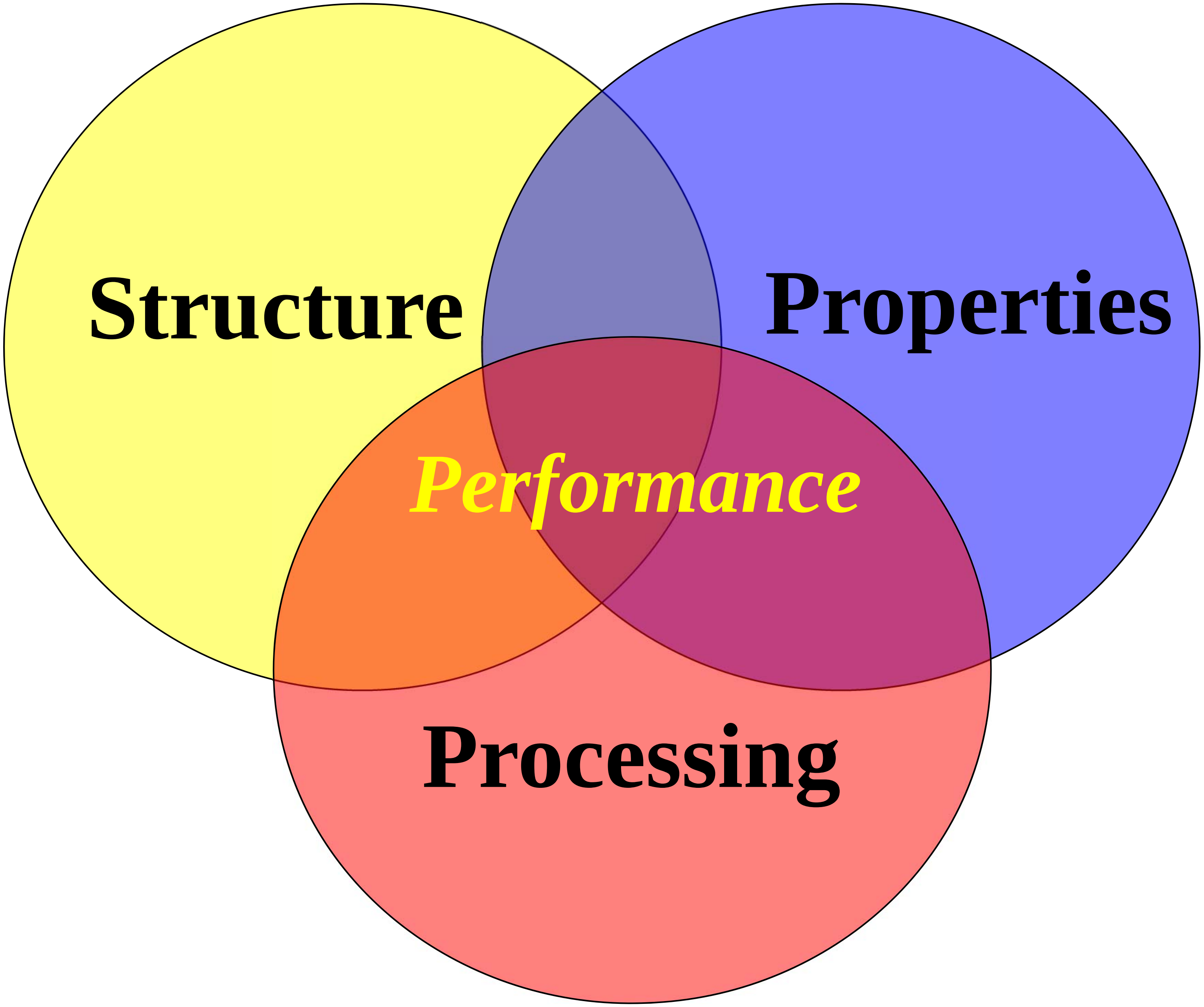
Some developments …. Next slide

http://www.asminternational.org/portal/site/www/NewsItem/?vgnextoid=1c10e1180fb2a310VgnVCM100000621e010aRCRD

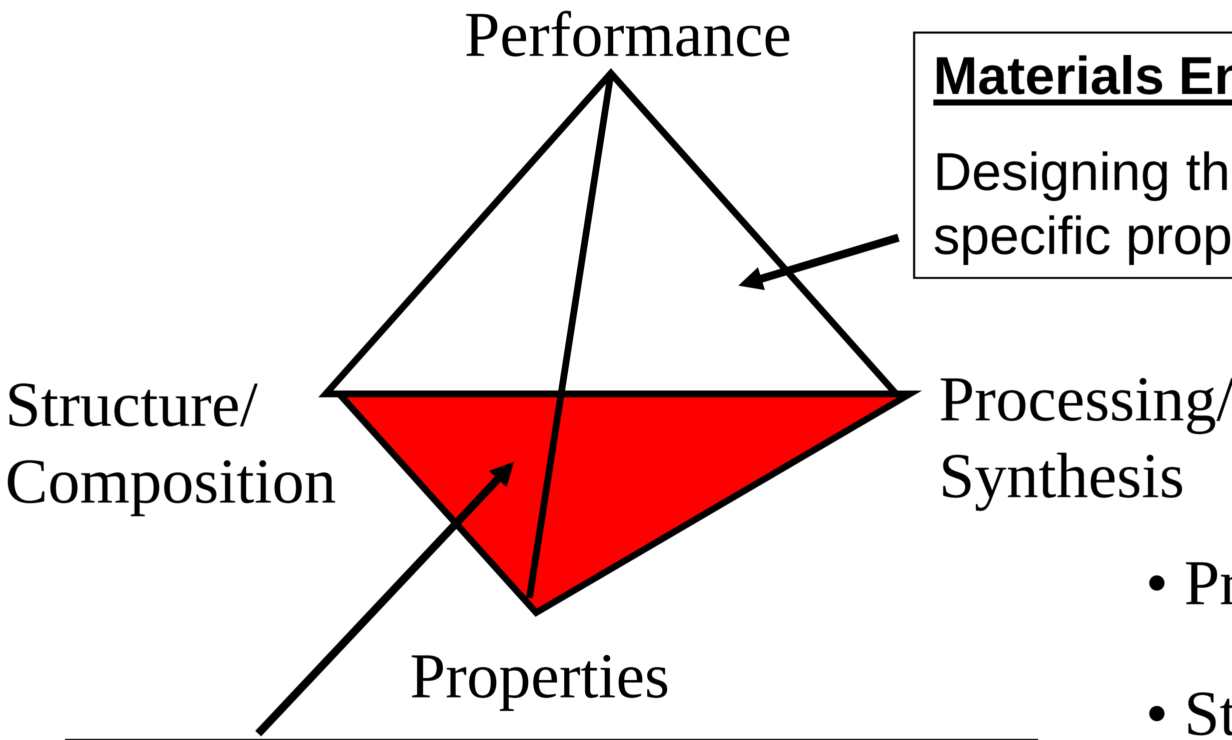
With an $11-million, five-year grant from the Department of Energy, a project that aims to drastically shorten that time.

The grants establish a DoE Software Innovation Center called the Predictive Integrated Structural Materials Science Center, or PRISMS.

"PRISMS will give us a quantitative means to figure out which materials knob we should be turning," Allison said.
"If I were studying fatigue of metals, for example, and I wanted to understand how to improve that property, I'd want to quantify or simulate how a certain microstructural feature might affect it."


Structure
Properties
Performance
Processing

Core elements of Materials Science and Engineering



Materials Engineering

Designing the structure to achieve specific properties of materials.

Materials Science

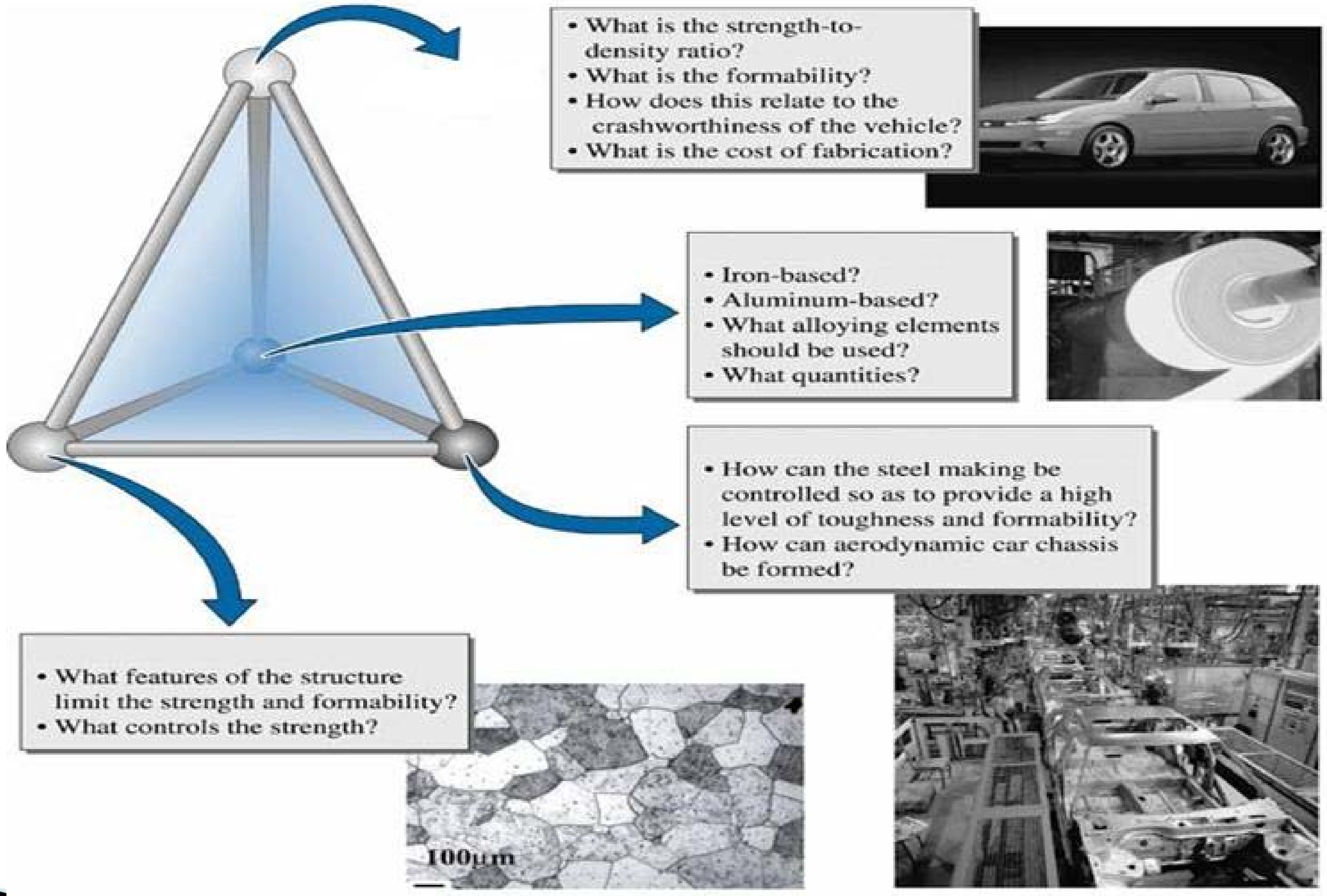
Investigating the relationship between structure and properties of materials.

- Processing
- Structure/Composition
- Properties/Synthesis
- Performance

The study of materials is a fascinating journey into the relationships between structure, properties, and performance.

- Composition means the chemical make-up of a material.
- Structure means a description of the arrangements of atoms or ions in a material.
- Synthesis is the process by which materials are made from naturally occurring or other chemicals.
- Processing means different ways for shaping materials into useful components or changing their properties.

Application of the tetrahedron of materials science and engineering to sheet steels for automotive chassis.



I'm a
Mechanical Engineer
Space Engineer
Civil Engineer
Chemical Engineer

Why do I need to know anything about materials and structures?

why is a knowledge of materials is relevant to me!

- **We all use computers every day ...**
- **how many materials needed to use a computer?**
  - **Chips:**
    - crystalline Si, SiO_2, poly-Si, aluminum, boron & phosphorus doping, adhesives, ceramic package,
    - all materials & chemicals required to make all of the above
  - **Other electronics:**
    - quartz, copper, carbon, dielectrics, plastic & ceramic insulators, circuit board (fiberglass), solder (lead & tin), ferrite transformer core, gold-plated electrodes
  - **Disk drive:**
    - magnetic motor components, magnetic films

- **CD ROM:**
  - optical lenses, laser components, reflective CD film
- **Monitor:**
  - glass, phosphors, tungsten filament
- **Communications:**
  - Fibre-optic cable, transmitter, receiver, amplifiers
- **Mechanical:**
  - plastics, steel, copper, aluminum
- **Plus:**
  - all materials needed to generate and transmit power
  - all materials required by telephones
  - all materials for building & furniture, ventilation etc!

The study of materials touches every aspect of modern technology.

Every creative engineer, regardless of their specialty, must have a solid grounding in the fundamentals of materials behavior.

Classification of Materials

Metals

- Good conductors of e^- and heat
- Strong, deformable
- Not transparent
- Susceptible to chemical degradation in some atmospheres
- High density

Ceramics

- Insulators of e^- and heat
- Hard, brittle, not deformable
- Some transparent
- Good corrosion resistance
- Heat resistant

Polymers

- Insulators of e^- and heat
- Very flexible, deformable, low strength
- Some transparent
- Good corrosion resistance
- Low resistance to heat
- Low density

THREE MAJOR CLASSES OF MATERIALS

- Some of these have descriptive subclasses.

  - Metals
    - Fe, Steel, Cu, Al, Brass
    - Alloys and Superalloys (e.g. aerospace applications)
    - Intermetallic Compounds (high-T structural materials)

  - Ceramics
    - Structural Ceramics (high-temperature load bearing)
    - Refractories (corrosion-resistant, insulating)
    - Whitewares (e.g. porcelains)
    - Glass
    - Electrical Ceramics (capacitors, insulators, transducers, etc.)
    - Chemically Bonded Ceramics (e.g. cement and concrete)

- Polymers
  - Plastics
  - Liquid crystals
  - Adhesives

- Electronic Materials
  - Silicon and Germanium
  - III-V Compounds (e.g. GaAs)
  - Photonic materials (solid-state lasers, LEDs)

- Composites
  - Particulate composites (small particles embedded in a different material)
  - Laminate composites (golf club shafts, tennis rackets, Damaskus swords)
  - Fiber reinforced composites (e.g. fiberglass)

- Biomaterials (bio-mimetic)
  - Man-made proteins (cytoskeletal protein rods or “artificial bacterium”)
  - Biosensors (Au-nanoparticles stabilized by encoded DNA for anthrax detection)
  - Drug-delivery colloids (polymer based)

PROPERTIES OF MATERIALS

- An alternative to major classes, you may *divide* materials into classification according to properties.

- One goal of materials engineering is to select materials with suitable properties for a given application, so it's a sensible approach.

- Just as for classes of materials, there is some overlap among the properties, so the divisions are not always clearly defined

Mechanical properties

A. Elasticity and stiffness (recoverable stress vs. strain)
B. Plasticity (non-recoverable stress vs. strain)
C. Strength
D. Brittleness or Toughness
E. Fatigue

PROPERTIES OF MATERIALS

Electrical properties

A. Electrical conductivity and resistivity

Dielectric properties

A. Polarizability
B. Capacitance
C. Ferroelectric properties
D. Piezoelectric properties
E. Pyroelectric properties

Magnetic properties

A. Paramagnetic properties
B. Diamagnetic properties
C. Ferromagnetic properties

PROPERTIES OF MATERIALS

Optical properties

A. Refractive index
B. Absorption, reflection, and transmission
C. Birefringence (double refraction)

Corrosion properties

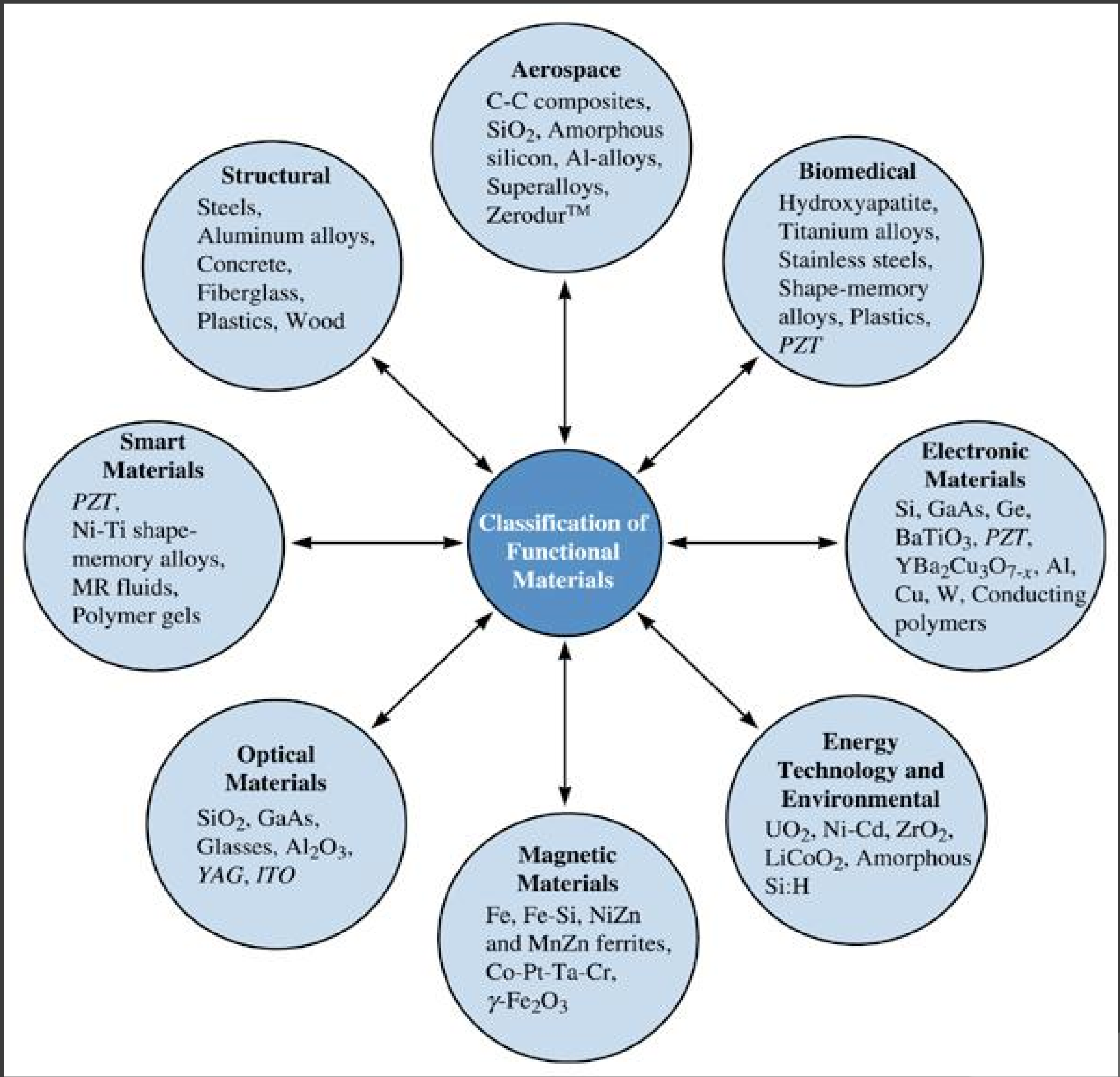
Deteriorative properties

Biological properties

A. Toxicity
B. bio-compatibility

Functional Classification of Materials

- Aerospace
- Biomedical
- Electronic Materials
- Energy Technology and Environmental Technology
- Magnetic Materials
- Photonic or Optical Materials
- Smart Materials
- Structural Materials

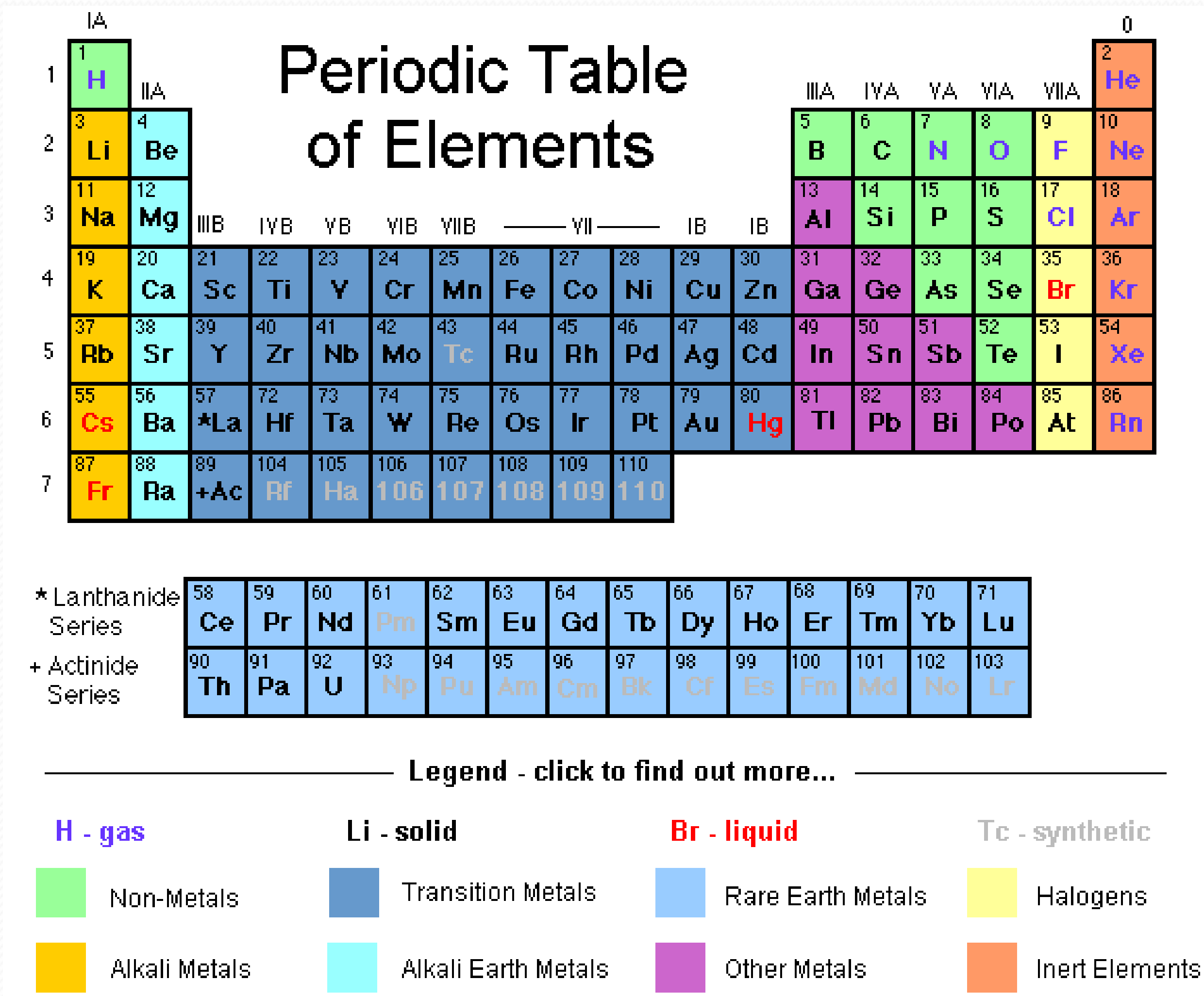


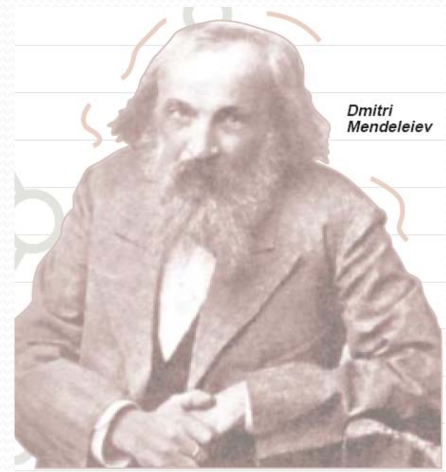
Functional classification of materials. Notice that metals, plastics, and ceramics occur in different categories. A limited number of examples in each category is provided

The Periodic Table

- First developed by D. I. Mendeleyev
- Significance?
  - Dictionary of Information
  - Assists in materials selection process

we need to recall and use knowledge from the periodic table





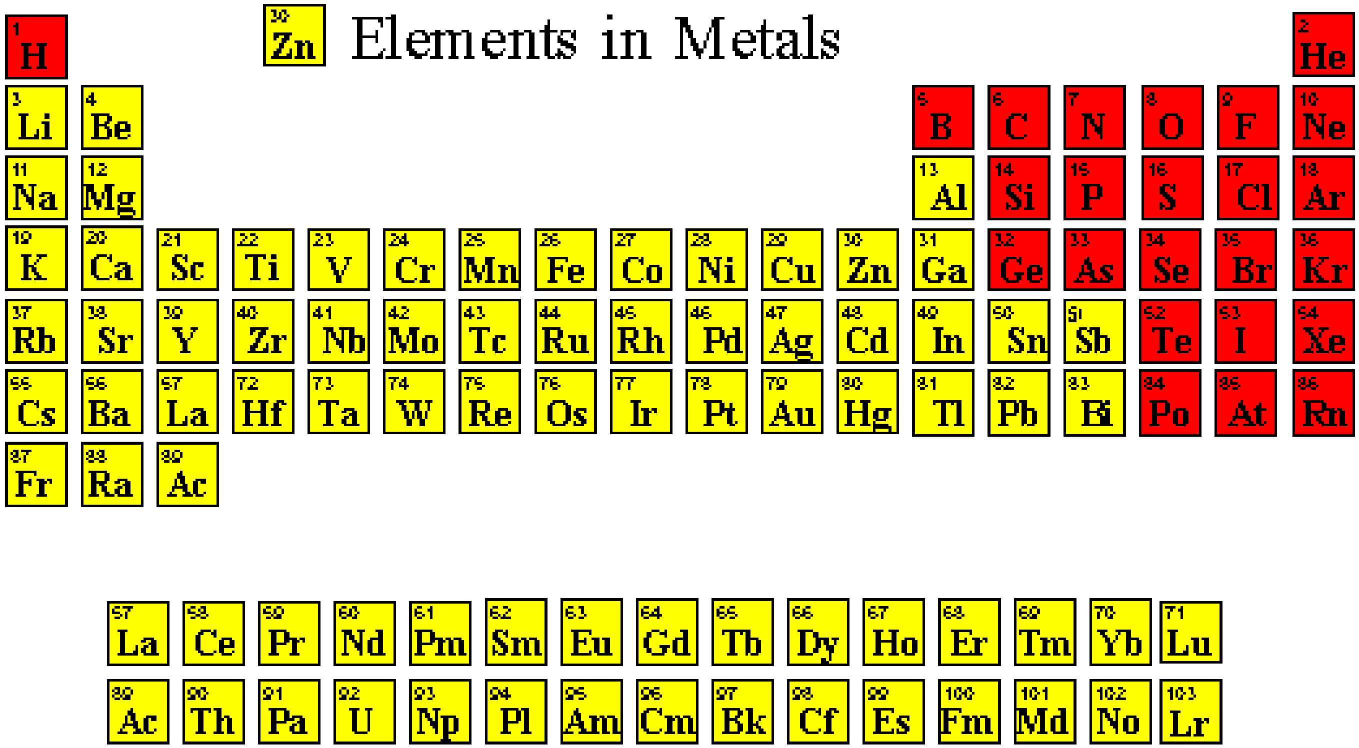
Materials from Elements

- Elements used in:
  - Elemental state – W, Cr, Ni, etc.
  - Alloys – combination of metals
  - Compounds – combination in definite proportions
  - Mixtures – physical blend
  - Molecule – smallest part of a compound
- Interaction of atoms

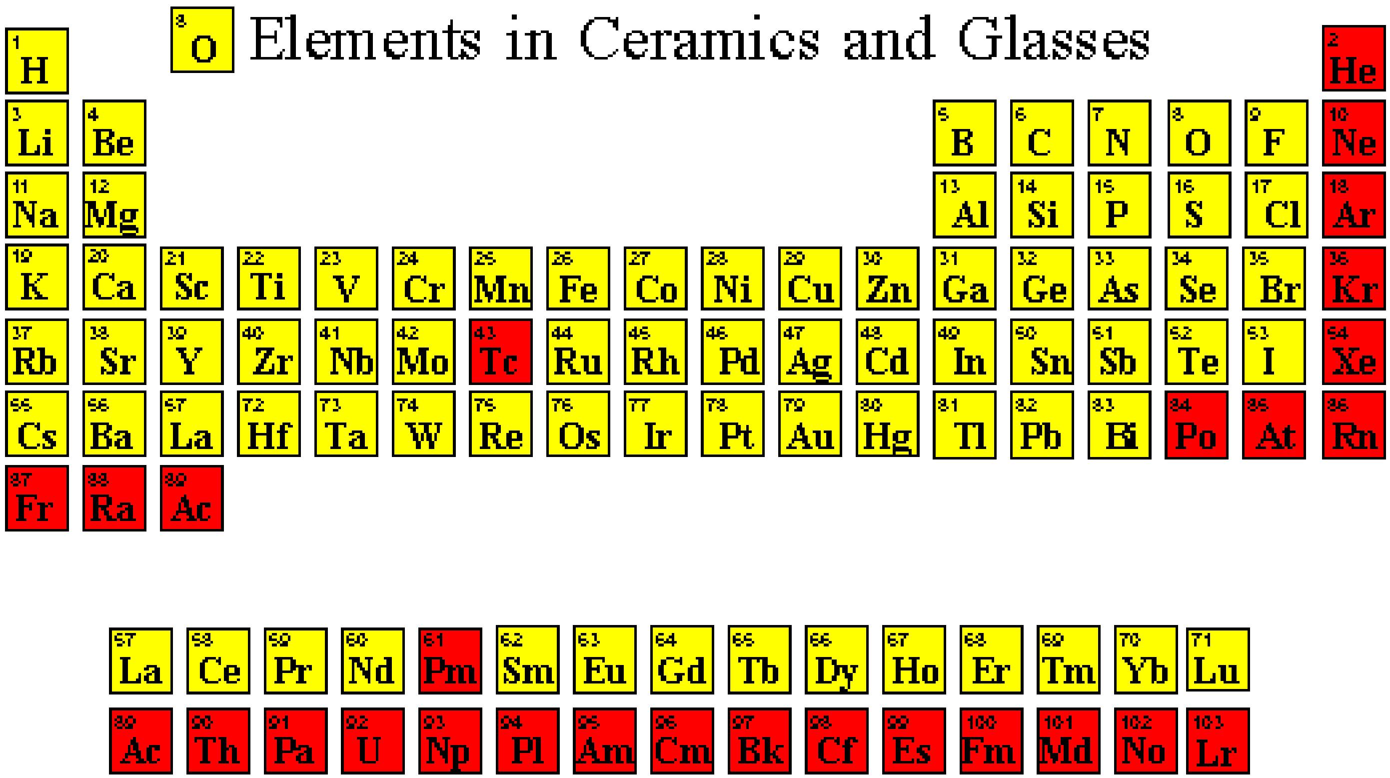
Critical Concepts

- Engineering materials are made from 51 elements
- Atomic properties determine macroscopic properties
- Atomic differences in different material forms
- Remember strengthening mechanisms

Metals

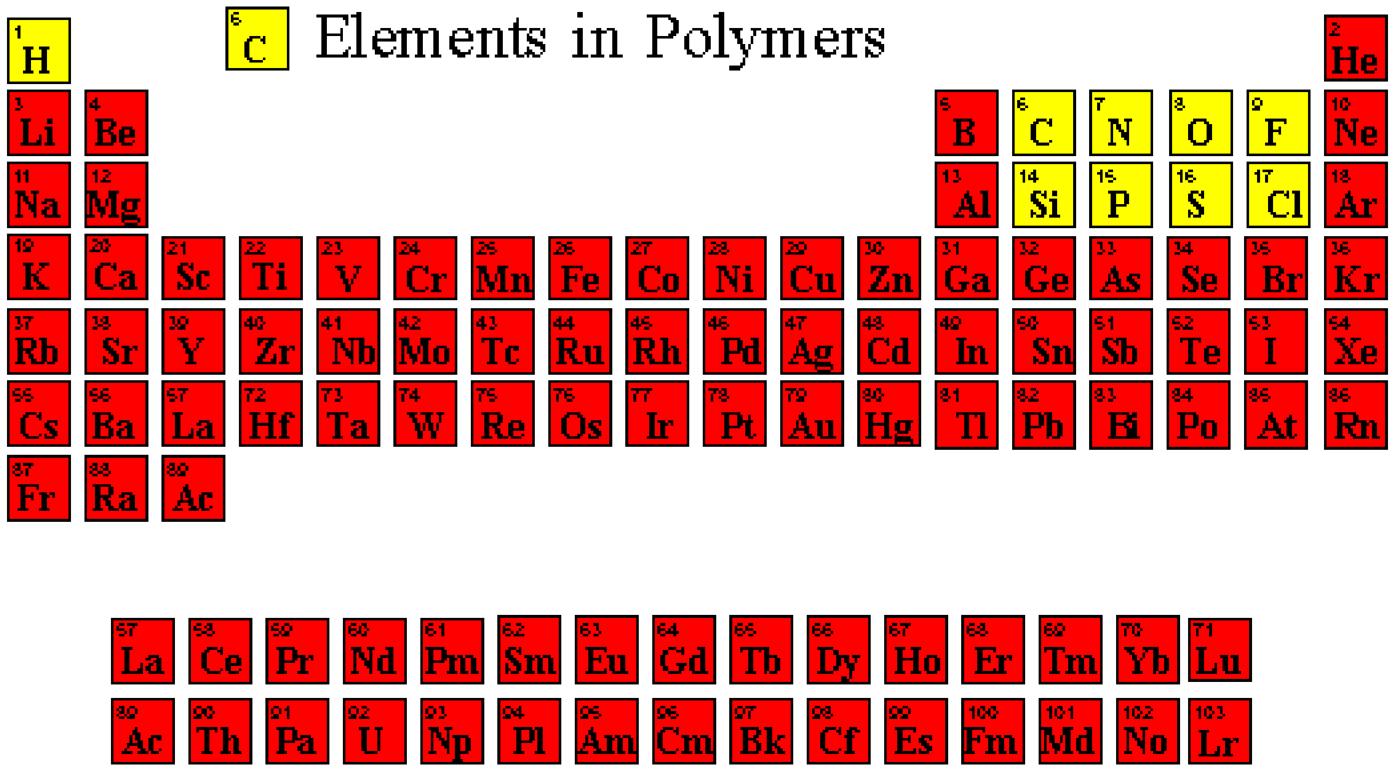

Elements in Metals
30 Zn
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pl
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

Ceramics



8 O Elements in Ceramics and Glasses
1 H
2 He
3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
55 Cs 56 Ba 57 La 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
87 Fr 88 Ra 89 Ac
57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pl 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr

Polymers


6 C
Elements in Polymers
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pl
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

THE NATURE OF CERAMICS

- Metals combined with nonmetals
- Ionic and covalent bonding
- Mechanically brittle
- Electrically insulating

The Nature of Polymers

- Long-chain repeating molecules
- Carbon backbone
  - Intra- and intermolecular forces
  - Covalent v. Van der Waals forces

The Nature of Metals 1

- Metals bound by ‘sea of electrons’
- Movement aided by ___________
  - Dislocations Example: moving a carpet Failure: deformation v. cleaving
- Strengthening mechanisms:
  - Solid solution, precipitation, dispersion, quench

The Nature of Metals 2

Distinguishing features

- Atoms arranged in a regular repeating structure
- Relatively good strength
- Dense
- Malleable or ductile: high plasticity Resistant to fracture: tough
- Excellent conductors of electricity and heat
- Opaque to visible light
- Shiny appearance

- Thus, metals can be formed and machined easily, and are usually long-lasting materials.

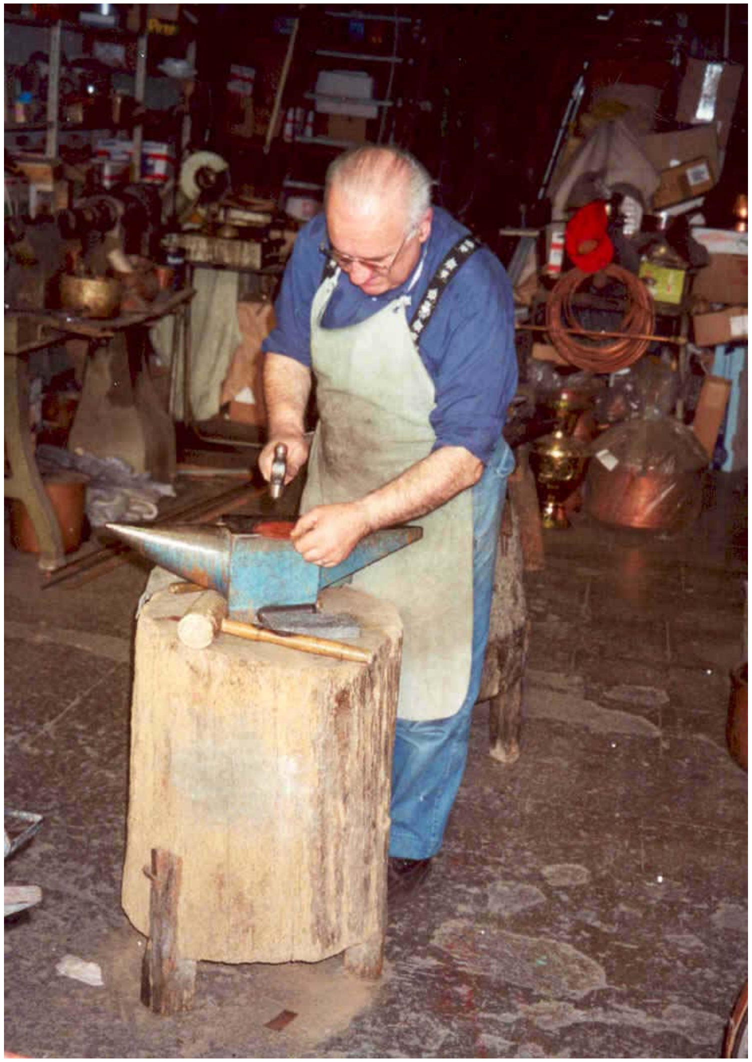
- They do not react easily with other elements, however, metals such as Fe and Al do form compounds readily (such as ores) so they must be processed to extract base metals.

- One of the main drawbacks is that metals do react with chemicals in the environment, such as iron-oxide (rust).

- Many metals do not have high melting points, making them useless for many applications.

The Nature of Metals 3

- Except for Mercury, all metals are solid at room temperature.
- When melted, metals can be easily manipulated.
- While hard, metals can be only minimally altered.



Metallurgy: Greek *metallon(metal),-ourgia* working

- متالوژی‒‒‒‒‒‒‒‒‒‒‒‒‒‒‒‒‒‒‒ متالورژی
- *Metal* - Any element that usually has a shiny surface, is a generally good conductor of heat and electricity, and can be melted or fused, hammered into thin sheets, or drawn into wires.
  - Of the 84 metals now known, only 7 were discovered before the 13th century AD:
    - Copper, Gold, Silver, Lead, Tin, Iron, Mercury

Metallurgy

- the extraction of metals from ores
- the preparation of metals for use
- the study of the relationship between structures, properties and processing of metals

Ferrous Metals: Applications

- Structural: building structures, concrete reinforcement
- Automotive: chassis, engine parts, drive train, body parts
- Marine: ship hulls, structure, engines
- Defense: tanks, weapons
- Consumer Products: appliances, recreational vehicles, toys, utensils and tools

NONFERROUS METALS: APPLICATIONS

- Architectural: aluminum windows and doors
- Automotive: aluminum engine blocks, copper wiring, mag wheels
- Marine: brass/bronze fittings, bearings, propellers
- Defense: brass shell casings
- Consumer Products: electrical wiring, utensils, jewelry, electronics

ASM HANDBOOK: METALS PROPERTIES AND PERFORMANCE COLLECTION

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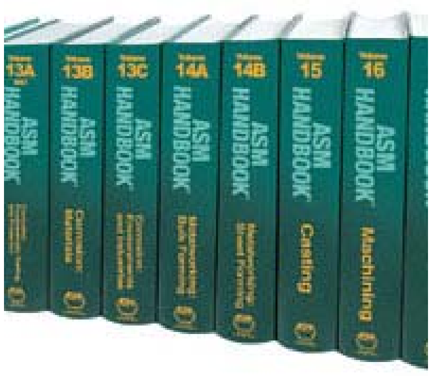

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