Materials for Engineers ME 1000
Introduction

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Materials for Engineers

Learning Objectives	• To provide overview of microstructure and properties of various engineering materials • To explore relations between performance of engineering products and microstructure, properties of materials that are used to construct them.
Learning Outcomes	After the completion of the course, students will be able: • To explain the microstructure and properties of materials like steels, polymers, ceramics, and composites. • To understand the correlation of microstructure-properties-performance of materials so as to select suitable materials for engineering products.
Contents of the course	• Classification and evolution of engineering materials, crystal structure, defects, crystallographic planes, directions, slip, deformation mechanical behavior, strengthening mechanisms, microstructure and properties of metal alloys (12) • Properties and processing of polymers, ceramics and composite materials, microstructure-property relationships (9) • Electrical, electronic and magnetic properties of materials, microstructure-property relationships (6) • Introduction to Nano, Bio, Smart and Functional materials. (3) • Introduction to selection of materials, Product based case studies on microstructure-property-performance of materials in the design of automobile; aircraft structures; e-vehicles; energy storage; electronic, optical and magnetic devices; and biomedical devices. (12)
Essential Reading	1. William D. Callister Jr., David G. Rethwisch, "Materials Science and Engineering: An Introduction", 10th Edition, Wiley, 2018. 2. Michael Ashby, Hugh Shercliff, David Cebon, "Materials – Engineering, Science, Processing and Design", 4th Edition, Butterworth-Heinemann, 2018.

Outline of this Lecture

- *Introduction*
  - Evolution of materials
  - Role of materials in Engineering
  - Material Science and Engineering
- *Structure and properties of materials*
- *Importance of studying about materials – example case study.*
- *Classification of materials*

Evolution of Materials

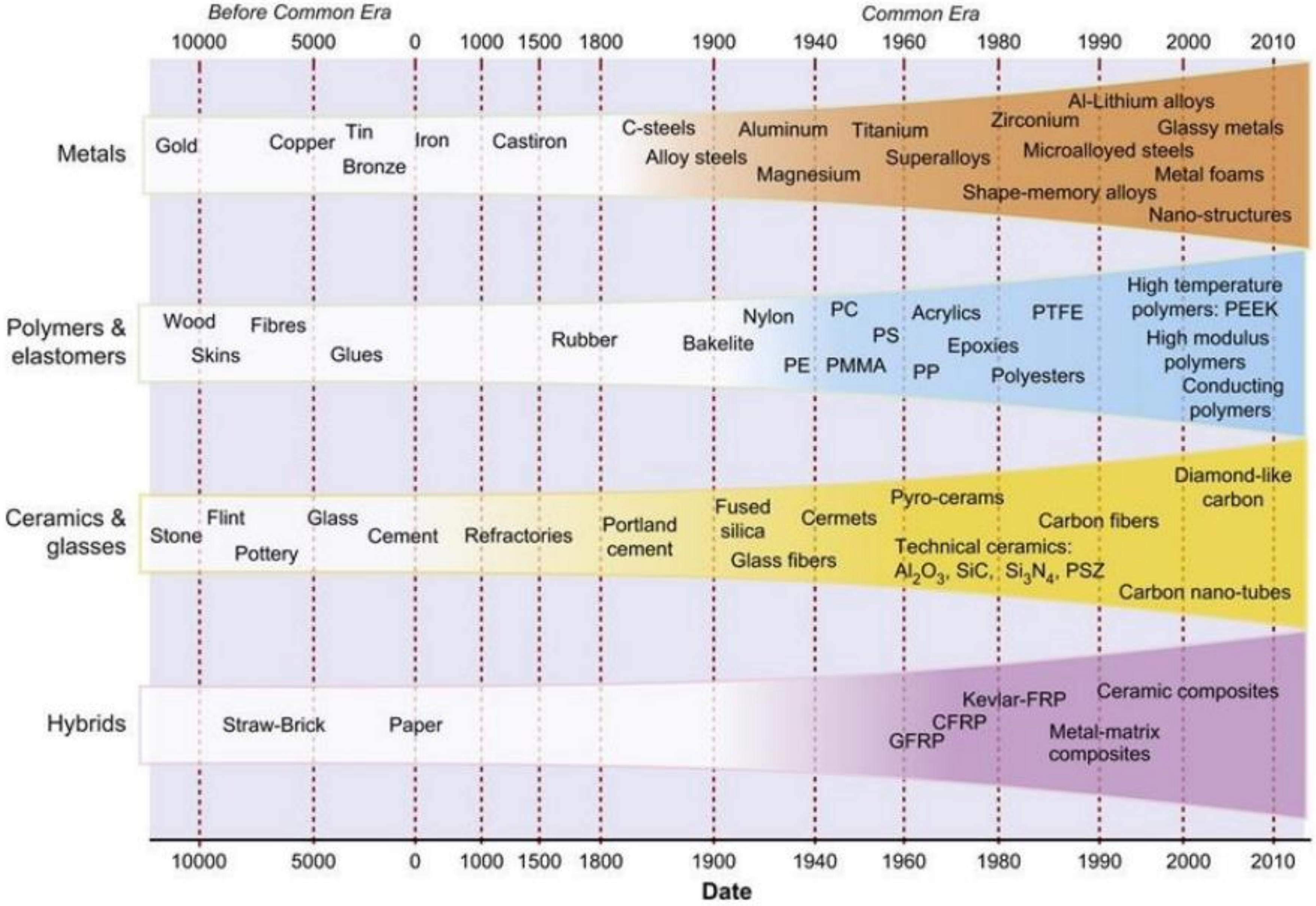


Figure 1. Development of materials over time, on the left are all natural materials. Development of thermo-chemistry and polymer chemistry enabled man made materials, shown in coloured zones.

Role of Materials in Engineering

- *Engineer*: skilfully arrange for something to occur

- To *make* things, *materials* are needed, and some *process* is required to shape, join or finish them.

- Material should *conform* to the purpose of the product.

- The process should be *compatible* to the material.

- The problem is to select the best performing, economical, efficient, environment friendly material for any application.

- Today's advanced technologies and applications are largely attributed to Progress in Materials Science.

- Materials of structural, functional (electrical, magnetic, optical) and multi–functional (involving two or more physical phenomena) are of equal interest today.

Materials Science and Engineering

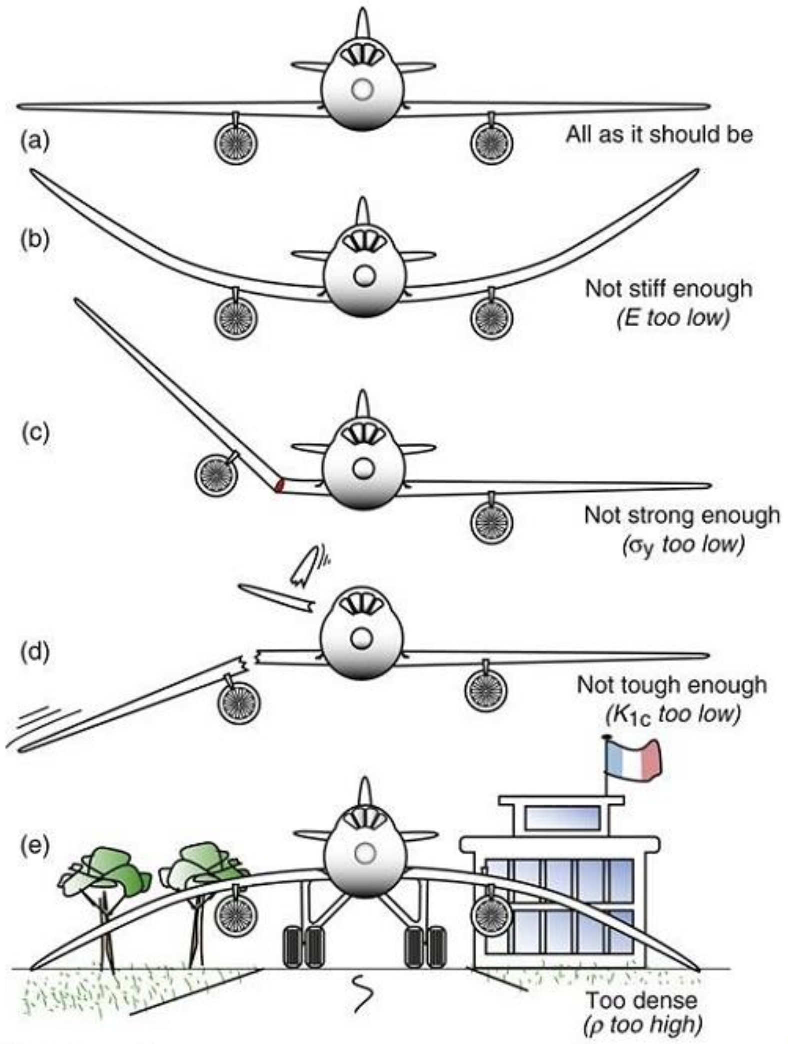
- *Materials Science* involves investigating the relationships that exist between the structures and properties of materials.
- They develop or synthesize new materials.

- *Materials Engineering* is, on the basis of these structure-property correlations, designing or engineering the structure of a material to produce a predetermined set of properties.
- Create new products or systems using existing materials.

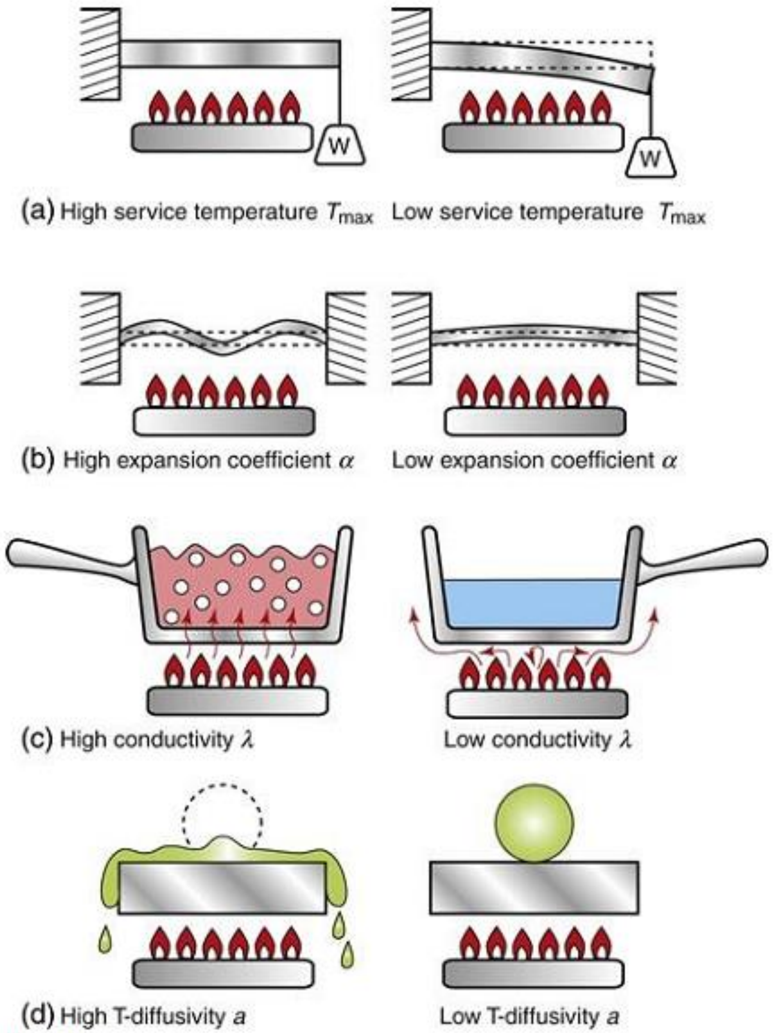
- Structure refers to arrangement of internal components.

- A property is a material trait in terms of the kind and magnitude of response to a specific imposed stimulus.
- Solid materials have properties such as:
- mechanical, electrical, thermal, magnetic, optical and deteriorative.

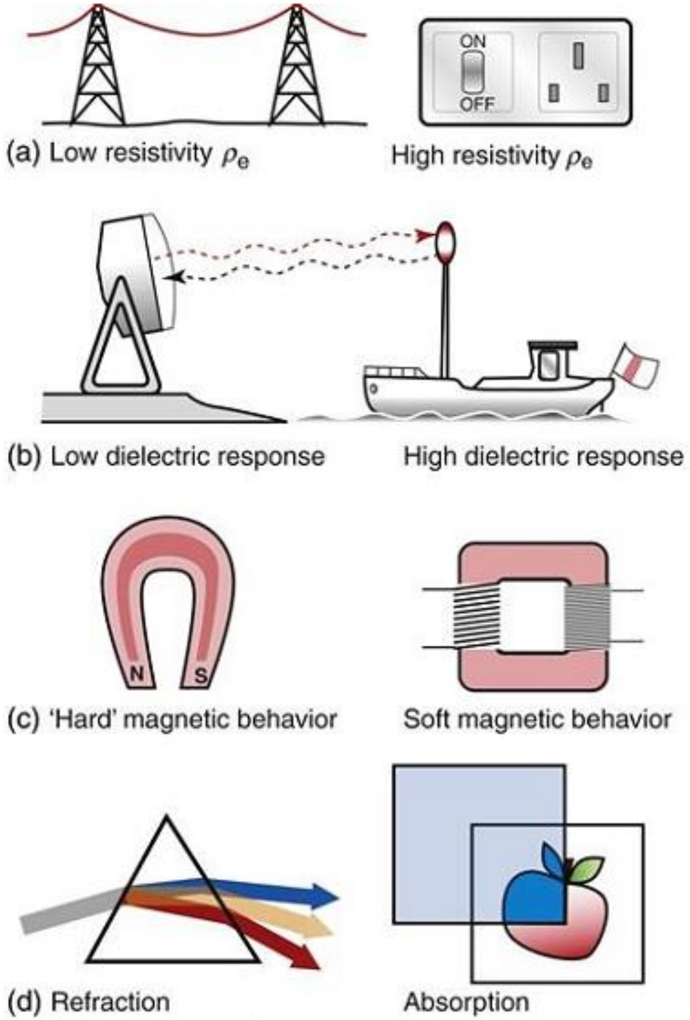
Material Properties



Mechanical properties.



Thermal properties.



Electrical, magnetic and optical properties.

Determination of Physical properties based on application.

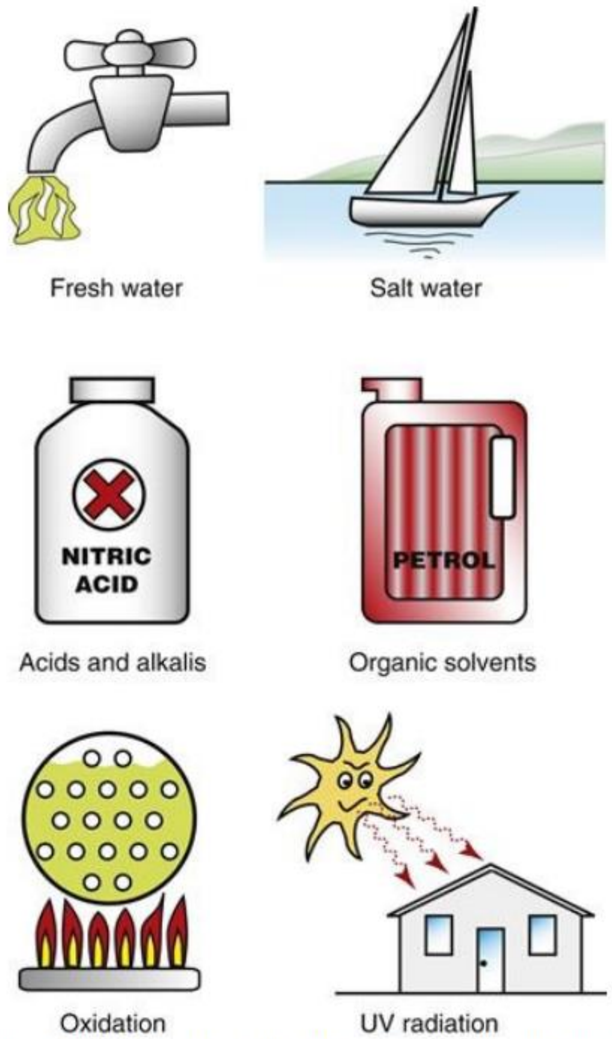
Processing and Performance

- Structure of a material depends on how it is processed.

- Material’s performance is a function of its properties.

Processing → Structure → Properties → Performance

- Design limiting properties: limits of properties that enable material to be chosen for a specific application.



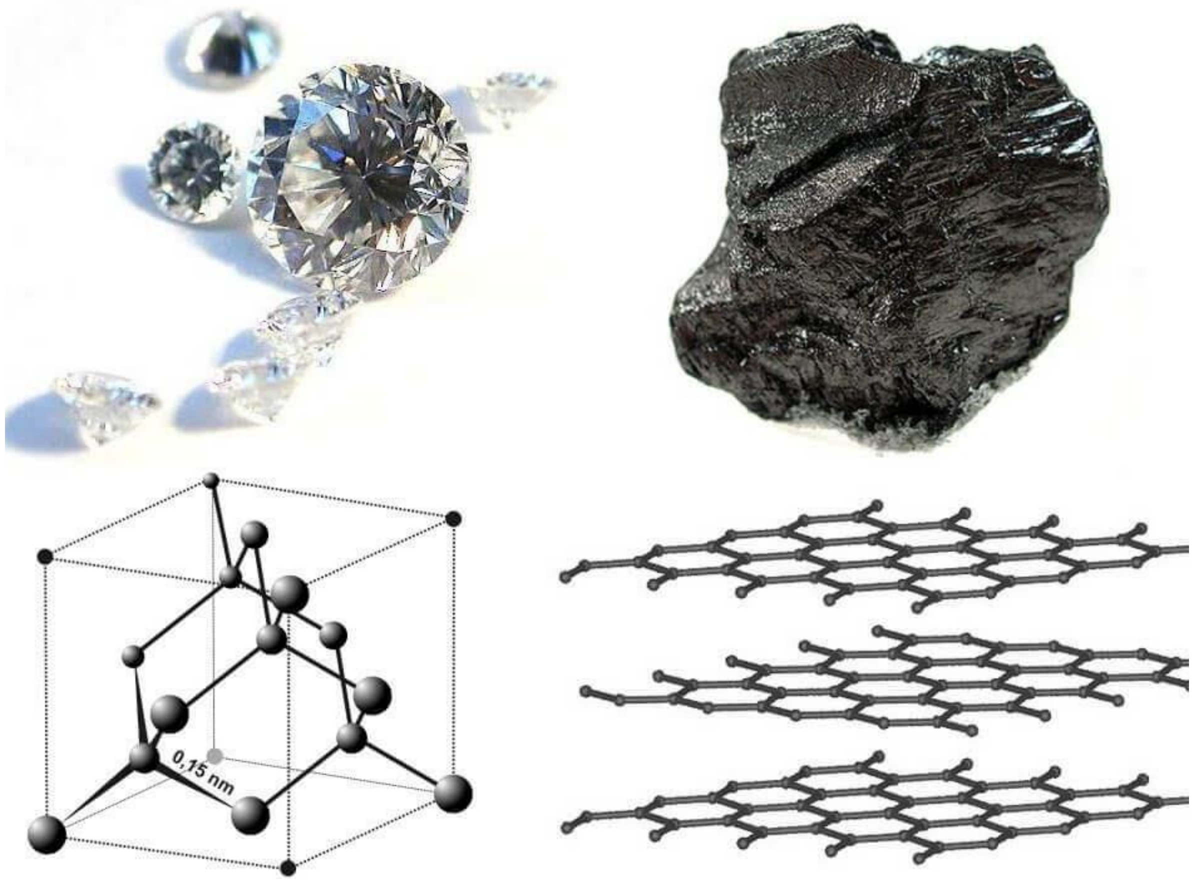
Chemical properties: resistance to water, acids, alkalis, organic solvents, oxidation and radiation.

Example of the relationship between the four components

- the optical properties (i.e., the light transmittance) of each of the three materials are different.
- these specimens are of the same material, aluminum oxide.
- leftmost one is a single crystal.
- center one is composed of numerous and very small single crystals.
- the specimen on the right is composed not only of many small, interconnected crystals, but also of a large number of very small pores or void spaces.
- the structures of these three specimens affect the optical transmittance properties.
- each material was produced using a different processing technique.
- If optical transmittance is an important parameter relative to the ultimate in-service application, the performance of each material will be different.

William D. Callister Jr./ Specimen preparation, P.A. Lessing

Chemical Composition and Structure (arrangement) both are equally important



DIAMOND VERSUS GRAPHITE

DIAMOND	GRAPHITE
Diamond is a very stable allotrope of carbon that is composed of sp^3 hybridized carbon atoms	Graphite is an allotrope of carbon that is composed of sp^2 hybridized carbon atoms
Hardest mineral found on earth	A soft mineral
Has four covalent bonds around one carbon atom	Has three covalent bonds around one carbon atom
Has a face-centered cubic crystal structure	Has a planar structure
Transparent	Opaque

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The Materials Selection Process

1. Select Application ⟶ Determine required Physical Properties

   Properties: mechanical, electrical, thermal, magnetic, optical, deteriorative.

2. Physical Properties ⟶ Identify candidate Material(s)

   Material: structure, composition.

3. Select Materials ⟶ Identify required Processing

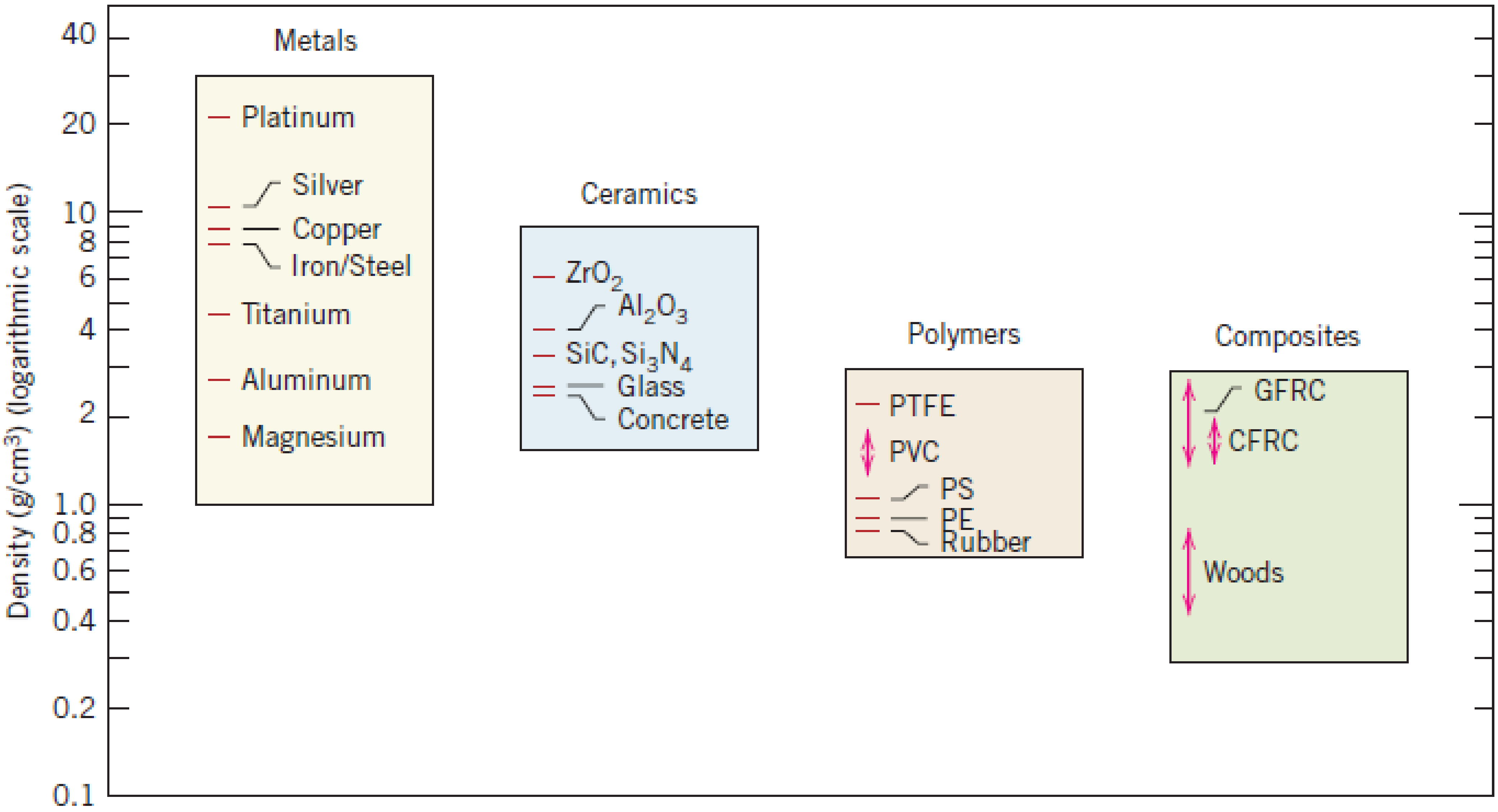
   Processing: changes *structure* and overall *shape*
   ex: casting, sintering, vapor deposition, doping
   forming, joining, annealing.

4. Consider other parameters such as cost
   ⟶ Finalize the Material and processing

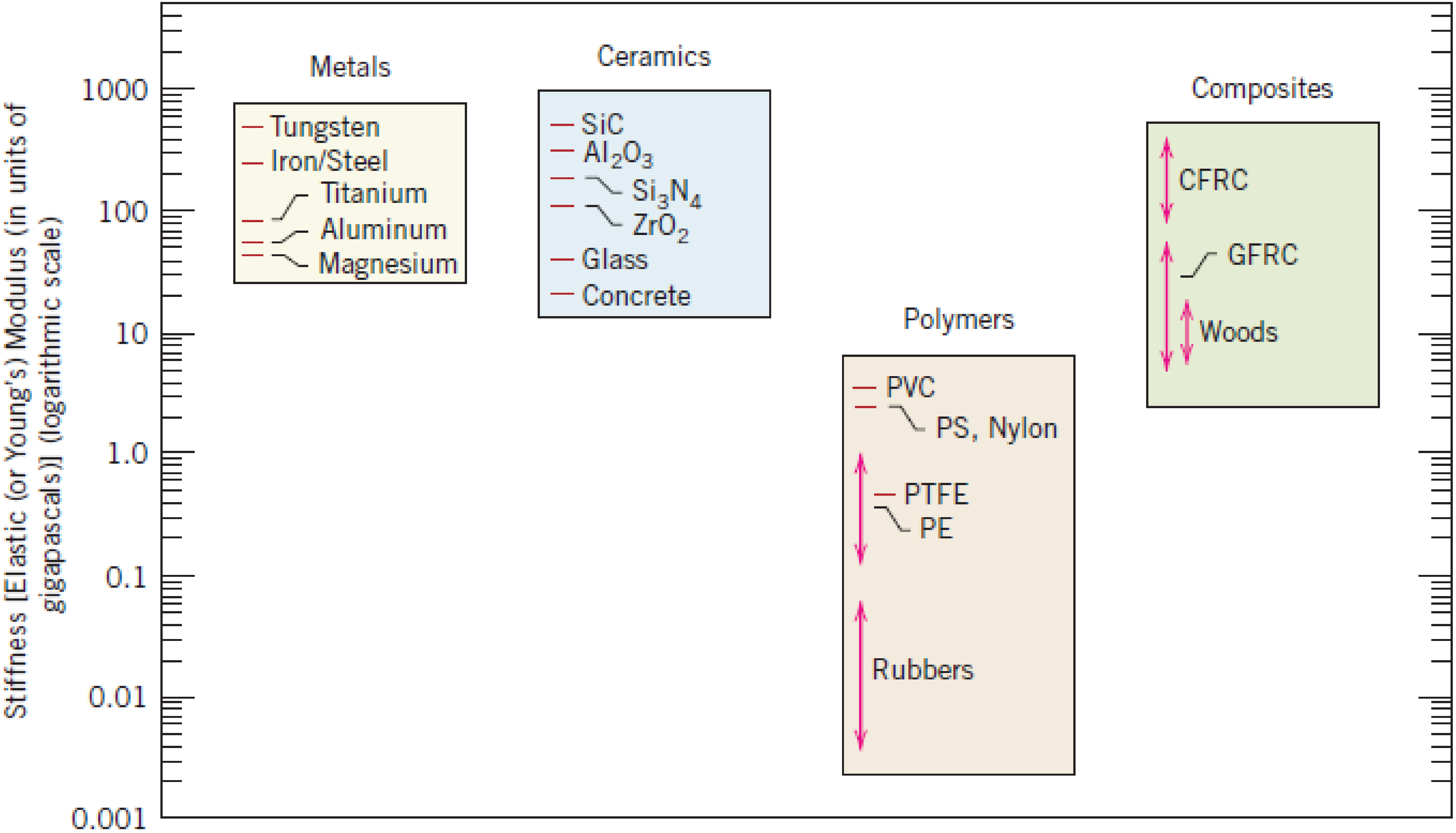
Types of Materials

- Metals:
  - Atoms in a very orderly manner, dense
  - Stiff, Strong, ductile
  - High thermal & electrical conductivity
  - Opaque, reflective.
- Polymers/plastics: Covalent bonding → sharing of e’s
  - Soft, ductile, low strength, low density
  - Thermal & electrical insulators
  - Optically translucent or transparent.
  - Chemically inert
- Ceramics: ionic bonding – compounds of metallic & non-metallic elements (oxides, carbides, nitrides, sulfides)
  - Stiffness & strength comparable to metals
  - Very hard, Brittle
  - Non-conducting (insulators)
- Composites:
  - Combination of 2 or more of other category of materials.
  - Goal is to achieve a combination of properties.
  - Eg. fiberglass

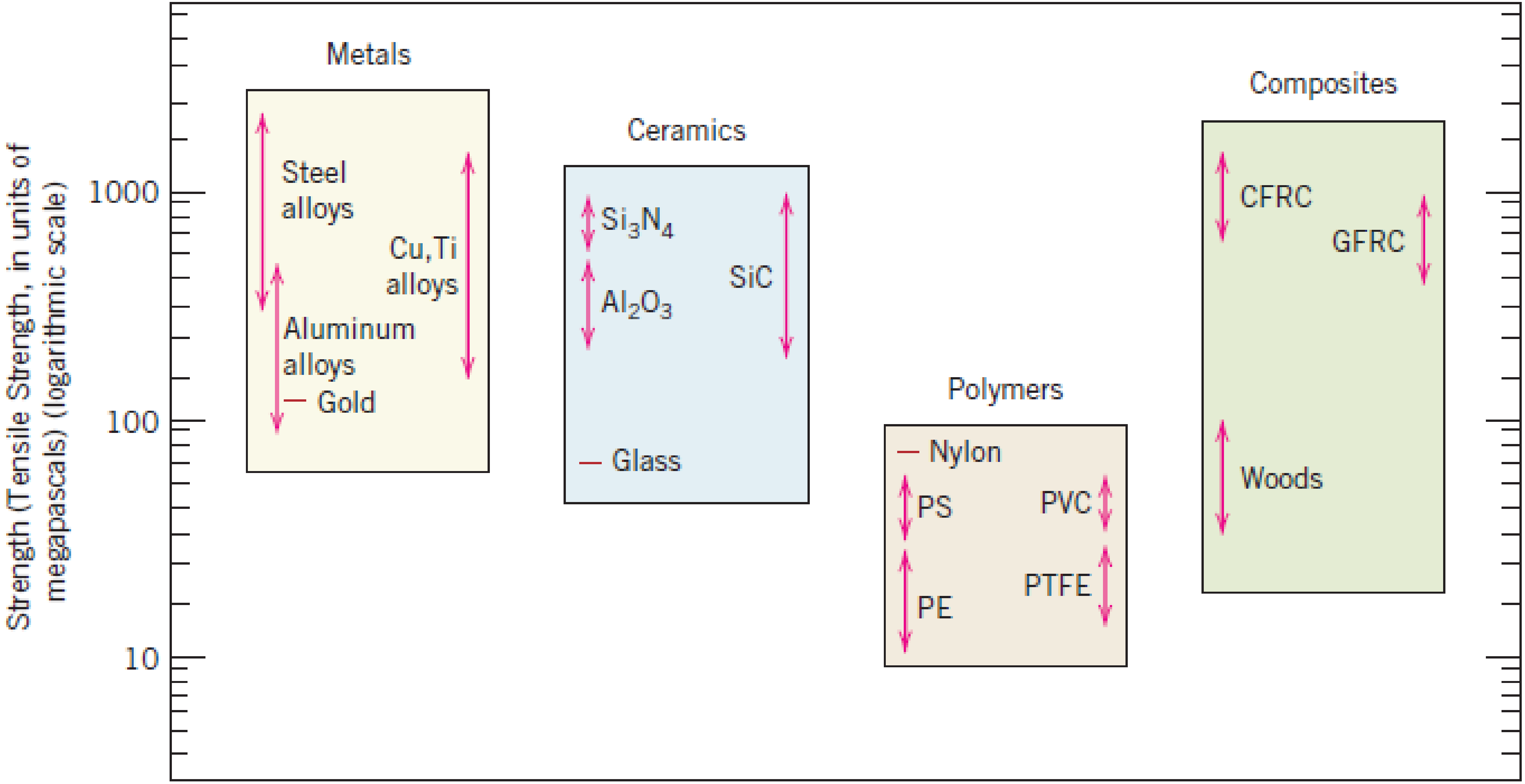
Classification of Materials



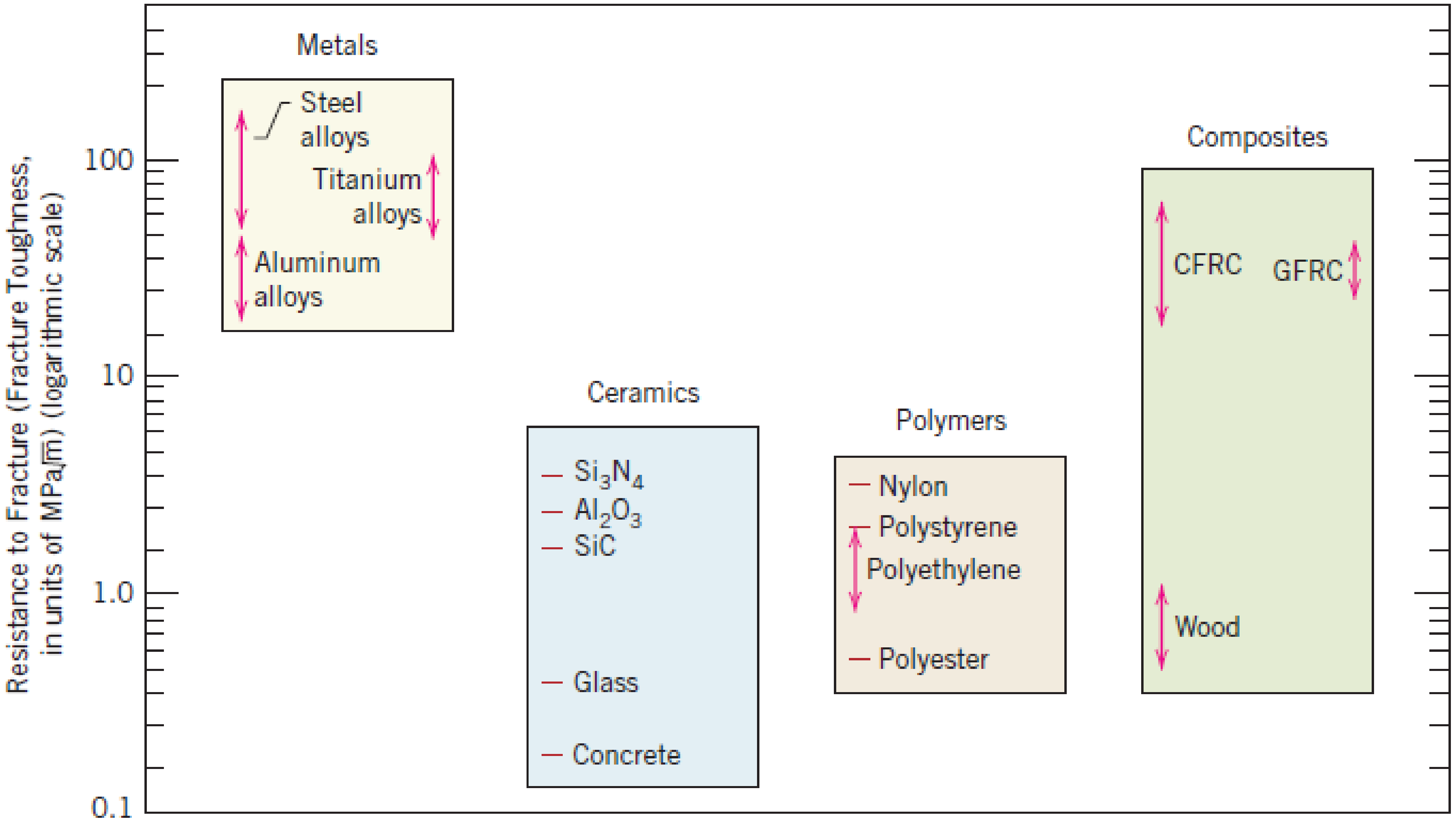
Classification of Materials



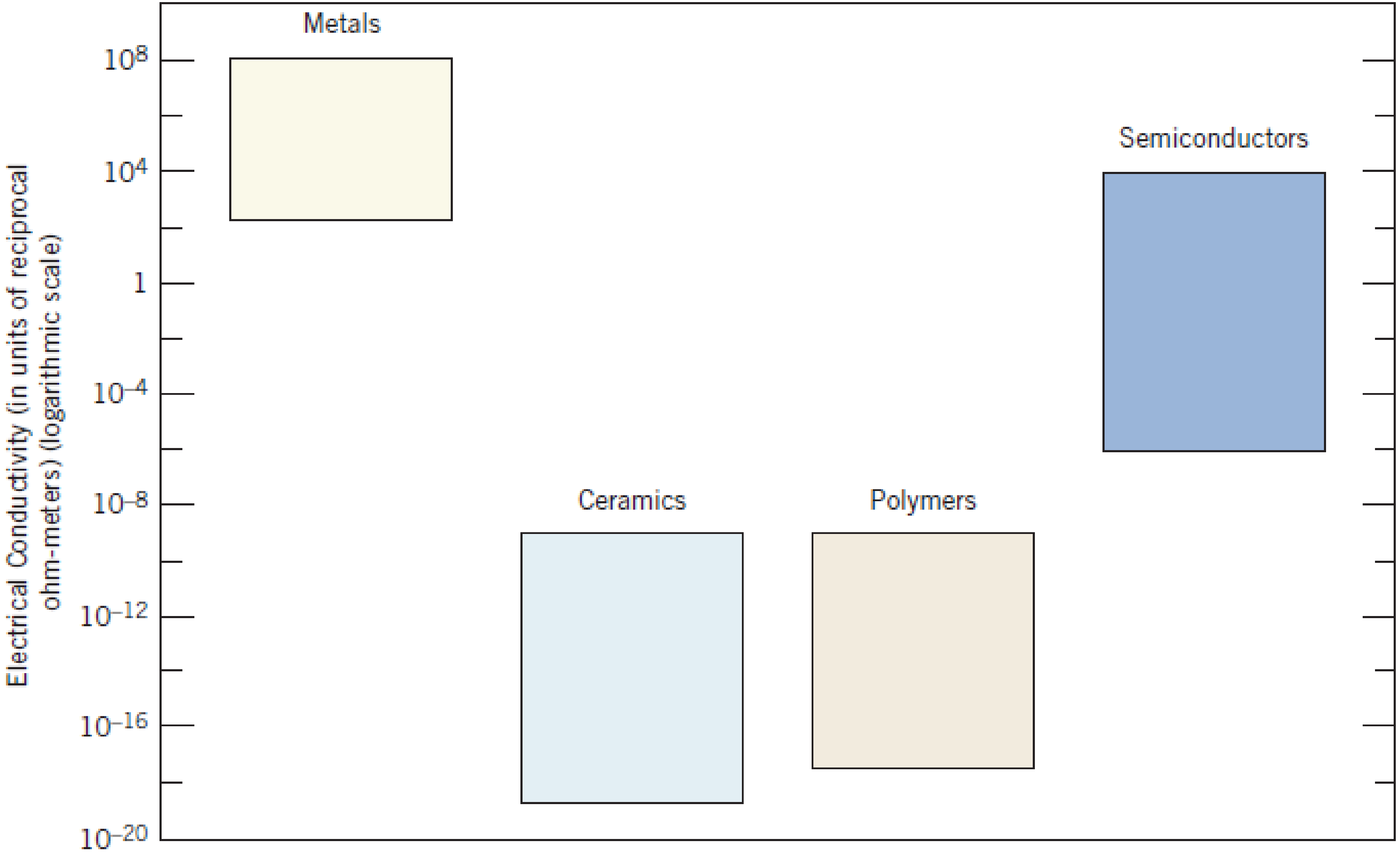
Classification of Materials



Classification of Materials

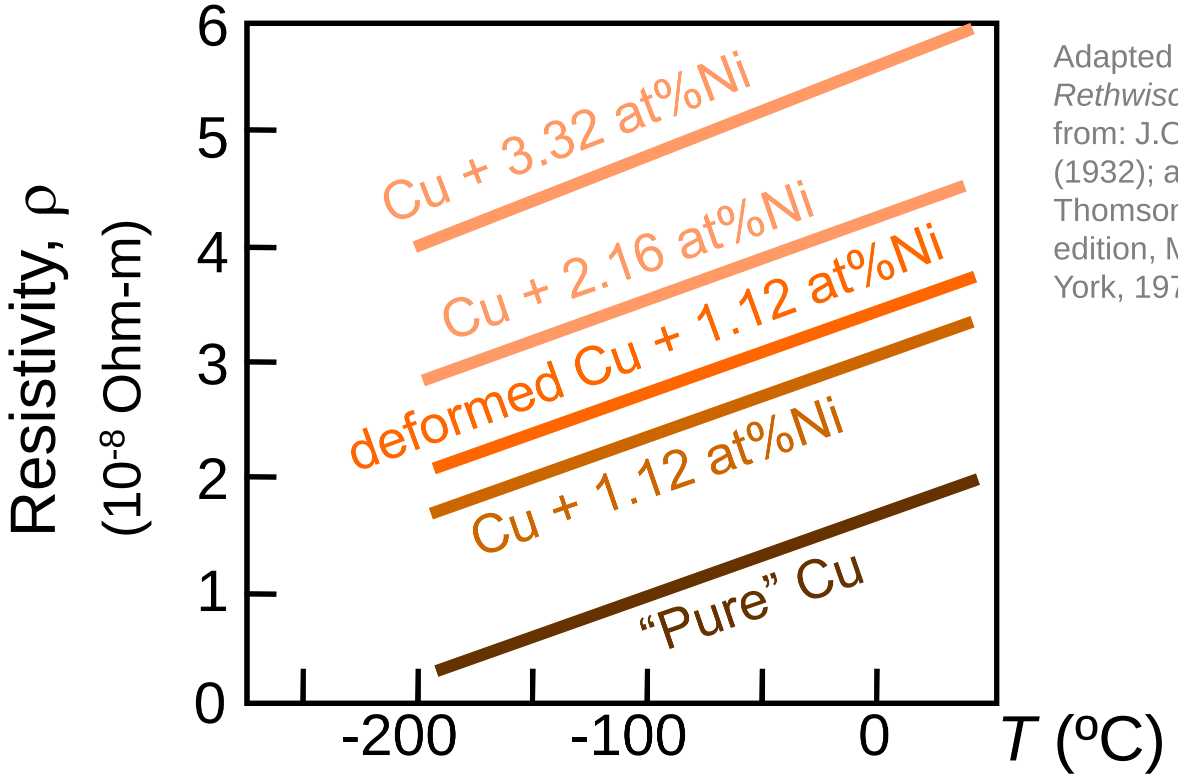


Classification of Materials



ELECTRICAL PROPERTIES

- Electrical Resistivity of Copper:



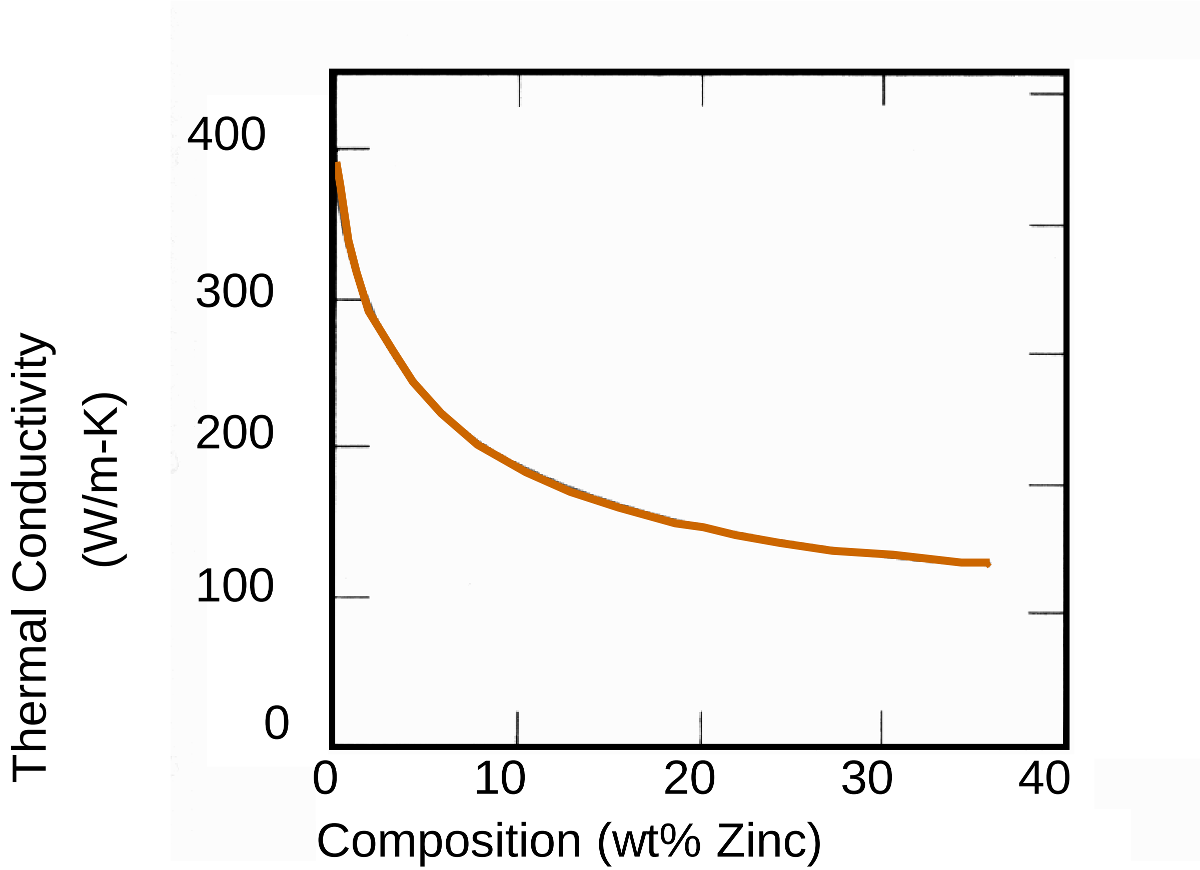
Adapted from Fig. 18.8, *Callister & Rethwisch 8e.* (Fig. 18.8 adapted from: J.O. Linde, *Ann Physik* **5**, 219 (1932); and C.A. Wert and R.M. Thomson, *Physics of Solids*, 2nd edition, McGraw-Hill Company, New York, 1970.)

- Adding "impurity" atoms to Cu increases resistivity.
- Deforming Cu increases resistivity.

THERMAL PROPERTIES

- Thermal Conductivity of Copper:

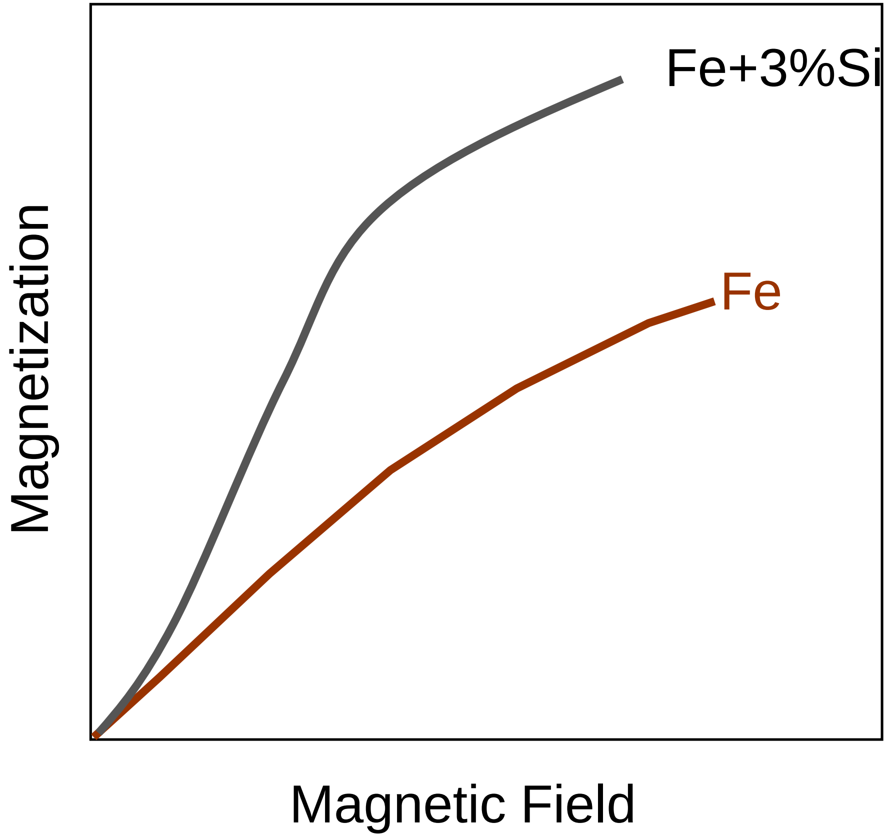
Decreases when Zinc is added



Adapted from Fig. 19.4, *Callister & Rethwisch 8e.* (Fig. 19.4 is adapted from *Metals Handbook: Properties and Selection: Nonferrous alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker, (Managing Editor), American Society for Metals, 1979, p. 315.)

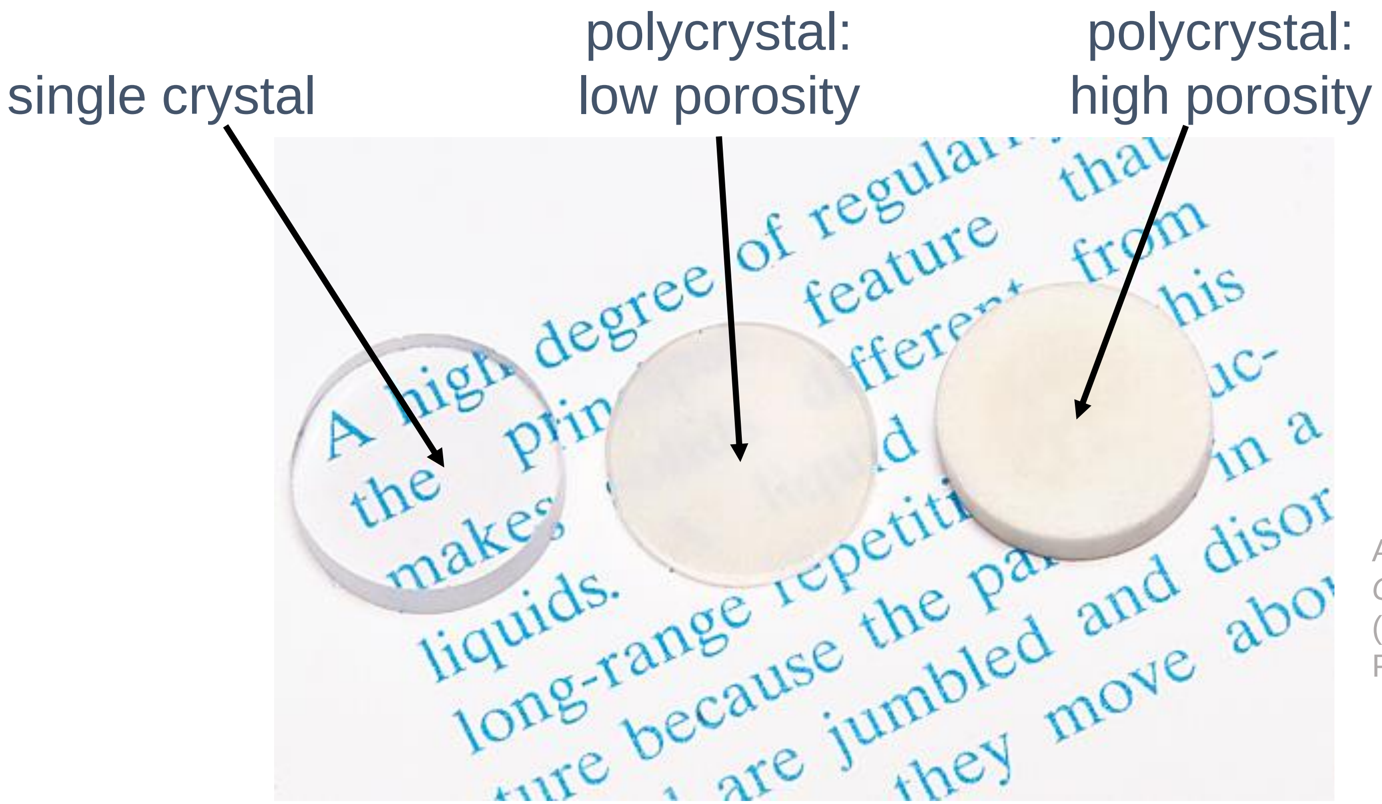
MAGNETIC PROPERTIES

- Magnetic Permeability vs. Composition:



OPTICAL PROPERTIES

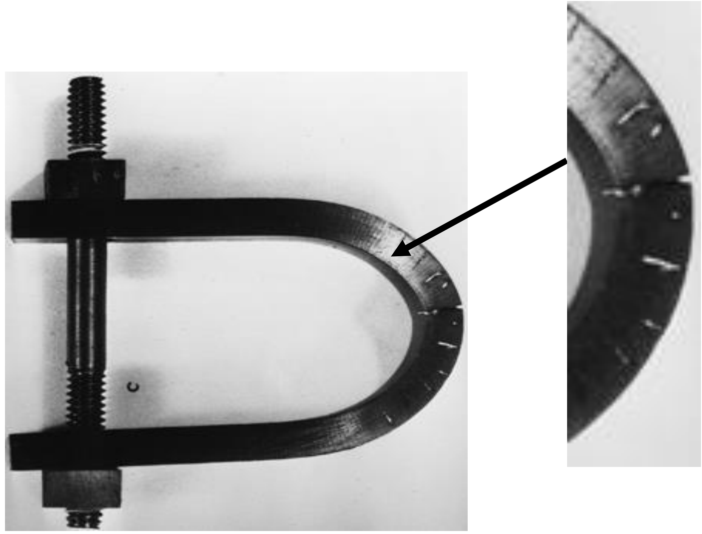
- Transmittance:
  - -- Aluminum oxide may be transparent, translucent, or opaque depending on the material structure.



Adapted from Fig. 1.2, *Callister & Rethwisch 8e.* (Specimen preparation, P.A. Lessing; photo by S. Tanner.)

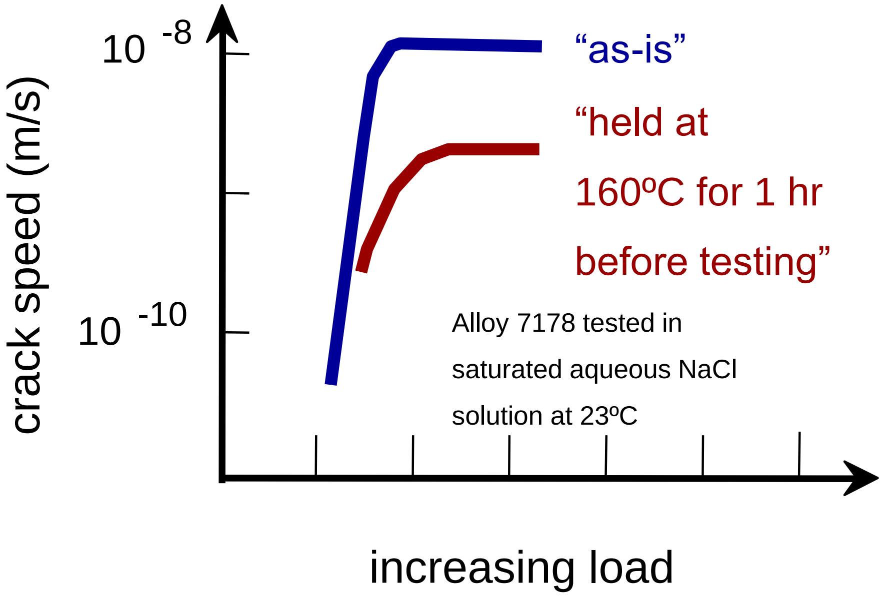
DETERIORATIVE PROPERTIES

- Stress & Saltwater...
  -- causes cracks!



Adapted from chapter-opening photograph, Chapter 16, *Callister & Rethwisch 3e.* (from *Marine Corrosion, Causes, and Prevention*, John Wiley and Sons, Inc., 1975.)

- Heat treatment: slows crack speed in salt water!



Adapted from Fig. 11.20(b), R.W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials" (4th ed.), p. 505, John Wiley and Sons, 1996. (Original source: Markus O. Speidel, Brown Boveri Co.)

Selection Criteria for Beverage Container

1. provide a barrier to the passage of carbon dioxide under pressure
2. be nontoxic, unreactive with the beverage
3. preferably be recyclable
4. Relatively strong and capable of surviving a drop from a height of several feet
5. be inexpensive and the cost to fabricate the final shape should be relatively low;
6. if optically transparent, retain its optical clarity;
7. capable of being produced having different colors

Aluminum alloy is relatively strong (but easily dented), is a very good barrier to the diffusion of carbon dioxide, is easily recycled, beverages are cooled rapidly, and labels may be painted onto its surface, however they are opaque and expensive to produce.

Glass is impervious to the passage of carbon dioxide, is a relatively inexpensive material, may be recycled, but it cracks and fractures easily, and glass bottles are relatively heavy

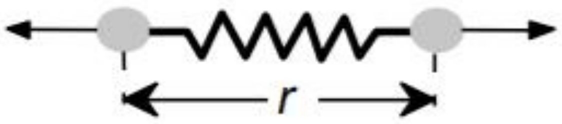
Plastic is relatively strong, may be made optically transparent ,is inexpensive and lightweight, and is recyclable, it is not as impervious to the passage of carbon dioxide as aluminum and glass

Bonding Energy

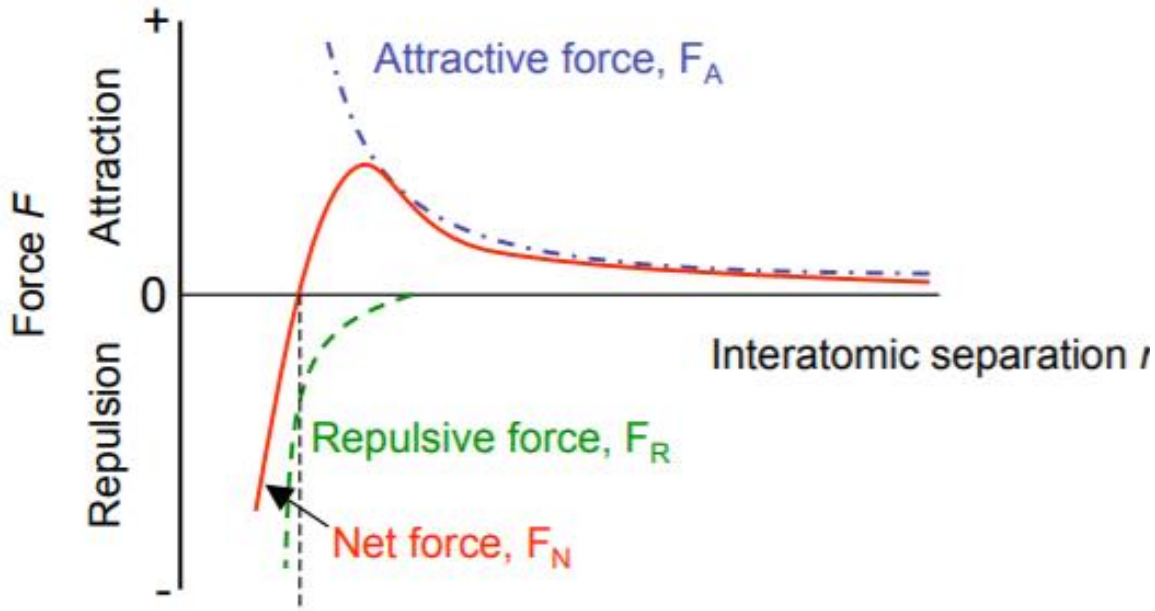
$$E = \int F dr$$

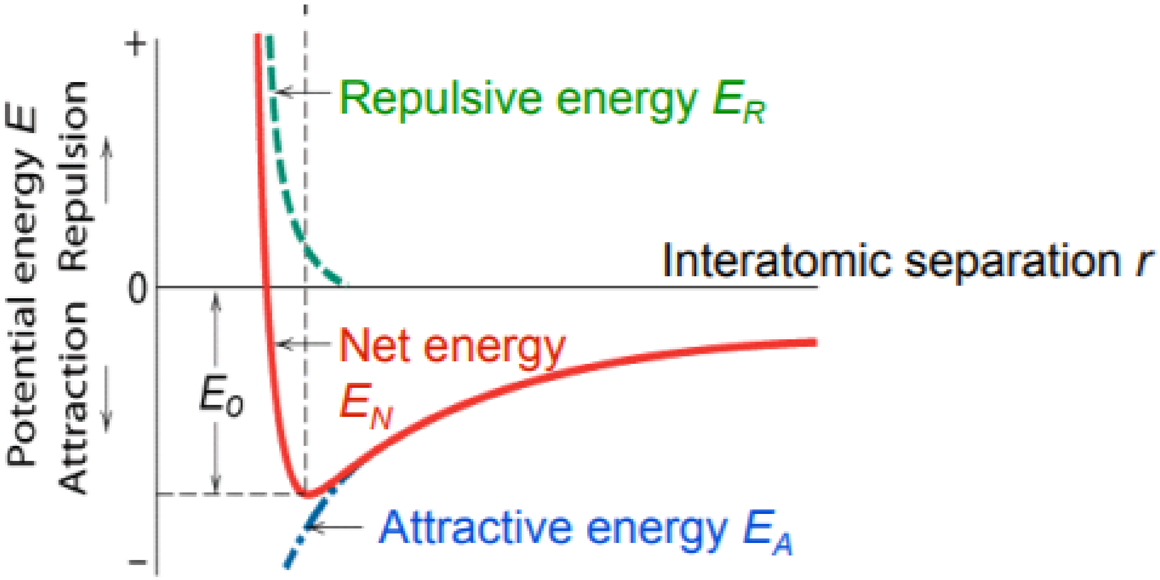
$$E_N = \int_{\infty}^{r} F_N dr = \int_{\infty}^{r} F_A dr + \int_{\infty}^{r} F_R dr$$

$$= E_A + E_R$$



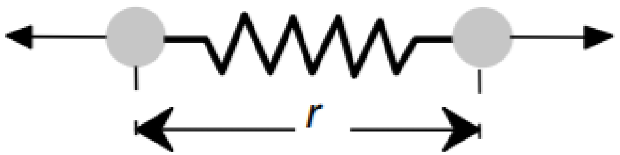
- Attractive force, F_A
- Repulsive force, F_R



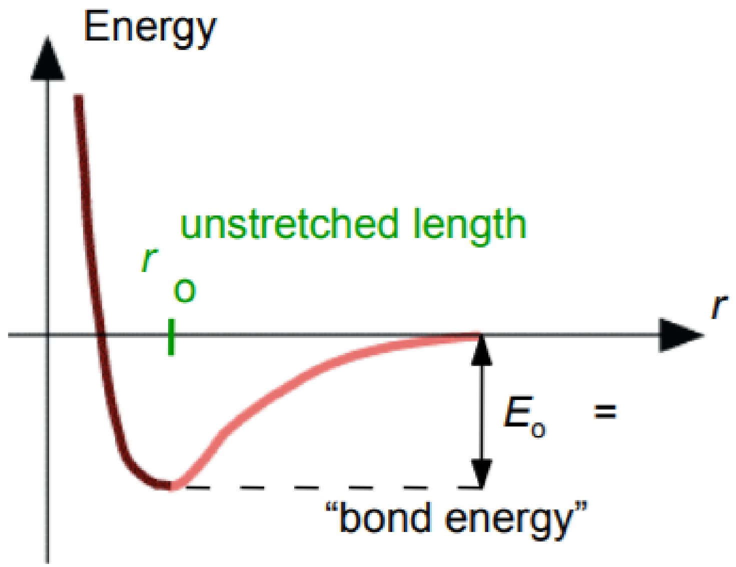


Melting properties from bonding

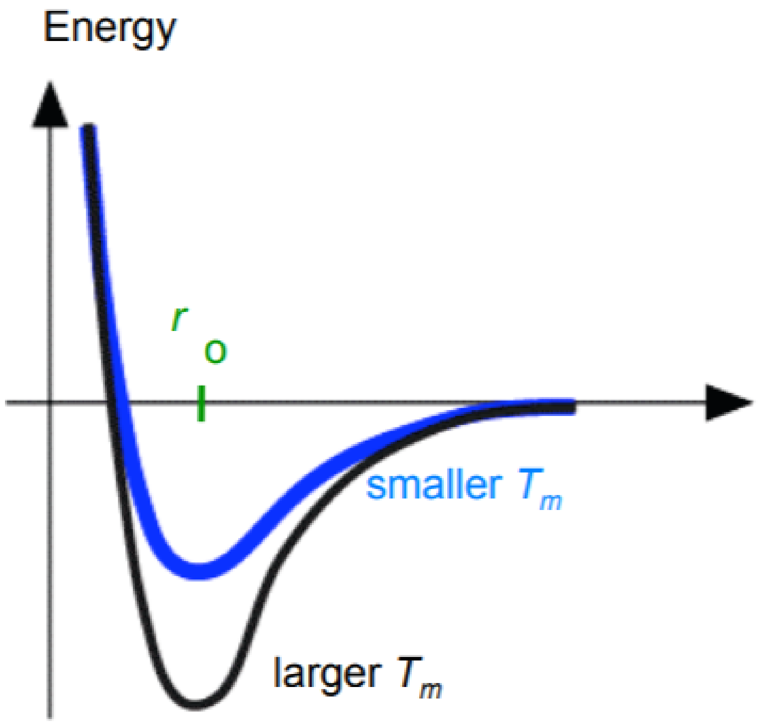
- Bond length, r



- Bond energy, E_o

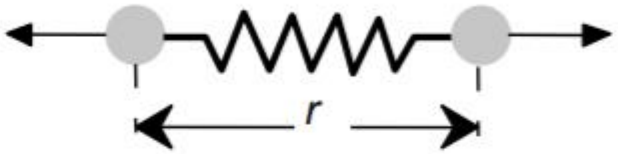


- Melting Temperature, T_m

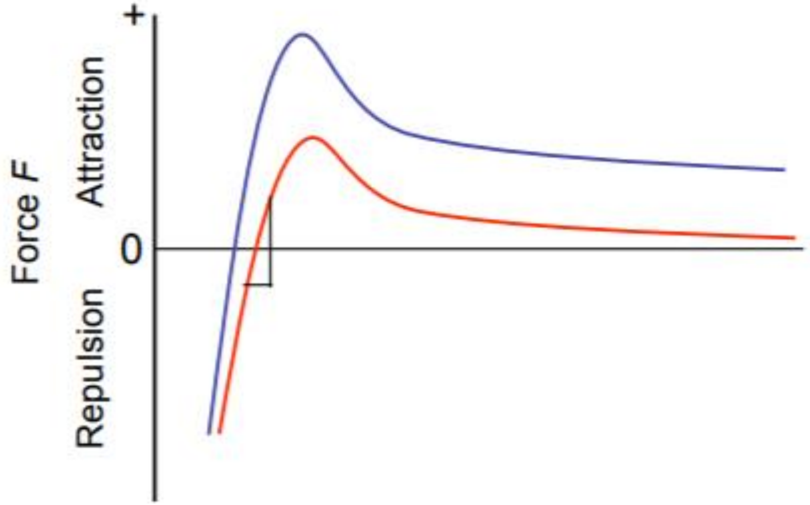


T_m is larger if E_o is larger.

Stiffness properties from bonding



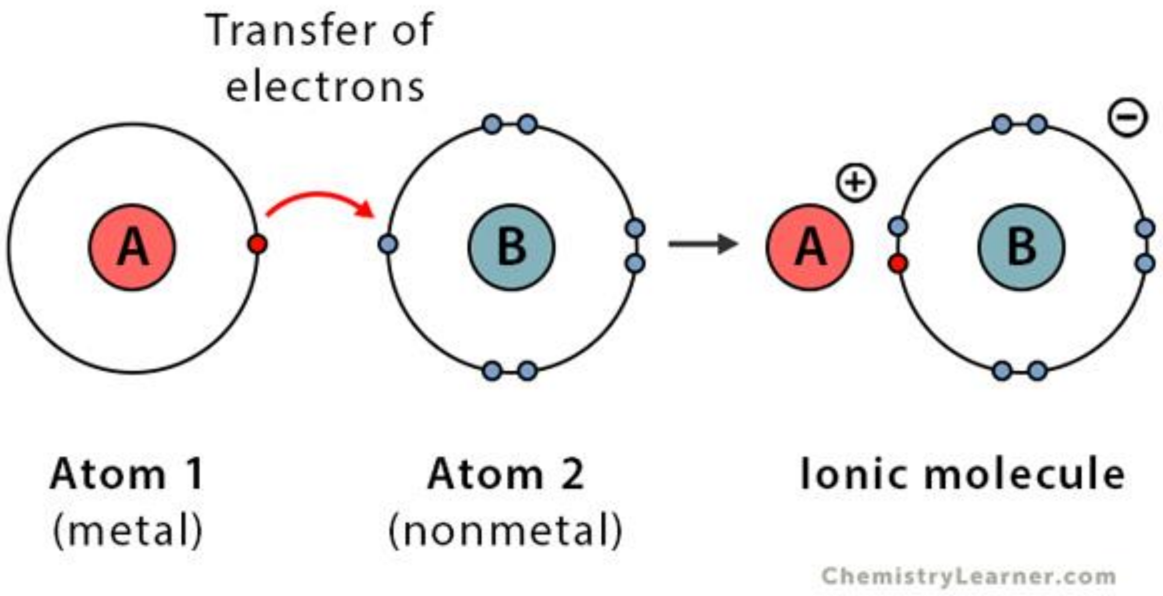
F = kx



Types of bonding

Ionic Bonding

- Occurs between + and - ions.
- Requires electron transfer.
- Large difference in electronegativity required.



Covalent Bonding

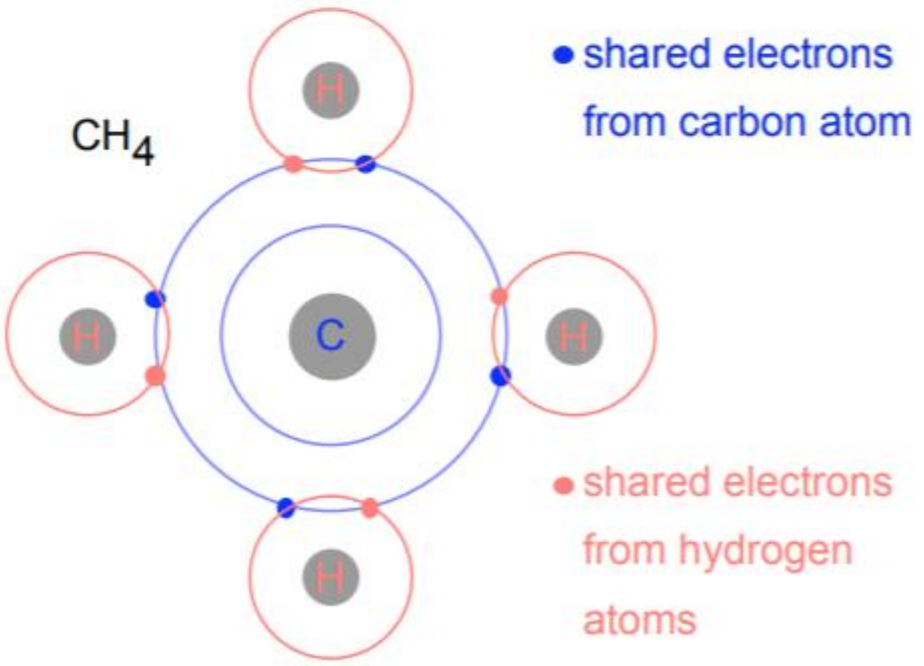
- similar electronegativity ∴ share electrons
- bonds determined by valence – *s* & *p* orbitals dominate bonding

- Example: CH_4

C: has 4 valence e^-,
needs 4 more

H: has 1 valence e^-,
needs 1 more

Electronegativities
are comparable.



Metallic Bonding

- Ions in a sea of electrons
- Attraction between free electrons and metal ions