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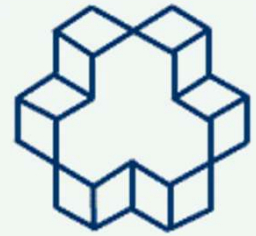
K. N. Toosi University of Technology

Faculty of Materials Science and Engineering



Selection of Engineering Materials

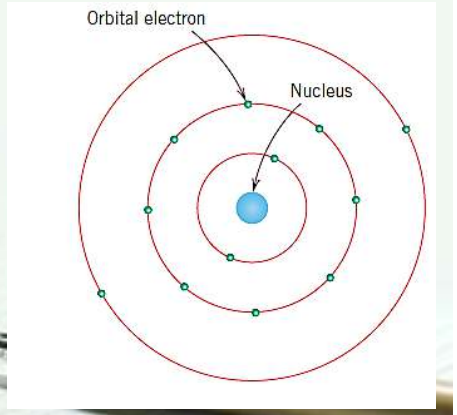
Second Session

(Introduction to Materials and Their Classification)

Reza Eslami-Farsani

Element and Material

- The smallest constituent of any substance is the atom.
- An atom contains electrons, protons, and neutrons.
- Protons and neutrons are in the nucleus of the atom, and electrons are rotating around the nucleus in orbitals.
- The number of electrons and protons is equal.
- The nucleus is 100,000 times smaller than the atom.
- Electrons have a negative charge, protons have a positive charge, and neutrons are neutral.



Element and Material

- An element is a pure material whose constituent atoms all have the same atomic number (number of protons), and this material cannot be further converted into simpler materials through decomposition.
- There are a total of 118 known elements, all of which have been discovered.
- The latest element (element 117) was artificially created in a laboratory in 2012 through nuclear reactions.
- In the periodic table, elements are classified based on their atomic number (number of protons).

Element and Material

- The atomic mass is the total number of protons and neutrons.
- 92 elements are known in nature (from the element hydrogen with atomic number 1 to uranium with atomic number 92).
- Out of the 92 natural elements, 88 are stable and 4 elements are unstable (radioactive).
- All elements beyond element 92 are non-natural and artificial.

Element and Material

- These elements are produced artificially in research laboratories through nuclear reactions. A heavy element is placed as a target in a cyclotron (accelerator) and bombarded with high-energy particles (such as protons) at high speeds under radiation to create new elements by adding protons to the nucleus.
- Artificial elements with high atomic numbers generally have very short half-life, so their properties are often not fully investigable and are mostly used for research purposes.

Element and Material

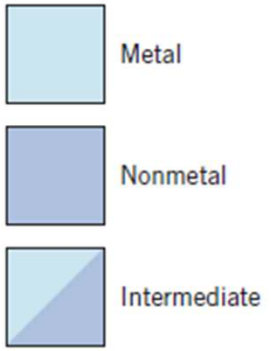
- The periodic table of elements was presented by Mendeleev in 1869.
- Elements in the periodic table are classified into three groups:

1. Metals (mercury is liquid and the rest are solid)
2. Metalloids (boron, silicon, germanium, arsenic, antimony, tellurium, and polonium)
3. Nonmetals (11 gases, one liquid (bromine, and the rest solid)

- Abundance percentage of elements in nature: O (46.6%), Si (27.7%), Al (8.1%), Fe (5%), Ca (3.6%), Na (2.8%), K (2.6%), Mg (2.1%), others (1.5%)
- Industrial metals: Fe, Al, Cu, Ni, Pb, Sn, Zn, Cr, Ti, Mg, Na, Mn, Si
- Industrial nonmetals: H, O, C, Cl, P, S, N

Element and Material

Mendeleev's periodic table



Key: 29 Cu 63.54 — Atomic number, Symbol, Atomic weight

IA							VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080	IIA																2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305	IIIB	IVB	VB	VIB	VIIB				IB	IIB	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.87	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.54	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.34	Rare earth series	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.2	76 Os 190.23	77 Ir 192.2	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.19	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	Acti-nide series	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)								

Rare earth series	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Element and Material

- All elements in the periodic table are classified based on their electron configuration.
- Elements in a group have the same valence electron structure.
- Elements in a group exhibit similar physical and chemical properties.
- The elements in the last group on the right (main group 8) are called noble or inert gases, which have full outer electron layers in other words, have a stable electron configurations.

Element and Material

- Alkali and alkaline earth metals (groups 1 and 2) have one and two more electrons than stable configurations, respectively.
- Elements in groups 6 and 7 have one and two fewer electrons than stable configurations, respectively.
- Group 7 elements are called halogens.
- Transition metals (located between the main groups 2 and 3) have several capacities and multiple oxidation states.

Element and Material

Materials

- Everything that has mass and occupies space is called a material.
- Each material has its own specific properties and characteristics that distinguish it from other material.
- Some materials consist of only one element, while others are composed of two or more elements.

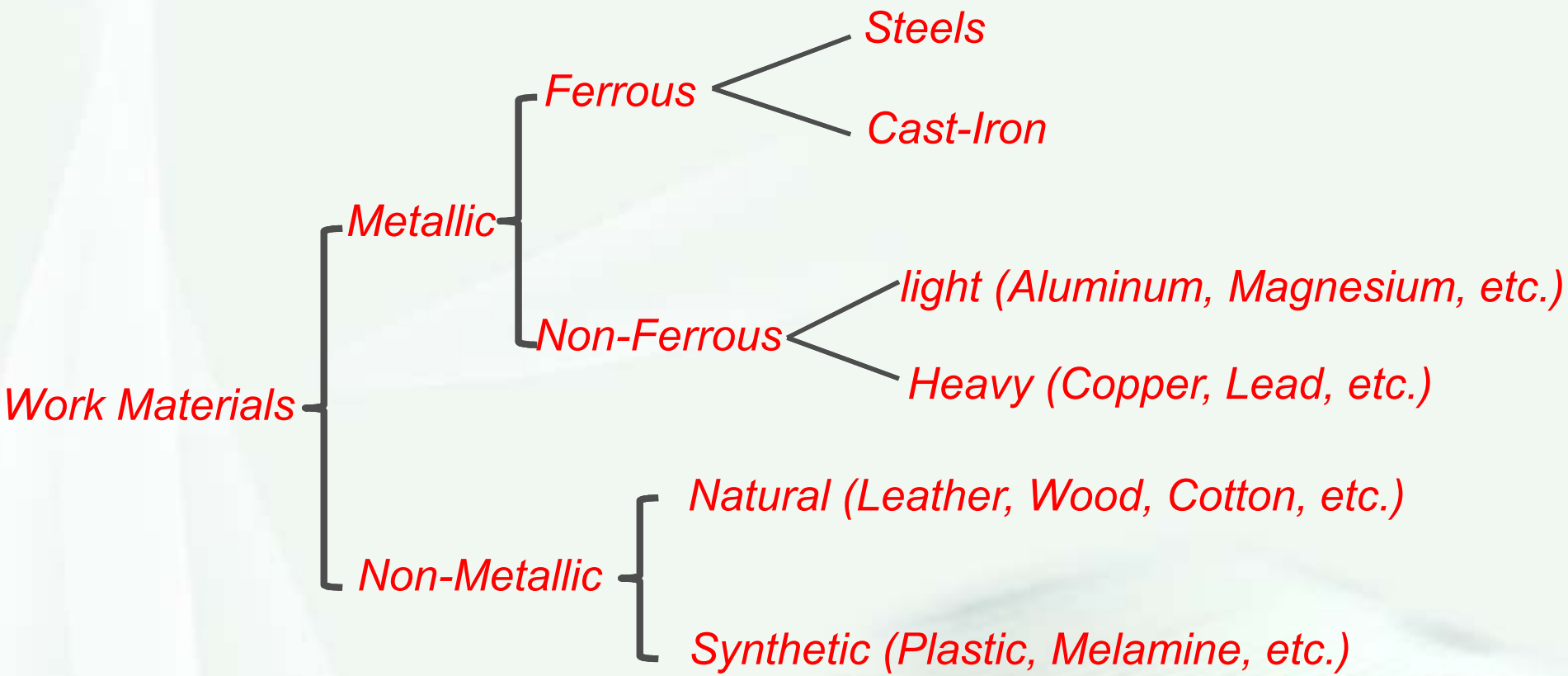
Classification of Materials

- Materials are classified based on various aspects, some of which include:

Classification of Materials

- **Inorganic (mineral):** Such as Fe, $CaCO_3$, etc.
- **Organic:** Such as polymers (rubbers and plastics) and others that are mainly composed of C, H, O, etc.

Classification of Materials



Engineering Materials

- Engineering Materials: These are materials that exhibit resistance to applied loads or deformation caused by forces.

- Most materials can be classified in the above three groups. However, most advanced and innovative materials are prepared by combining two or three of these mentioned materials, such as composites, smart materials, functional materials, etc.
- This classification is based on chemical composition and atomic structure.

Engineering Materials

- Metals (materials with metallic bonding and crystalline structure)

✓ Advantages: Strength and ductility, suitable for static applications

✓ Disadvantages: Poor stability in dynamic conditions and low strength at high temperatures

- Ceramics (non-metallic and non-organic base materials mainly combined with metals)

✓ Advantages: Corrosion resistance, high strength, and preservation of mechanical properties at high temperatures

✓ Disadvantages: Brittleness and prone to fracture

Engineering Materials

- Polymers (materials with long molecular chains containing carbon, hydrogen, oxygen, etc.)

✓ Advantages: Lightness, corrosion resistance, and formability

✓ Disadvantages: Low strength and intolerance to high temperatures

Engineering Materials

Comparison of Metals-Ceramics-Polymers

Material	Type of bonding	Structure	Advantages	Disadvantages
Metals	Metallic	Crystalline	Stiffness, Strength, Conductivity, Formability	Fracture, Fatigue
Ceramics	Covalent and Ionic	Crystalline and Amorphous	Stiffness, Hardness, Strength, Heat and Corrosion Resistance	Brittleness and Lack of Formability
Polymers	Covalent and Secondary	Molecular Chains (Crystalline, Semi-Crystalline and Amorphous)	Lightness, Corrosion Resistance	Low Strength and Stiffness, Low Melting Point, Creep

Examples of Advanced Engineering Materials

- Special Alloys (super alloys, etc.)

Metallic base materials with special properties and applications

- Advanced Polymers (conductive, heat-resistant, etc.)

Novel polymers with unique and different properties from conventional polymers

- Advanced Ceramics (superconducting, piezoelectric, etc.)

Novel ceramics with specific and unique characteristics

Examples of Advanced Engineering Materials

- Composites (fiberglass, carbon-carbon, etc.)

Combination of two or more constituent materials (metal, ceramic, polymer) with different physical or chemical properties as matrix and reinforcement materials

- Intermetallic Compounds

Combination of two or more elements, usually metallic, with different structure and properties from constituent materials

- Cermets

Metal-ceramic mixtures with carbide and oxide base

Examples of Advanced Engineering Materials

- Smart Materials (shape memory, self-healing, etc.)

Materials capable of sensing their environment and reacting to it

- Functionally Graded Materials (FGM)

Materials with continuous and gradual change in properties from one level to another

- Nanomaterials

Materials with at least one dimension in the nanoscale range (1-100 nm)

- Biomaterials (biocompatible materials)

Materials compatible with the body without eliciting an immune response