NAZARBAYEV UNIVERSITY

School of Engineering

Engineering Materials

Lecture 1:

Course Overview & Introduction

Class Policy

- ❑Attendance is mandatory
- ❑Switch off all mobile electronic devices while in class
- ❑Grading: 10% Quiz avg.
  30% Midterm
  60% Final Exam
- ❑Cheating will NOT be tolerated
- ❑Moodle will be utilized

Lecture Schedule

				Group 1	Group 2	
Grig	wk1	16-Aug	22-Aug	L1	L1	
Grig	wk2	23-Aug	29-Aug	L2	L2	
Grig	wk3	30-Aug	5-Sep	Hoilday	L3	
Grig	wk4	6-Sep	12-Sep	L3	L4	
Grig	wk5	13-Sep	19-Sep	L4	L5	
Grig	wk6	20-Sep	26-Sep	L5	Hoilday	
Grig	wk7	27-Sep	3-Oct	L6	L6	
	wk8	4-Oct	10-Oct		Midterm	
	wk9	11-Oct	17-Oct		Project week	
Match	wk10	18-Oct	24-Oct	L7	L7	
Match	wk11	25-Oct	31-Oct	L8	L8	
Match	wk12	1-Nov	7-Nov	L9	L9	
Match	wk13	8-Nov	14-Nov	L10	L10	
Match	wk14	15-Nov	21-Nov	L11	L11	
Grig	wk15	22-Nov	28-Nov	L12	L12	
Grig	wk16	29-Nov	5-Dec	L13	L13	Review
	Final	6-Dec	10-Dec		Final examination	

Lecture Schedule (2)

L1	General
L2	Atomic Structure and Interatomic Bonding
L3	Structure of Crystalline Solids
L4	Imperfections in Solids
L5	Diffusion
L6	Phase Diagrams
Midterm	
Project wk	
L7	Mechanical Properties of Metals
L8	Dislocations and Strengthening Mechanisms
L9	Failure
L10	Fatigue
L11	Metal casting and forming
L12	Phase Tranformations
L13	Processing of metal alloys

Major Topics

- Effects of structure on material properties;
- Mechanical properties, failure and strengthening mechanisms;
- Applications and processing of common engineering materials such as metals & nonferrous alloys, ceramics, polymers, and composites;
- Economic, environmental and social issues of material usage and considerations for materials selection in designs.

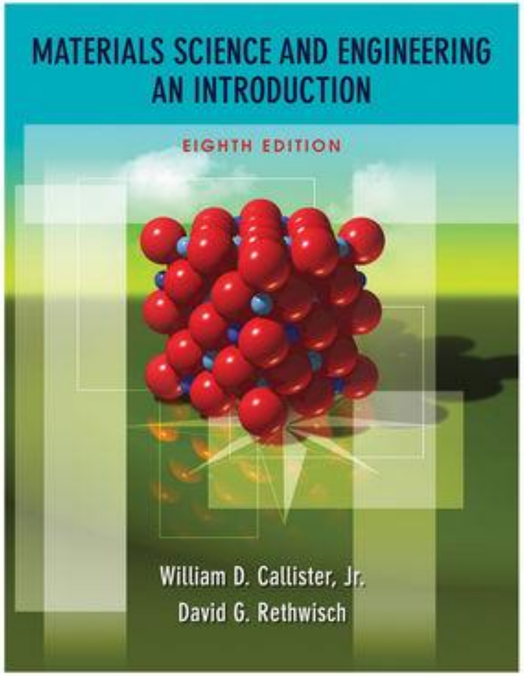
Learning Outcomes

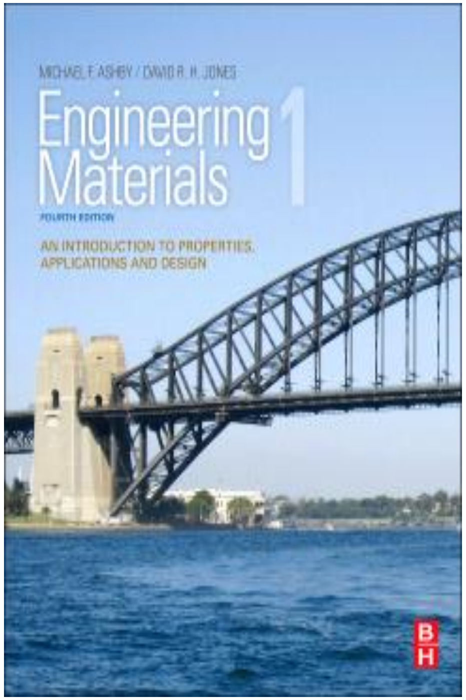
On completion of the course the students will be able to:

- Explain the influences of microscopic structure and defects on material properties, including dislocation and strengthening mechanisms
- Design and control heat treatment procedures to achieve a set of desirable mechanical characteristics
- Understand the applications and processing of common engineering materials including metals & nonferrous alloys, ceramics, polymers, and composites
- Utilize the knowledge in materials selection processes taking further considerations of the economic, environmental and social issues

Textbooks

Materials Science and Engineering:
An Introduction, 8th Edition
William D. Callister, David G. Rethwisch





Engineering Materials 1: An Introduction to Properties, Applications and Design, 4th Edition Michael F. Ashby, D R H Jones

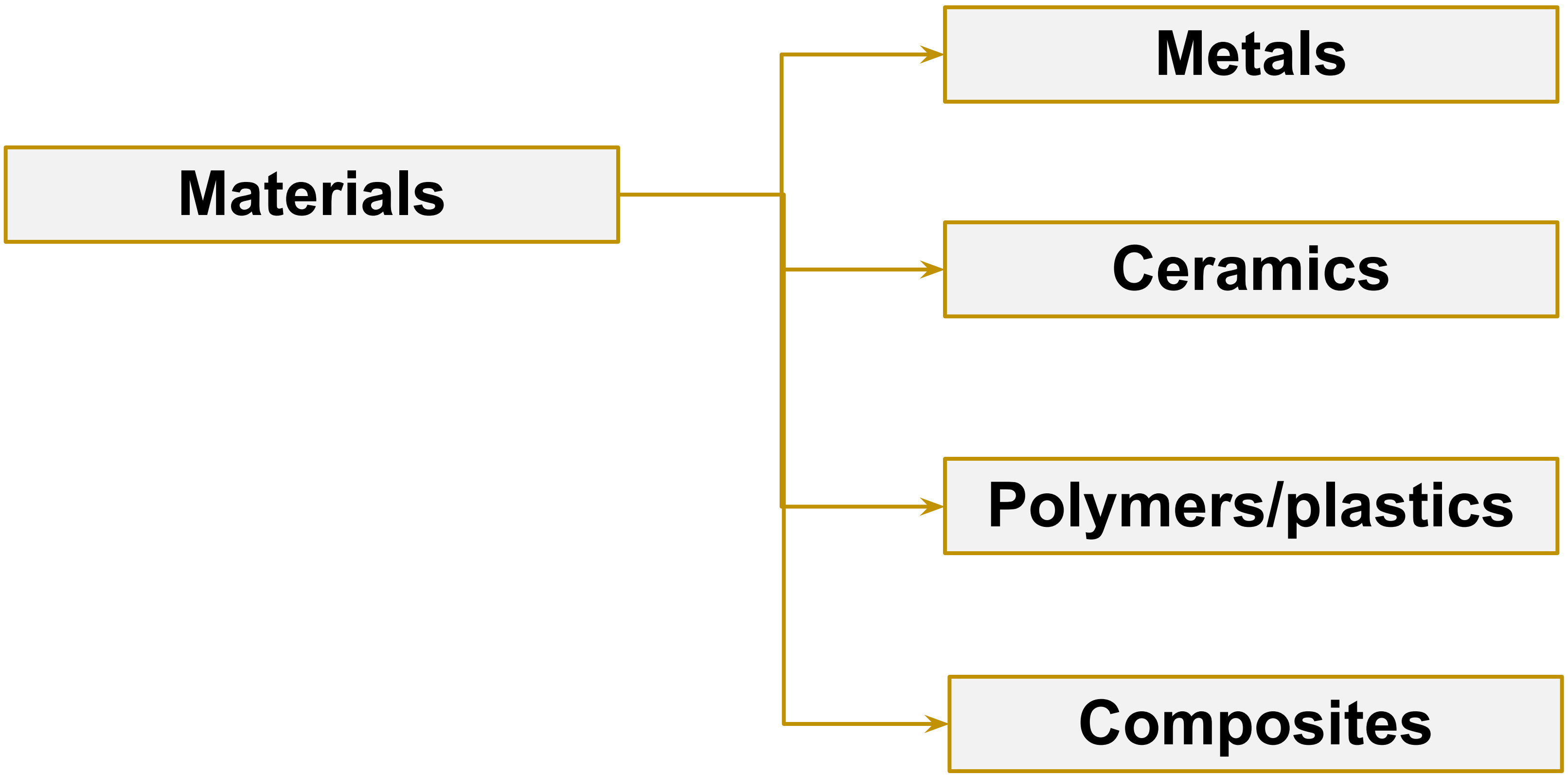
Classification of Materials

Based on functions and applications:

- Aerospace
- Biomedical
- Electronic Materials
- Energy Technology and Environment
- Magnetic Materials
- Optical and Photonic Materials
- "Smart" Materials
- Structural Materials

Classification of Materials

Based on chemical makeup and atomic structure



Properties of Materials

classified on basis of chemical makeup and atomic structure

Metals

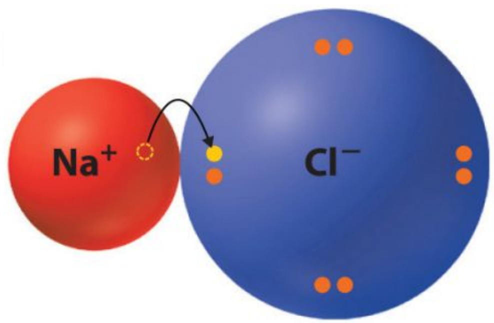
- **Strong, ductile**
- **High thermal conductivity**
- **High electrical conductivity**
- **Not transparent, shiny**

Properties of Materials

classified on basis of chemical makeup and atomic structure

Ceramics

- **Ionic bonding (refractory)**
- **Compounds of metallic & non- metallic elements** (oxides, carbides, nitrides, sulfides)
- **Strong, brittle, may or may not be transparent**
- **Non-conducting (insulators)**



Ionic bond

Complete transfer of one or more valence electrons.
Full charges on resulting ions.

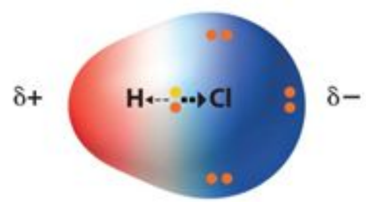
Properties of Materials

classified on basis of chemical makeup and atomic structure

Polymers/plastics:
chains of organic molecules

- **Covalent bonding □ sharing of electrons**
- **Soft, ductile, low strength, low density**
- **Thermal & electrical insulators**
- **Optically translucent or transparent**

Nonpolar covalent bond
Bonding electrons shared equally between two atoms. No charges on atoms.

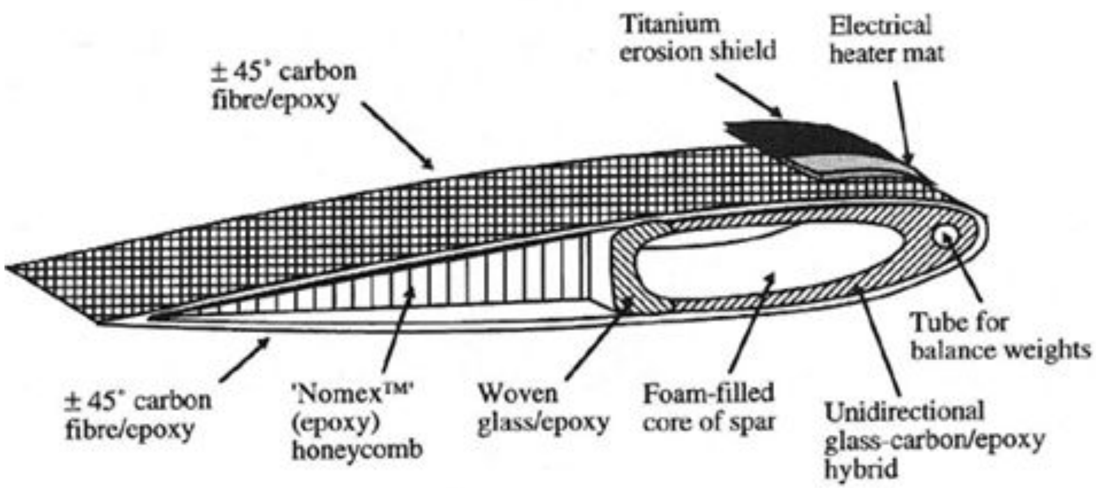


Polar covalent bond
Bonding electrons shared unequally between two atoms. Partial charges on atoms.

Properties of Materials

classified on basis of chemical makeup and atomic structure

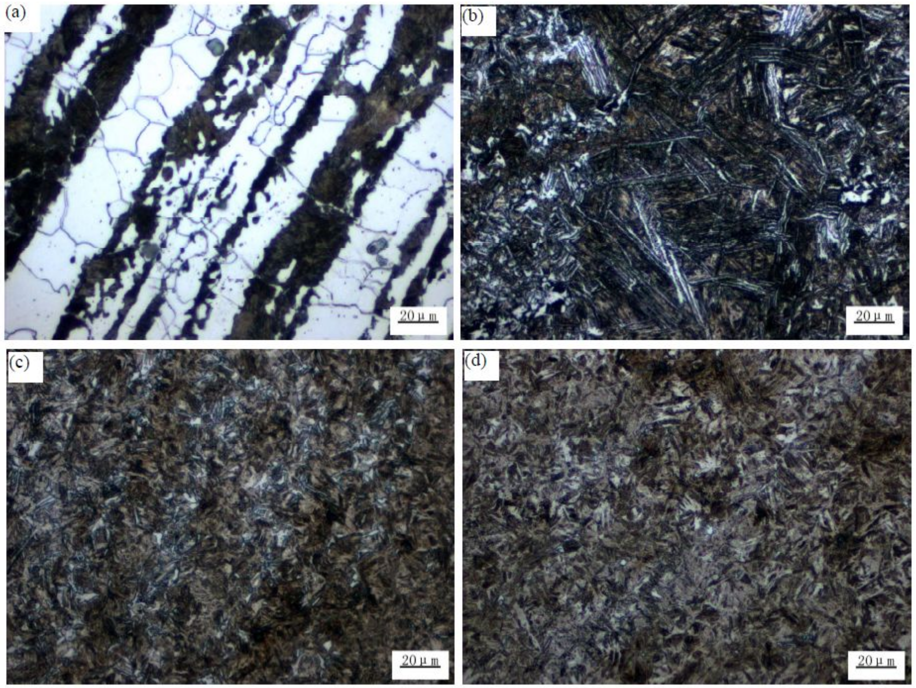
Composites → **Compounds of two (or more) individual materials (metals, ceramics, polymers) with combination of properties**

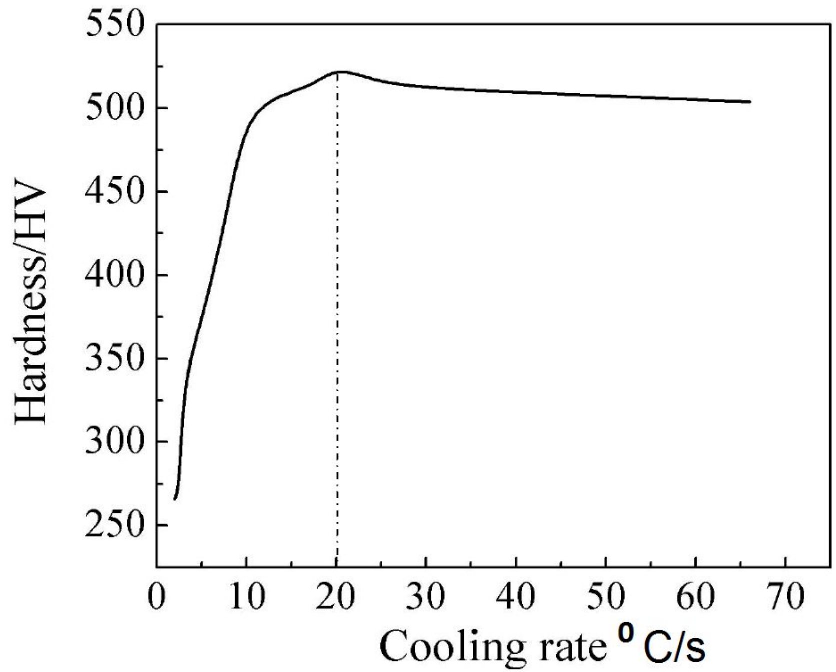


Schematic section through a typical composite construction for a helicopter rotor blade. (Courtesy of Westland Helicopters.)

Structure, Processing, & Properties

- Properties depend on structure, e.g.: steel hardness
- Processing can change structure, e.g.: structure versus cooling rate of steel





Effects of cooling rate on microstructures of bearing-B steel:
(a) 0.5 ℃/s, (b) 5 ℃/s, (c) 8 ℃/s, (d) 20℃/s

Structure, Processing, & Properties

Processing → Structure → Properties → Performance

Different materials should be processed differently; Same materials can be processed differently for different geometries

- Moulding process
- Plastic deformation process
- Joining process
- Mechanical working process
- Heat treatment process

Structure, Processing, & Properties

Processing → Structure → Properties → Performance

Structure can be viewed in different "length" scales

- Sub atomic level –
  e.g. interatomic bonding
- Atomic level –
  e.g. arrangement of atoms
- Microscopic level –
  e.g. grain arrangement seen with microscope
- Macroscopic level –
  e.g. structural elements view with naked eye

Structure, Processing, & Properties

Processing → Structure → Properties → Performance

Property is a material trait in terms of the type and magnitude of response to a specific imposed stimulus.

- Mechanical – response to applied load, e.g. ultimate strength
- Electrical – response to electric field, e.g. resistivity
- Thermal – response to heat, e.g. thermal conductivity
- Magnetic – response to magnetic field, e.g. magnetic permeability
- Optical – response to light, e.g. transparent, translucent, opaque
- Deteriorative – relates to chemical reactivity, e.g. heat treatment can slow crack speed of some alloy in salt water

The Materials Selection Process

1. **Pick Application** → Determine required Properties

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

2. **Properties** → Identify candidate Material(s)

   Material: structure, composition.

3. **Material** → Identify required Processing

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

Materials Selection Considerations

- Cost
- "Green" – environmentally friendly
- Sustainability: e.g. bamboo bicycle frame
- Easily available commercially in large quantities
- Political: e.g. sanctions on nuclear materials
- Technology: e.g. heat shield for space shuttle
- Degradation during service: e.g. corrosion

Module Summary

You will learn in this module about:

- material structure
- how structure dictates properties
- how processing can change structure
- commonly used engineering materials

This module will help you to:

✔ Use the right material for the job.

✔ Understand the relation between properties, structure, and processing.

✔ Recognize new design opportunities offered by materials selection.

Approach

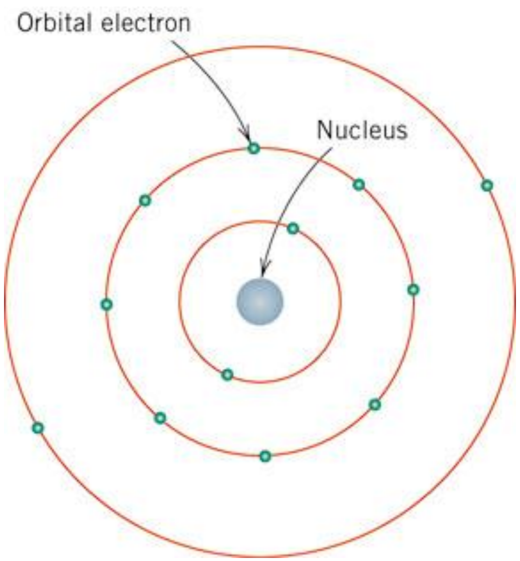
- Study microstructures, starting with the atom, atomic bonding, and how different classes of materials are bonded together
- Look at the effect of composition on microstructure
- Look at the effect of processing on microstructure
- Connect how microstructure relates to properties

We shall first do some revision

Revision - Atomic Structure

ATOM = (PROTONS+NEUTRONS) + ELECTRONS

NUCLEUS



Mass of an atom:

Proton and Neutron: ~ 1.67×10^{-27} kg

Electron: 9.11×10^{-31} kg

Charge:

Electrons and protons: (±) 1.60×10^{-19} C

Neutrons are neutral

Revision - Atomic Structure

Z = Atomic number = number of protons in nucleus
This is used to identify element

N = number of neutrons in nucleus
This is used to identify isotopes, written as ${}^{(Z+N)}X_Z$: (e.g. ${}^{14}C_6$ and ${}^{12}C_6$)
where: A = Atomic mass unit (amu)

1 amu is defined as the 1/12 of the atomic mass ${}^{12}C_6$

Atomic mass of ${}^{12}C_6$ is 12 amu: 6 protons (Z=6) + 6 neutrons (N=6)

This is approximately the total mass of protons + total mass of neutrons

Therefore 1 amu = $Mass_{proton} \sim Mass_{neutron} = 1.67 \times 10^{-27}$ kg
and A = Atomic Mass = Z + N

N_{AV} = 1 mole = 6.023×10^{23} molecules or atoms (Avogadro's number)
Atomic weight is expressed in amu/atom, i.e. 1 amu/atom = 1g/mol

Revision - Mole Concept

$$N_A = N_{AV}\left(\frac{\rho}{M}\right)$$

- N_A = number of atoms per cm^3
- ρ = material density g per cm^3
- M = atomic weight of material g per mole
- N_{AV} = Avogadro's number = 6.023×10^{23}

Revision – Periodic Table

Key: 29 (Atomic number), Cu (Symbol), 63.54 (Atomic weight)

Metal

Nonmetal

Intermediate

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1 H 1.0080																	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											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)

Test Your Understanding?

Compare the number of atoms per cm^3 for Graphite (Carbon) and Diamond (Carbon) given:

- Graphite ρ = 2.3 g per cm^3,
- Diamond ρ = 3.5 g per cm^3;

$$N_A = N_{AV}\left(\frac{\rho}{M}\right)$$

- Graphite $N_A = 11.5 \times 10^{22}$ atoms per cm^3,
- Diamond $N_A = 17.5 \times 10^{22}$ atoms per cm^3;

Any ideas why?

Announcements

Reading:

- Chapter 1 in Materials Science & Engineering for this lecture
- Chapter 2 in Materials Science & Engineering for next lecture

Self-help problems:

- **None**