2019 Fall

Introduction to Materials Science and Engineering

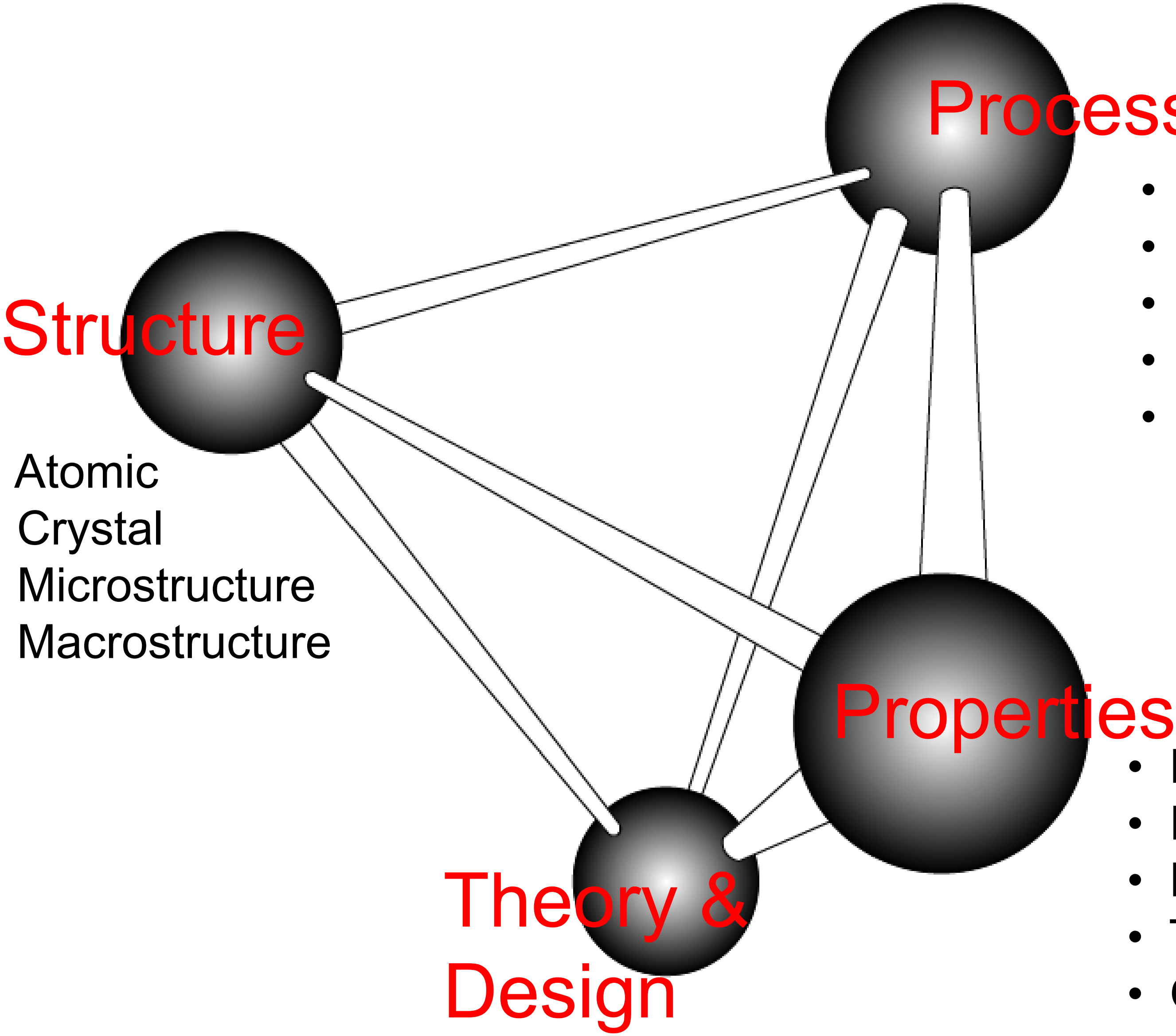
09. 05. 2019

Eun Soo Park

Office: 33-313
Telephone: 880-7221
Email: espark@snu.ac.kr
Office hours: by appointment

Contents for previous class

Materials Science and Engineering



Processing:
- Sintering
- Heat treatment
- Thin Film
- Melt process
- Mechanical

Structure:
- Atomic
- Crystal
- Microstructure
- Macrostructure

Properties:
- Mechanical
- Electrical
- Magnetic
- Thermal
- Optical

Materials Science and Engineering

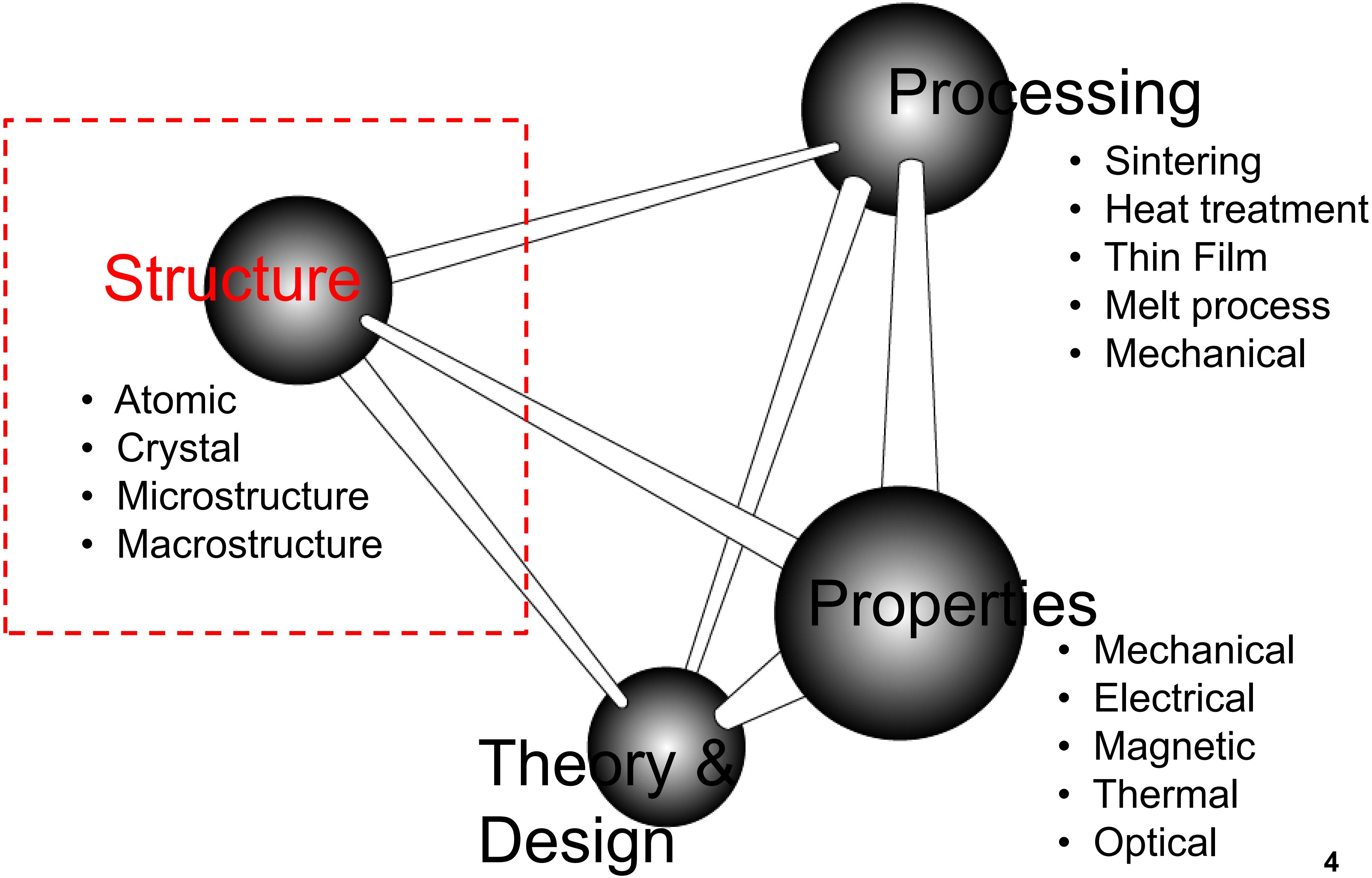
합금설계 + 공정조절 ➡

Microstructure Control of Materials

⬇

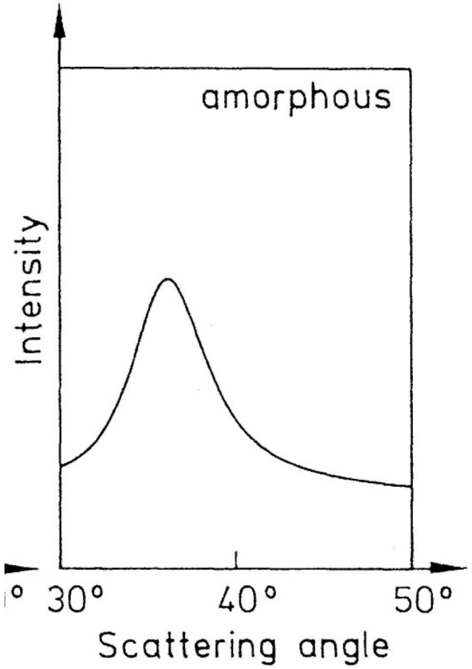
Better Material Properties

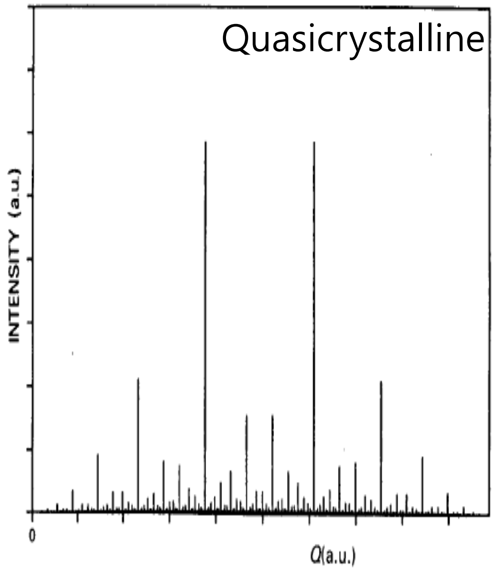
Materials Science and Engineering

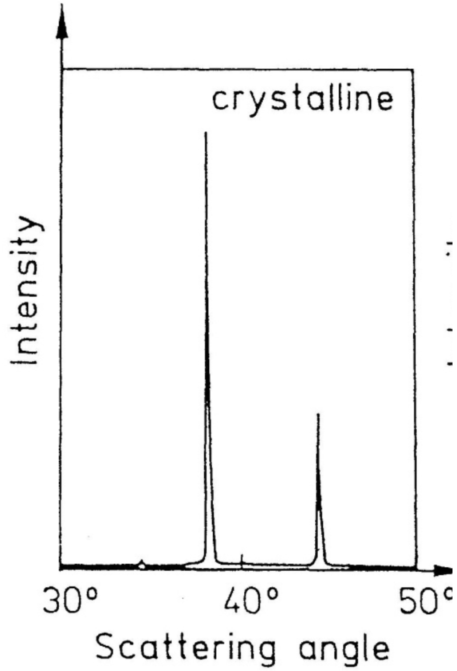


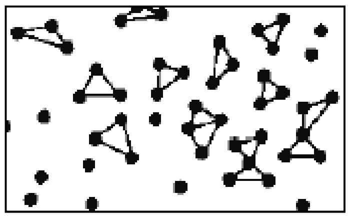
Atomic structure

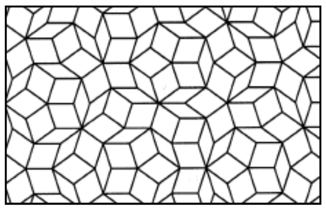
Short-range order ⟷ **Periodic order**

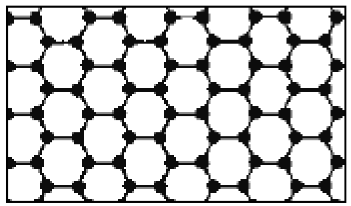






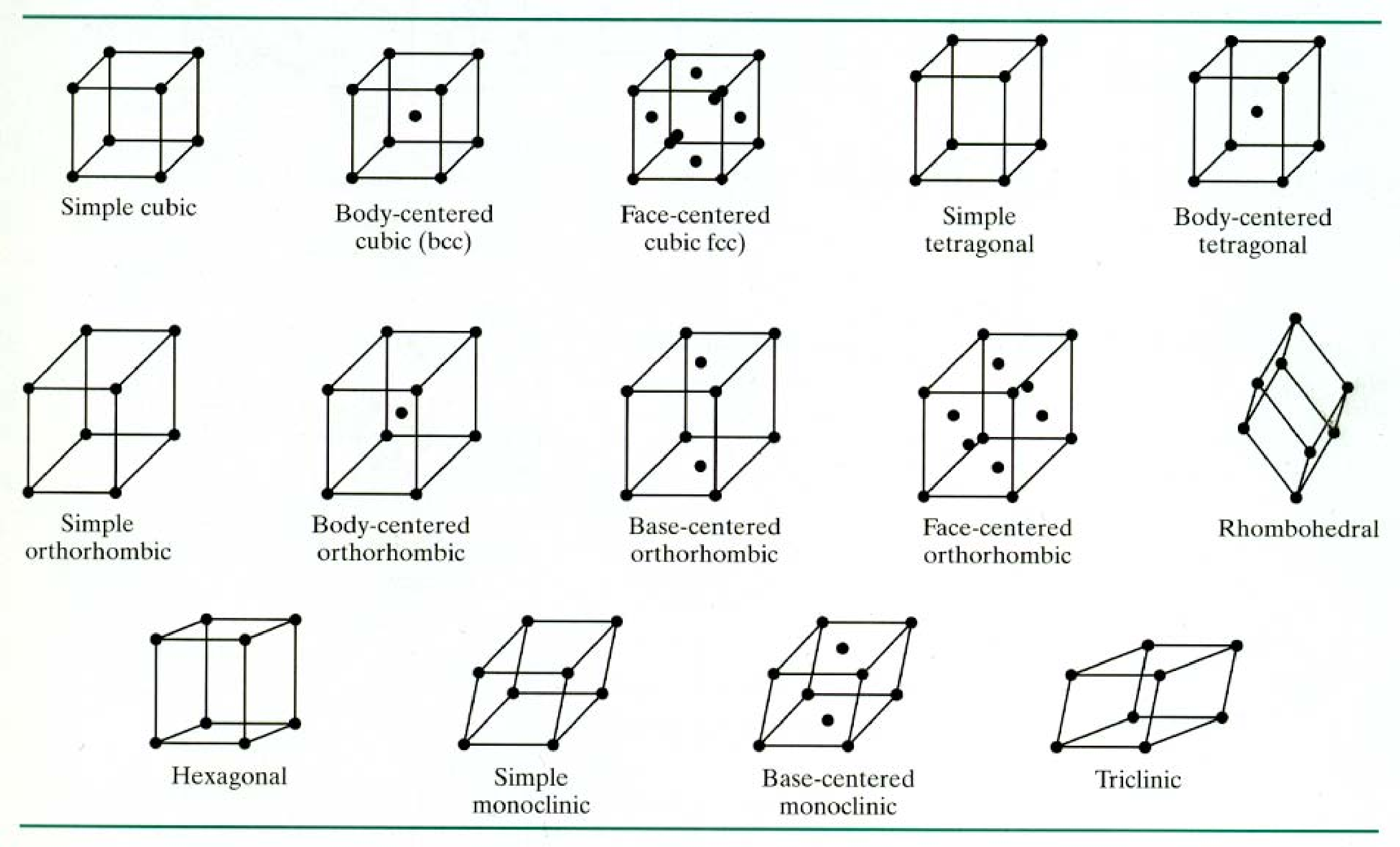






Crystal structure

14 Bravais Lattice



- Only 14 different types of unit cells are required to describe all lattices using symmetry
- simple (1), body-centered (2), base-centered (2) face-centered (4 atoms/unit cell)

What is microstructure?

Microstructure originally meant the structure inside a material that could be observed with the aid of a microscope.

In contrast to the crystals that make up materials, which can be approximated as collections of atoms in specific packing arrangements (crystal structure), microstructure is the collection of defects in the materials.

What defects are we interested in?

Interfaces (both grain boundaries and interphase boundaries), which are planar defects,

Dislocations (and other line defects), and

Point defects (such as interstititals and vacancies as well as solute atoms in solution)

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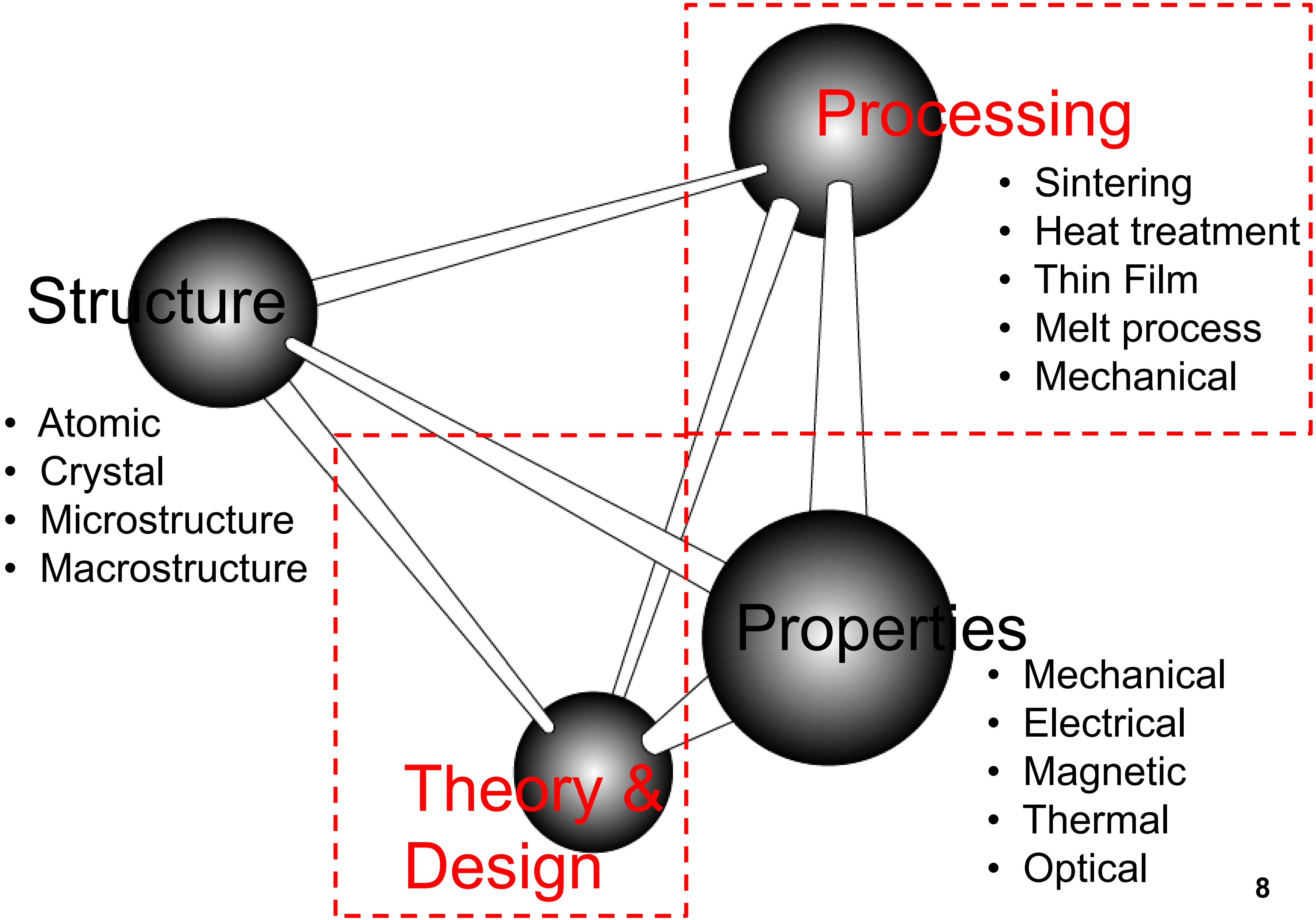


Important!!!

Understanding and *Controlling*

Phase Transformation of Materials

Phase Transformation

- **Solidification: Liquid → Solid**

- **Phase transformation in Solids**

  1) Diffusion-controlled phase transformation ;

  Generally long-distance atomic migration

  - Precipitation transformation
  - Eutectoid transformation (S → $S_1 + S_2$)
  - etc.

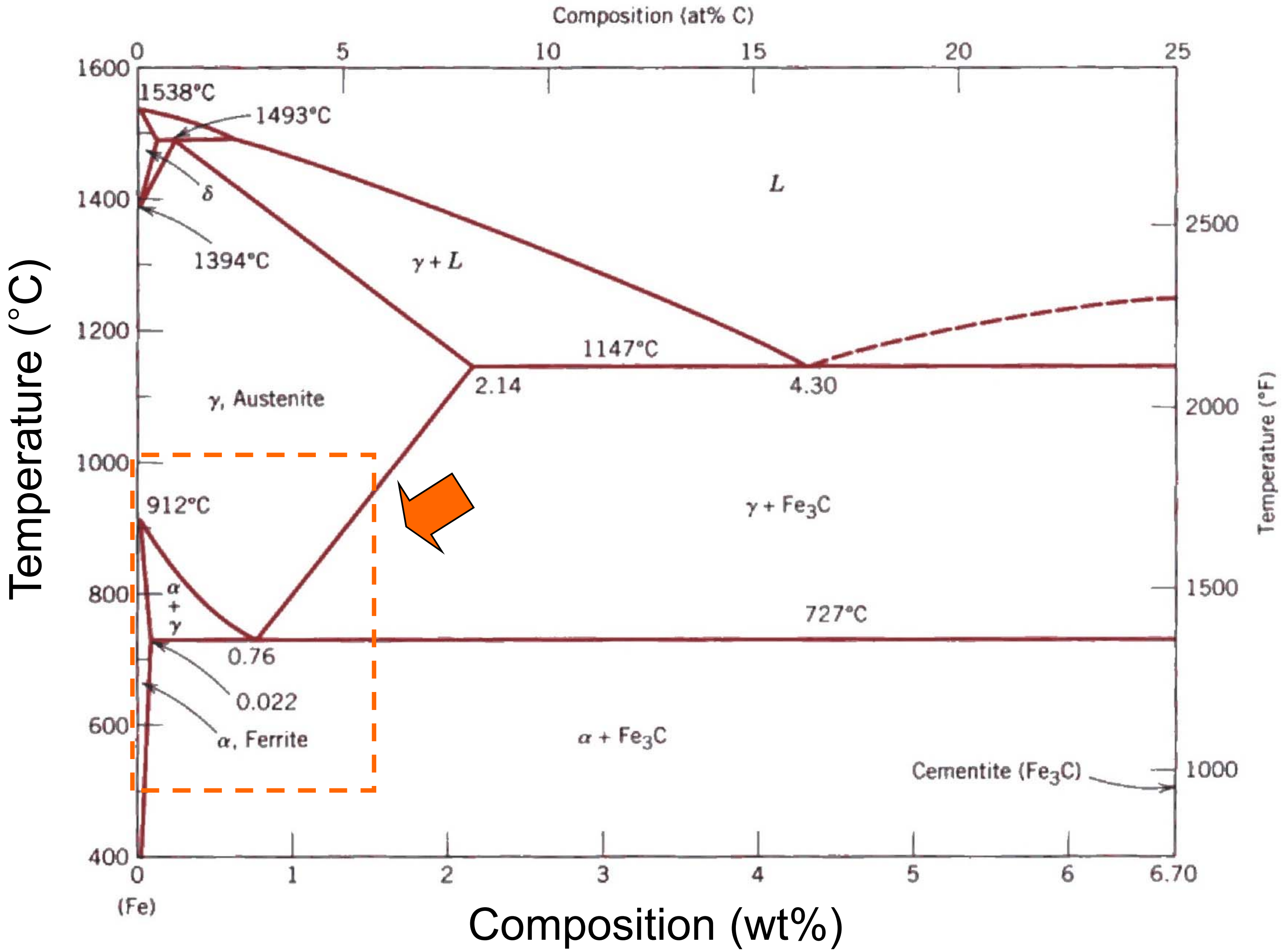
  2) Diffusionless transformation ;

  Short-distance atomic migration

  - Martensitic transformation

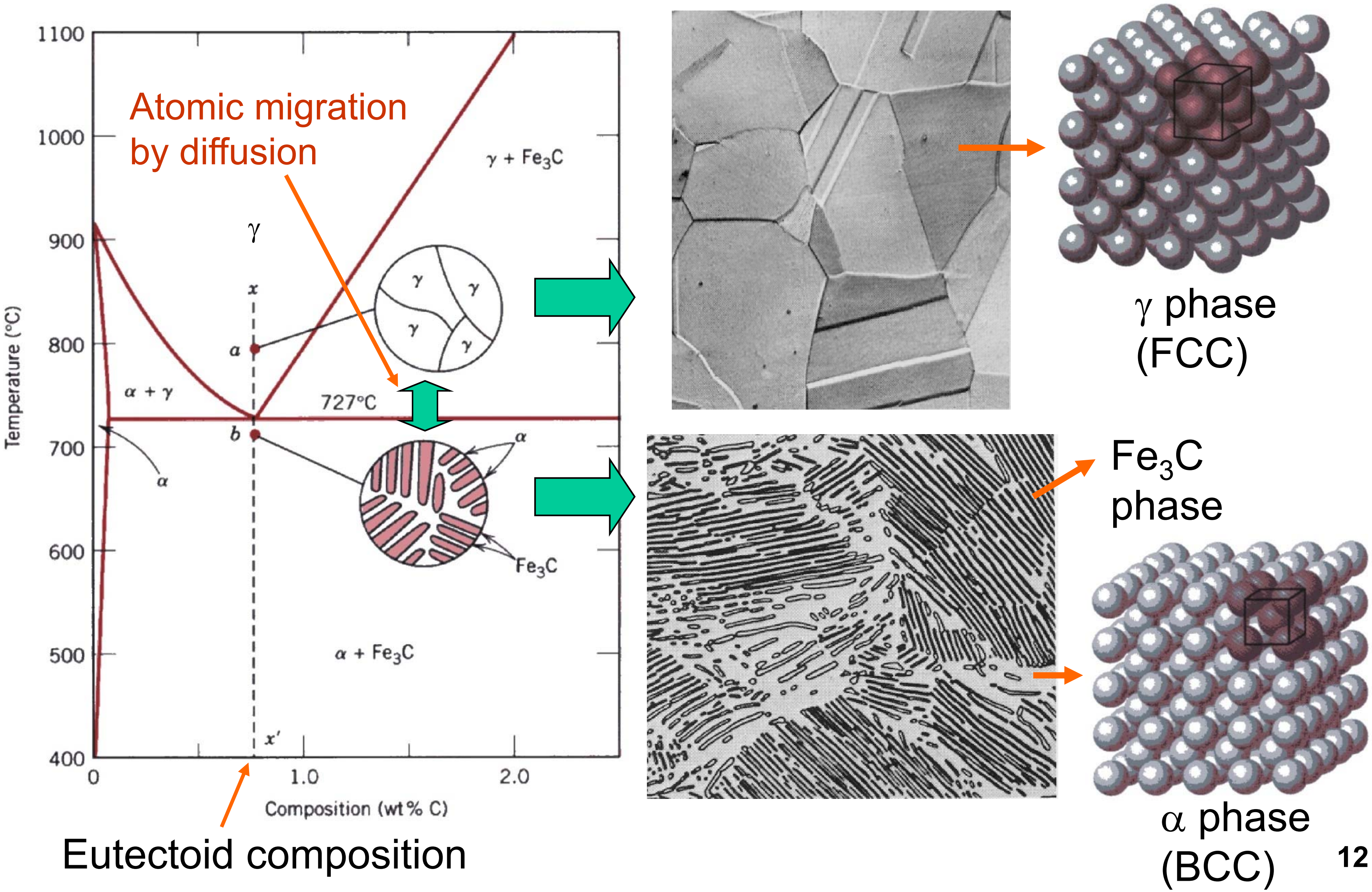
미세구조 조절: 2) Secondary phase control during solidification

Phase Diagram of Iron–Carbon Alloy



미세구조 조절: 2) Secondary phase control during solidification

Equilibrium Phases of Iron-Carbon Alloy



Diffusion-Controlled Phase Transformation
time dependency

↓

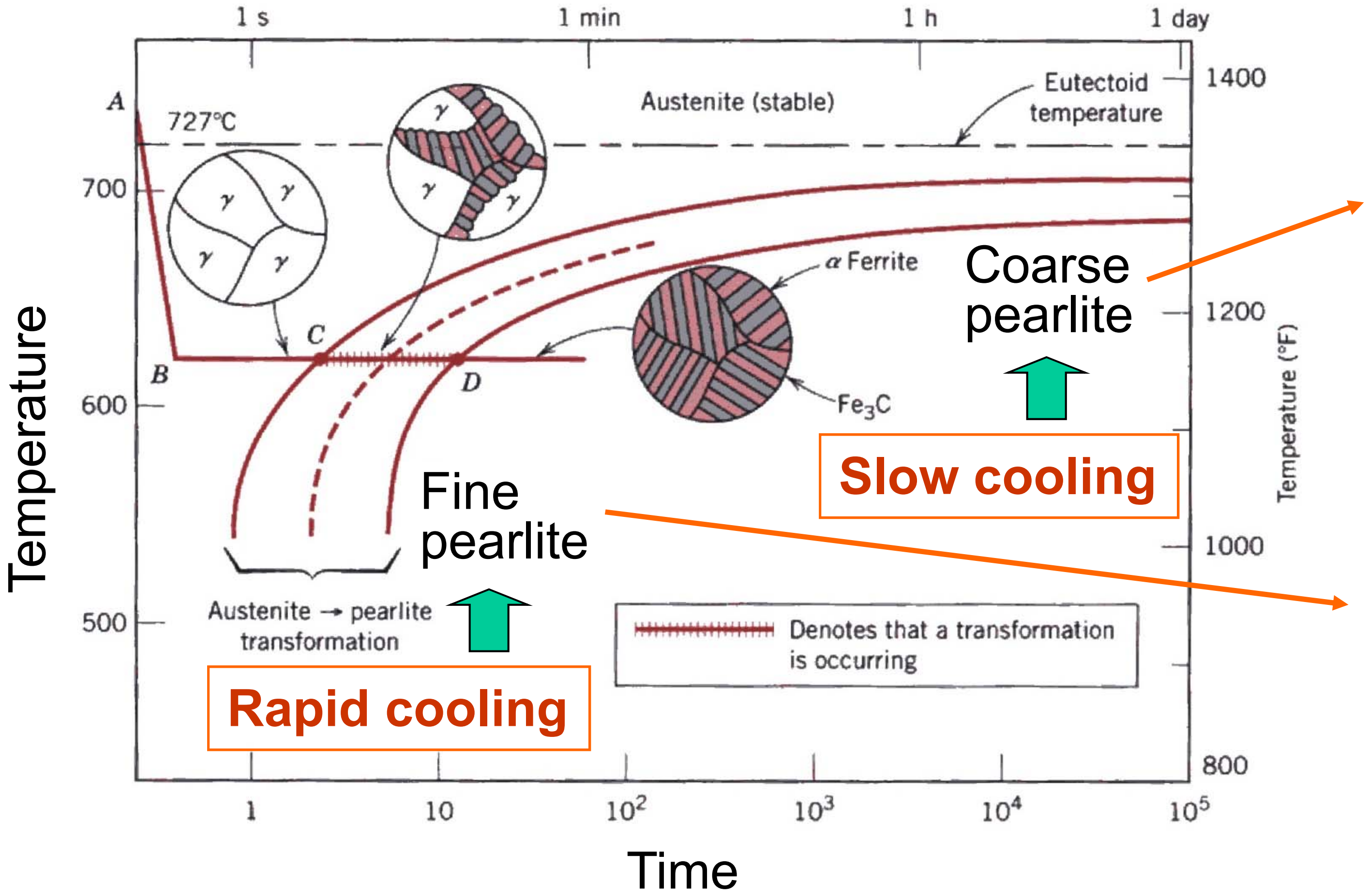
Non-Equilibrium Phases

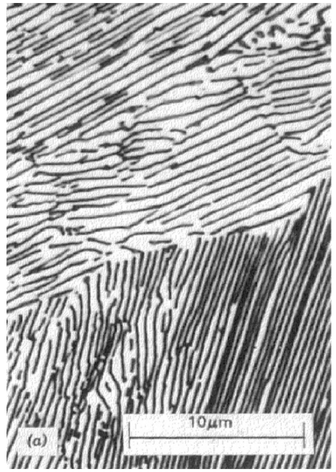
↓

Need of Controlling
not only *Temperature* & *Composition*
but *Process conditions* (Cooling Rate)

Isothermal Transformation Diagram of a Eutectoid Iron-Carbon Alloy

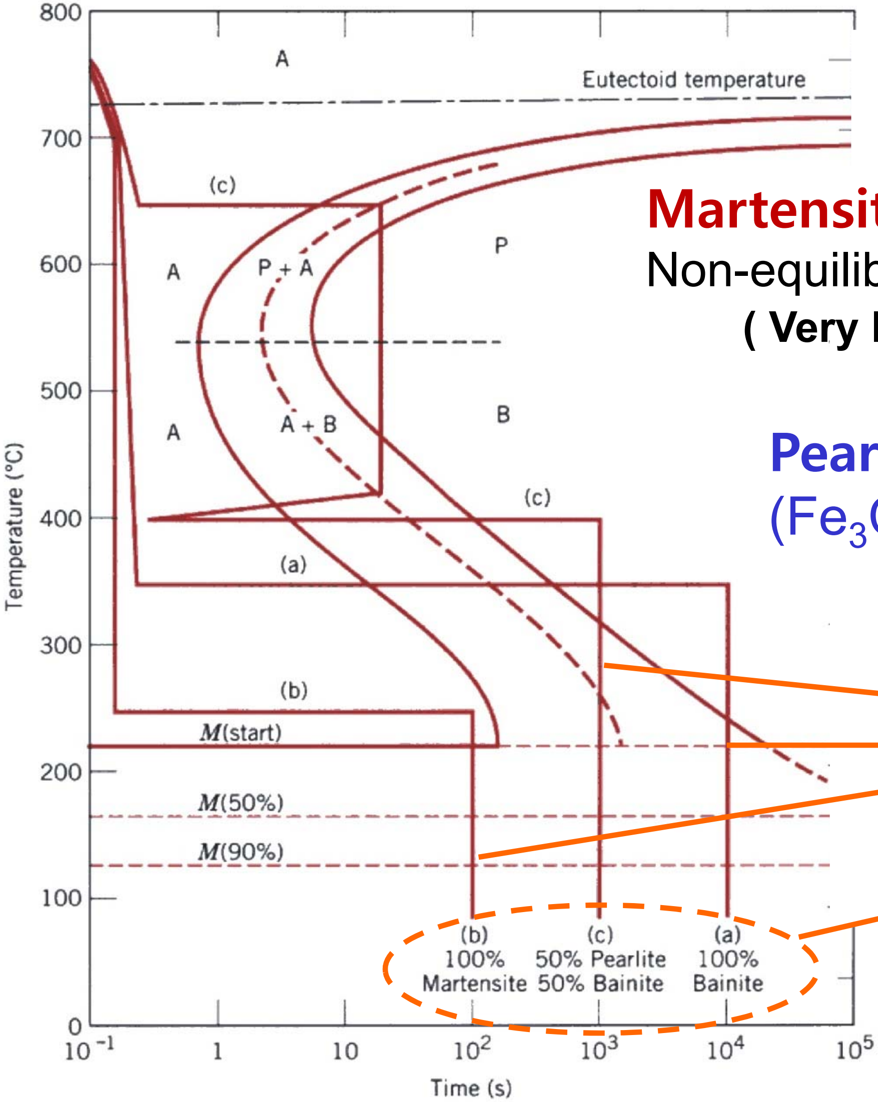
γ Austenite ➡ α Ferrite + Fe_3C graphite





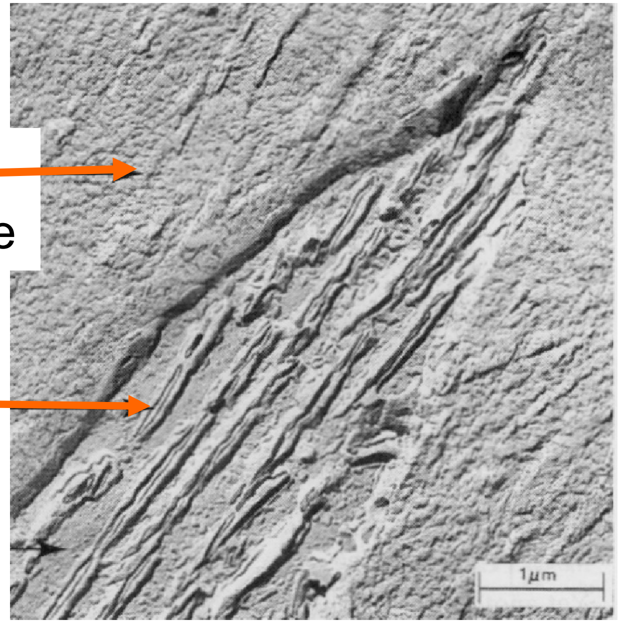
➡ ***Phase Transformation* 제어를 통한 *microstructure*의 조절 가능**

Control of Phases by Heat Treatment



Martensite ;
Non-equilibrium phase
(Very hard)

Pearlite
(Fe_3C+ferrite)



Heat Treatment 공정조절

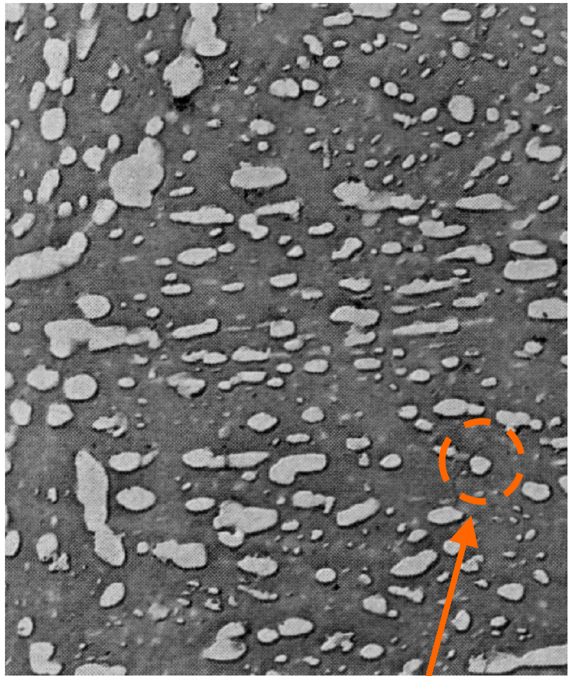
Phase & Microstructure

Properties of Material

Control of Mechanical Properties by Proper Heat Treatment in Iron-Carbon Alloy

공정조절

Proper heat treatment (tempering)



Martensite

- Tip of needle shape grain
- ⇒ Nucleation site of fracture
- ⇒ Brittle

Tempered martensite

- ⇒ Very small & spherical shape grain
- ⇒ Good strength, ductility, toughness

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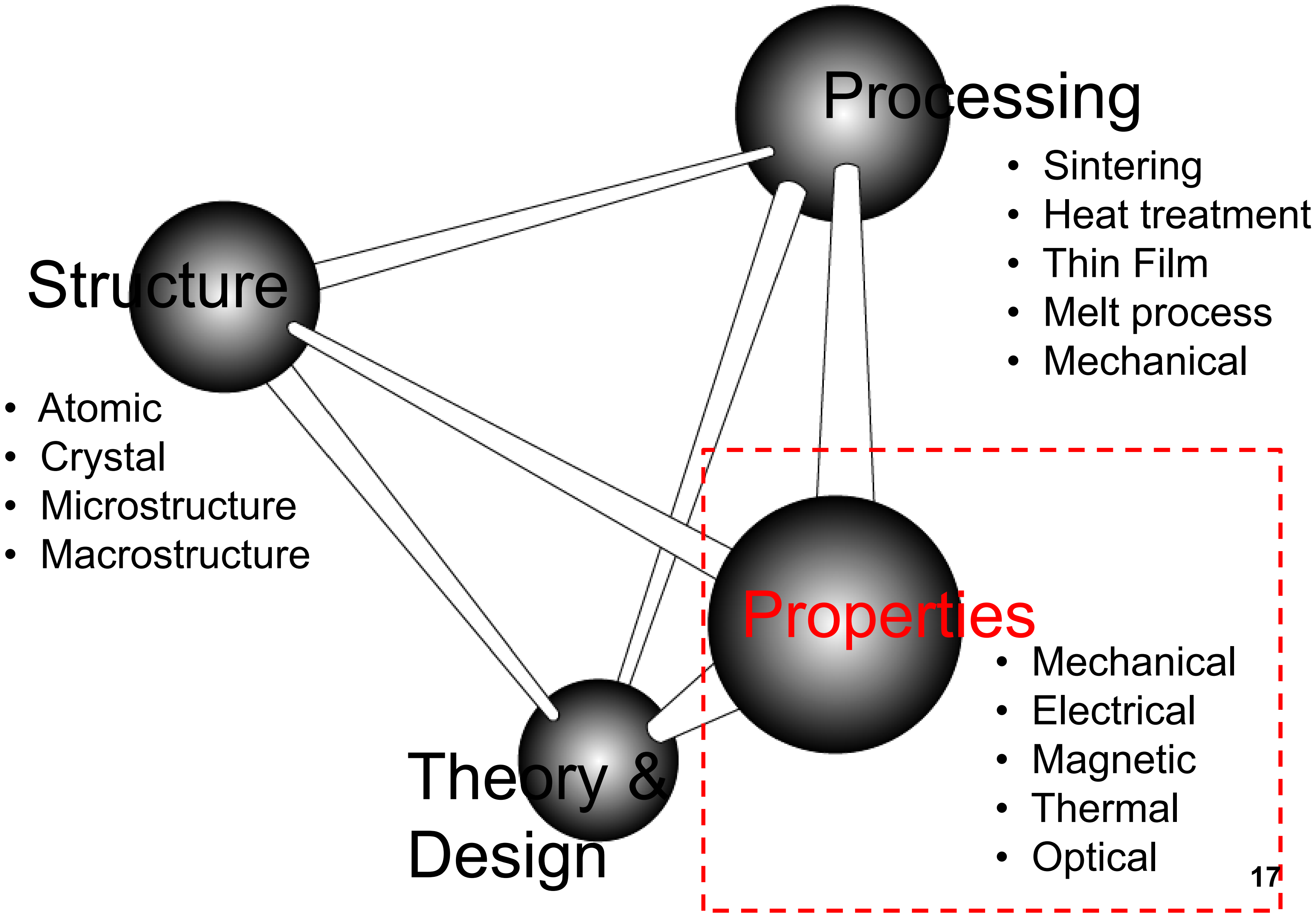
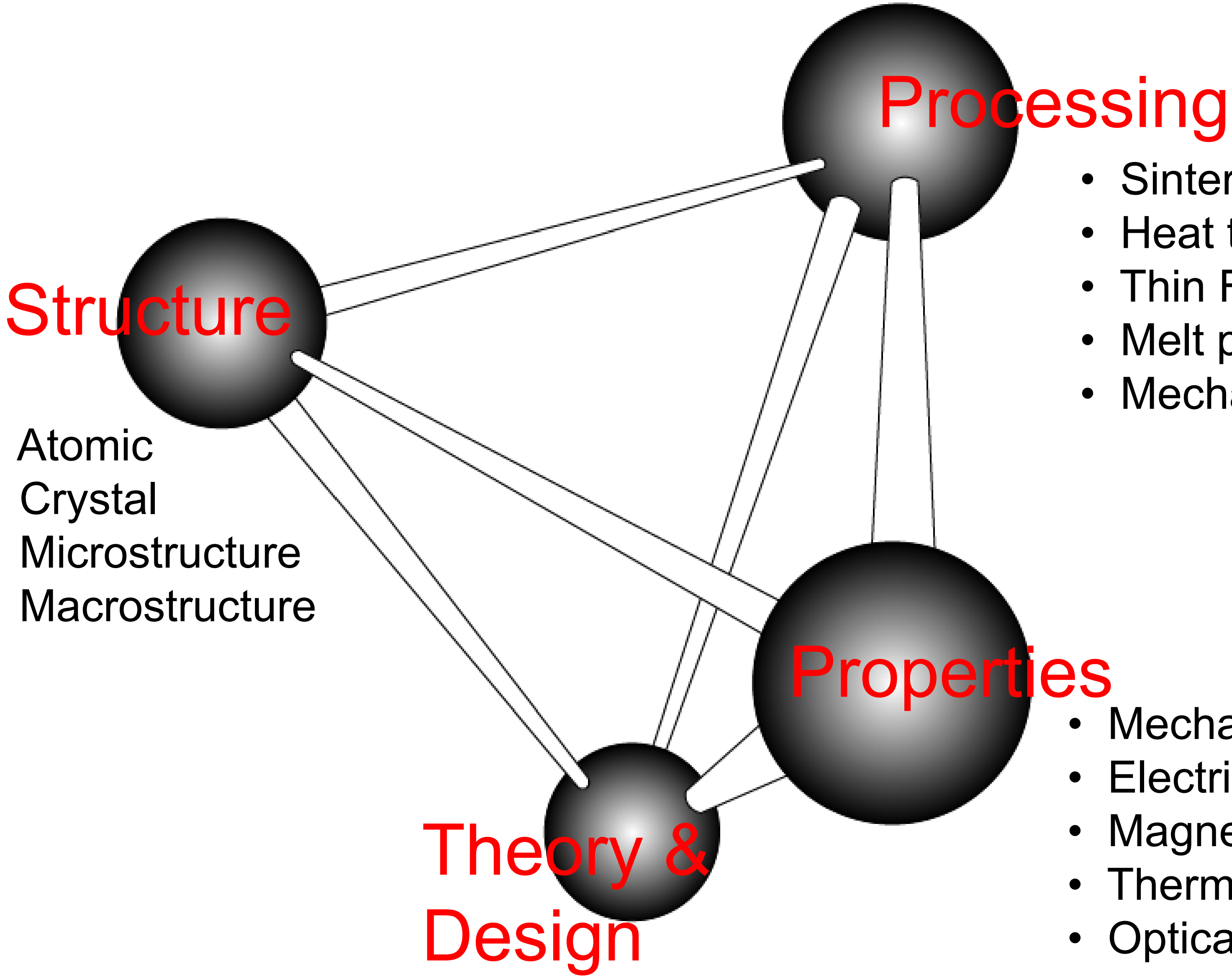


High performance materials

- High/low temperature
- High specific strength (strength/weight)
- High electrical performance
  - High/low dielectric, Ferroelectric, Superconductor
- Nano materials
- Bio-materials
- High performance coatings
- Structural materials
- Optical materials (LED, OLED, Fluorescent)
- Magnetic/Superconducting materials
- Materials are involved in everywhere…. You name it,…

Contents for previous class

Materials Science and Engineering



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창의와 도전 – "미래를 여는 연금술사"

차시별 강의 계획			
회차	수업 일시 (강의 장소)	주제 또는 수업 내용	수강생 활동 및 활용자료
1차	9월 3일(화) 17:00~18:30 33동 230호	금속, 인류의 역사와 함께하다! 역사 속 금속 이야기	수업자료
2차	9월10일(화) 17:00~18:30 33동 230호	**Alloying: Understanding the Basics**	수업자료
3차	9월17일(화) 17:00~18:30 33동 230호	분임 토의	팀 구성 및 각 도전주제 합금설계 브레인스토밍
4차	9월24일(화) 17:00~18:30 33동 230호	각 팀별 연구계획발표	모든 팀원 협동 발표
5차	10월15일(화) 17:00~18:30 33동 230호	각 팀별 합금 제조	모 원소 준비/ 아크 용해 주조 실험
6차	10월29일(화) 17:00~18:30 33동 230호	제조 시편의 미세구조 분석 I	시편 전처리/ 광학현미경 관찰
7차	10월30일(수) 17:00~18:30 33동 230호	제조 시편의 미세구조 분석 II	전자현미경 관찰 실험
8차	11월05일(화) 17:00~18:30 33동 230호	제조시편 기초 물성 분석	X-선 회절분석, 경도 등 실험
9차	11월12일(화) 17:00~18:30 33동 230호	제조시편 타겟 물성 분석	타겟 물성 평가 실험 (강도, 연신 등)
10차	11월26일(화) 17:00~18:30 33동 230호	최종연구결과 발표 및 토의	개발 합금의 미래첨단기술 적용 아이디어 제안 포함

Schedule

week 1 *Introduction*

week 2 *Atomic Structure and Interatomic Bonding* (Chap. 2)

week 3 *Fundamentals of Crystallography* (Chap. 3)

week 4 *The Structure of Crystalline Solids* (Chap. 4)

week 5 *Imperfections in Solids* (Chap. 6)

week 6 *Diffusion* (Chap. 7) & *Mid-term*

week 7 *Mechanical Properties of Metals* (Chap. 8)

week 8 *Dislocations and Strengthening Mechanisms* (Chap. 9)

week 9 *Failure* (Chap. 10)

week 10 *Phase Diagram* (Chap. 11)

week 11 *Phase Transformation* (Chap. 12)

week 12 *Polymer Structures* (Chap. 5)

week 13 *Characteristics, Applications, and Processing of Polymers* (Chap. 15)

week 14 *Functional Polymers* (Chap. 16)

week 15 *Presentation of Team project and Final Exam*

CHAPTER 2: BONDING AND PROPERTIES

ISSUES TO ADDRESS...

- What promotes bonding?
- What types of bonds are there?
- What properties are inferred from bonding?

Contents for today's class

Atomic Structure

2.2 **Fundamental concepts**

2.3 **Electrons in atoms**

: atomic models, Quantum #s, Electron configurations

2.4 **Periodic table**

Atomic Structure (Freshman Chem.)

- atom – electrons – 9.11×10^{-31} kg
  protons
  neutrons } 1.67×10^{-27} kg
- atomic number = # of protons in nucleus of atom (Z)
  = # of electrons of neutral species (N)
- atomic mass unit (A≈Z+N) = amu = 1/12 mass of ^{12}C

  Atomic wt = wt of 6.023×10^{23} molecules or atoms

  1 amu/atom = 1g/mol

  C 12.011 A H 1.008 A
  Fe 55.85 amu/atom = **55.85 g/mol** etc.
- isotope same Z, but different N: two or more different A

Atomic Structure

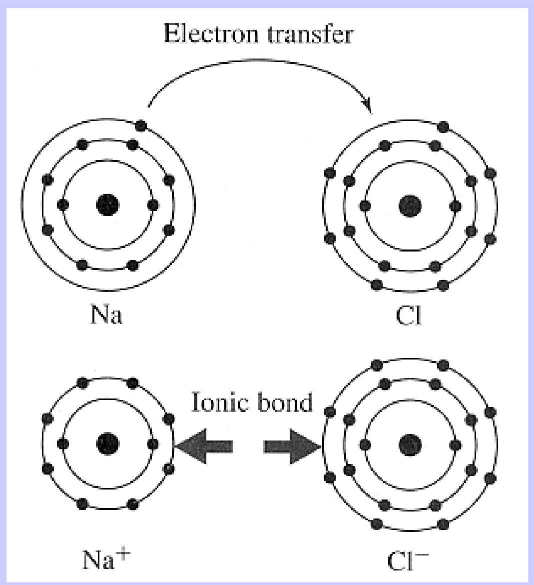
- Valence electrons determine following properties

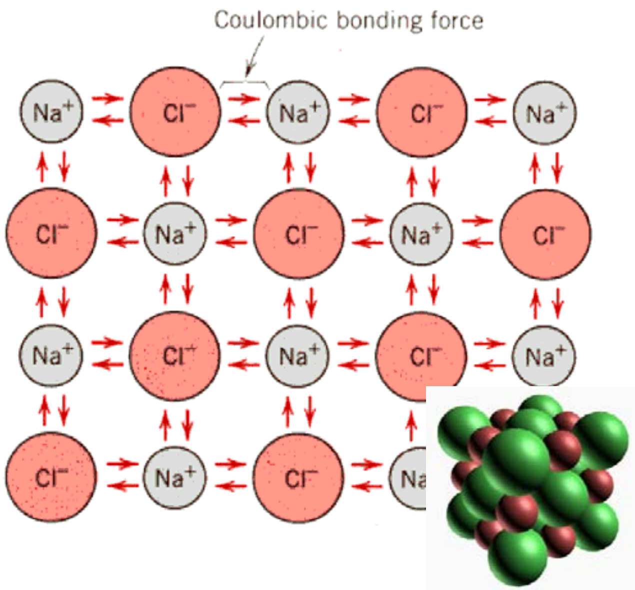
  1) Chemical
  2) Electrical
  3) Thermal
  4) Optical
  5) Mechanical

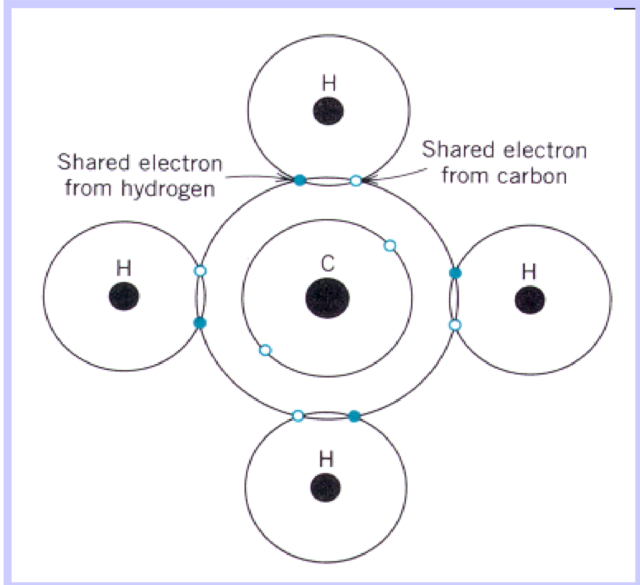
Fundamental Concepts

➢ Atomic Bonding

❖ It involves the <u>transfer or sharing of electrons</u> between atoms, resulting in electrostatic or mutual attractions.







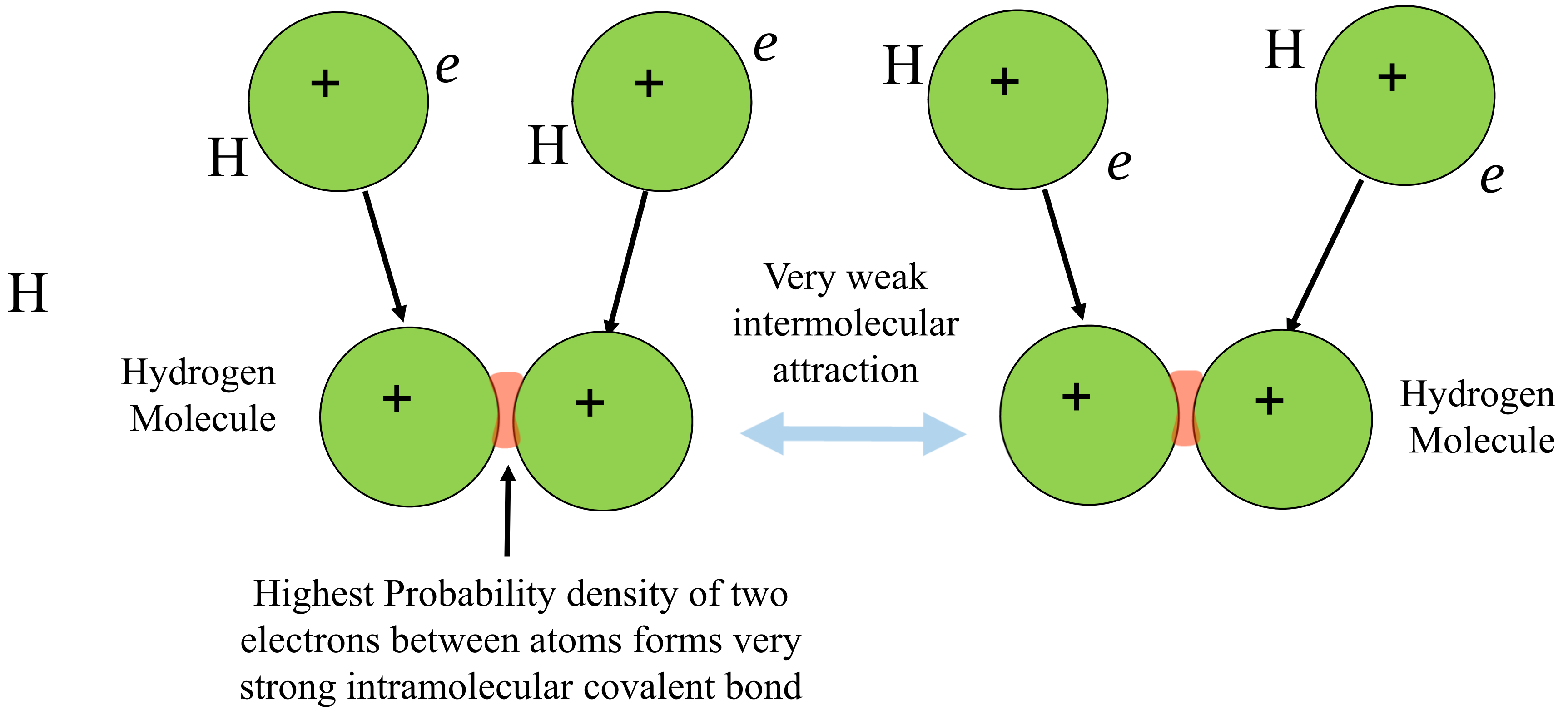
❖ atomic structures & electronic configurations are important ingredients to understanding bonding.

Fundamental Concepts

❑ Two fundamental types of bonding:

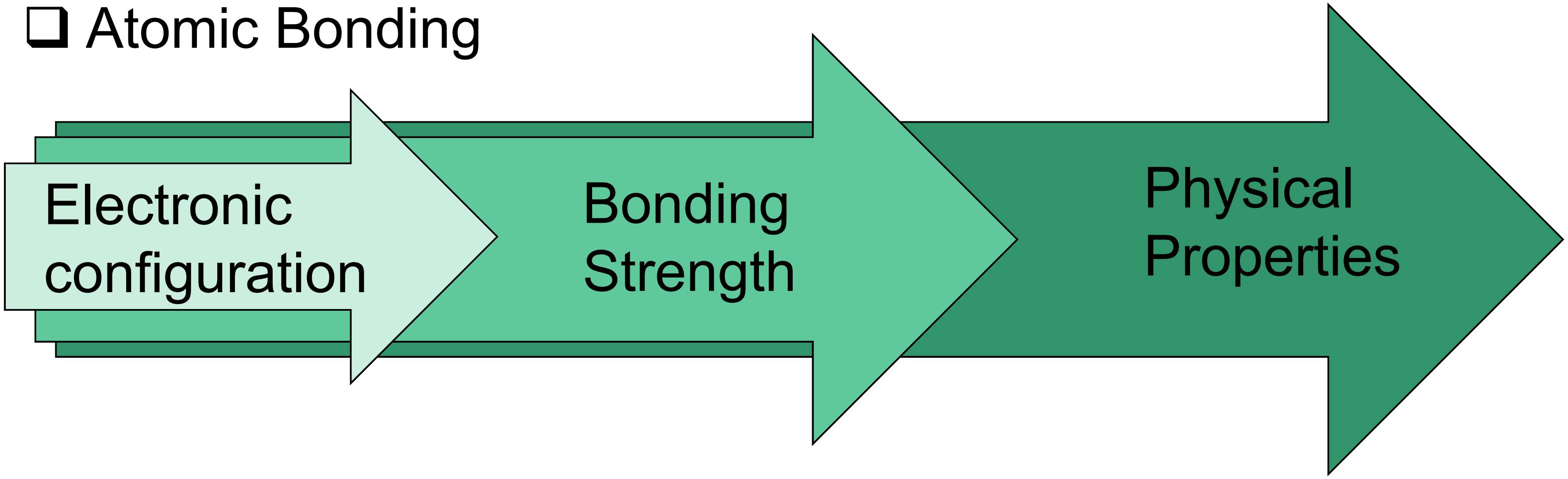
❑ **primary bonds**: strong atom-to-atom attractions produced by changes in electron position of the ***valence*** e^-. *Example : covalent atom between two hydrogen atoms*

❑ **secondary bonds**: much weaker. It is the attraction due to overall "electric fields", often resulting from electron transfer in primary bonds. *Example: intramolecular bond between* H_2 *molecules* ➔ ***gas***



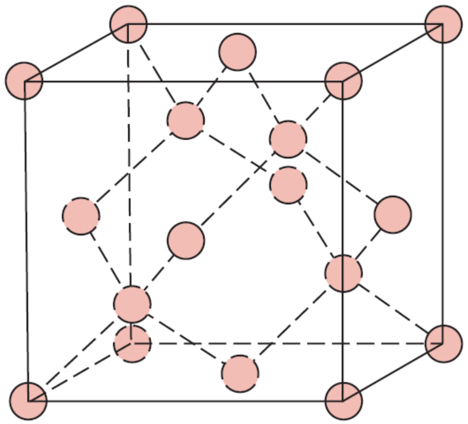
Fundamental Concepts

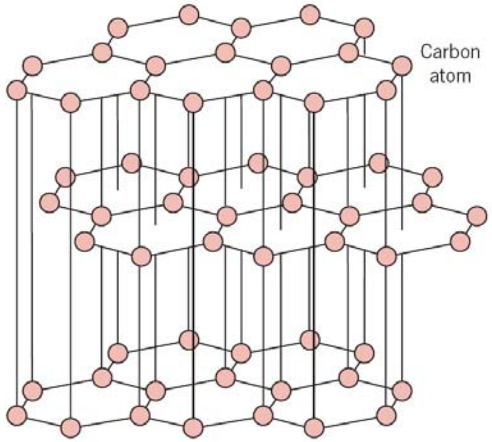
- Atomic Bonding



- Example: carbon exists as ***graphite*** (soft with greasy feeling) or ***diamond*** (hardest known material)

graphite

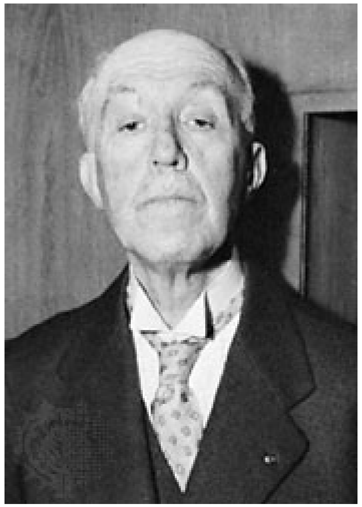




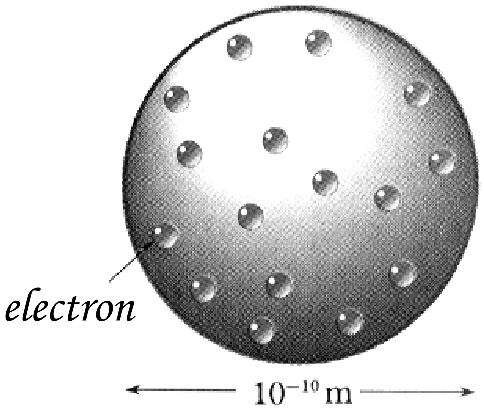
diamond

Early atomic model

- 1858 : cathode ray identified by Pluker
- 1869 : negative charge of cathode ray identified by Hittorf
- 1874 : momentum of cathode ray detected by Crookes
- 1876 : cathode ray named by Goldstein
- 1890 : electron named by Stony
- 1897 : properties of cathode ray ➔ particle-like electron by J. J. Thomson



Louis-Victor Broglie
1958

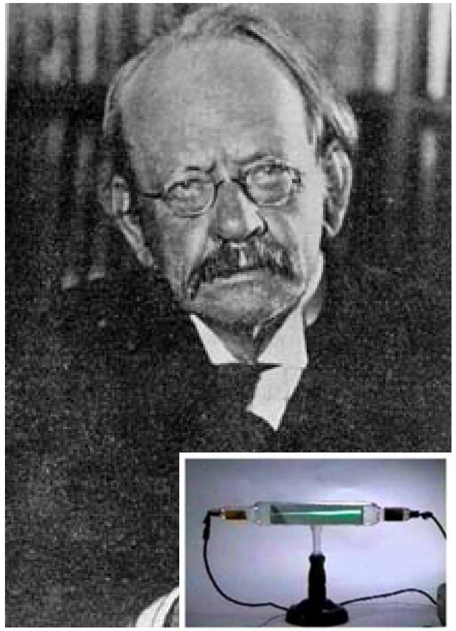


Photoelectric effect – particle
Diffraction – wave like

Sir George Paget Thomson

(1895-1975),
Nobel Prize in 1937

Thomson, Sir Joseph John

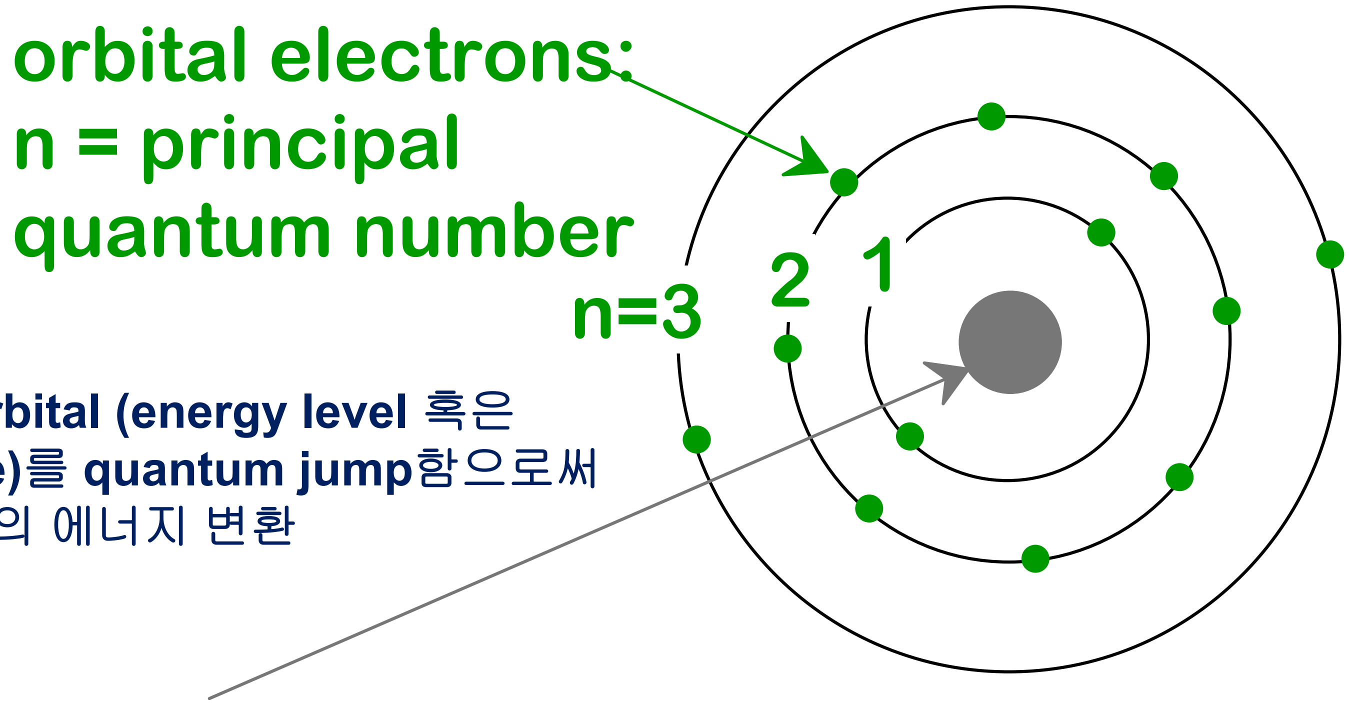


(1856-1940),
Nobel Prize in 1897

Bohr Atom:

전자는 정해진 궤도를 가지고 원자주위를 돌고 있다고 가정

(원자내 전자의 위치_'전자궤도'와 에너지_'양자화된 에너지 수준'을 설명)



각 **orbital (energy level** 혹은 **state)**를 **quantum jump**함으로써 전자의 에너지 변환

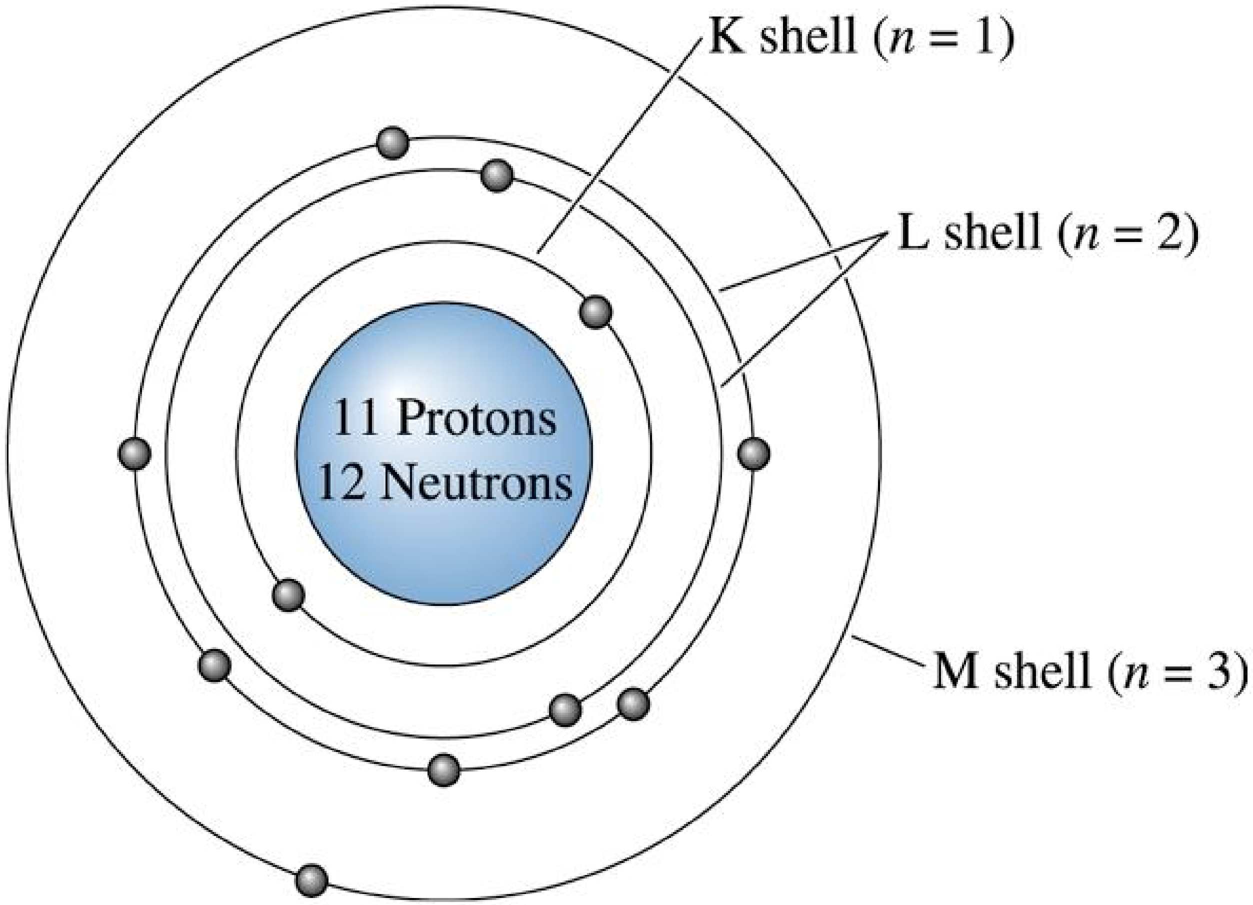
Nucleus ; Z = # protons

= 1 for hydrogen to 94 for plutonium

N = # neutrons

Atomic mass A ~ Z + N

Atomic structure of sodium (Na)

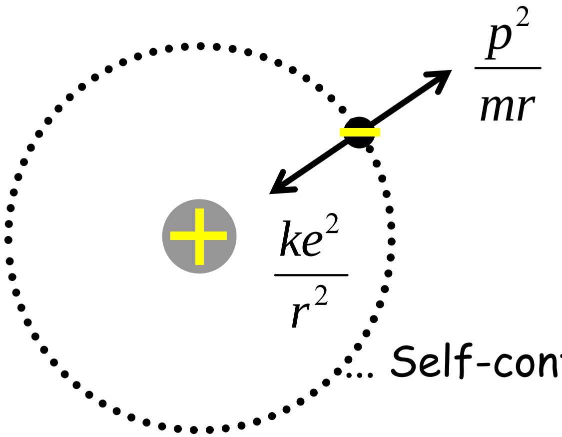


Bohr Atom

- electrons & protons are electrically charged: 1.60×10^{-19} C (기본전하)
- mass-proton = mass-neutron = 1.67×10^{-27} kg
- mass-electron = 9.11×10^{-31} kg
- atomic number (Z) = # protons
- atomic mass (A) = mass-protons (Z) + mass-neutrons (N)
- # of protons: same for all atoms of an element
- # of neutrons is variable ⇨ “isotopes” (elements with 2 or more atomic masses)
- atomic weight = weighted average of the atom’s isotopes
- the atomic weight of an element may be specified as mass/mole of material
  - 1 amu = 1/12 atomic mass of carbon 12 (^{12}C)
  - 1 mole = 6.023×10^{23} (Avogadro’s number) atoms or molecules
  - 1 amu/atom (or molecule) = 1 g/mol

Limitations in Bohr's model

... Classic mechanical theory was employed ...

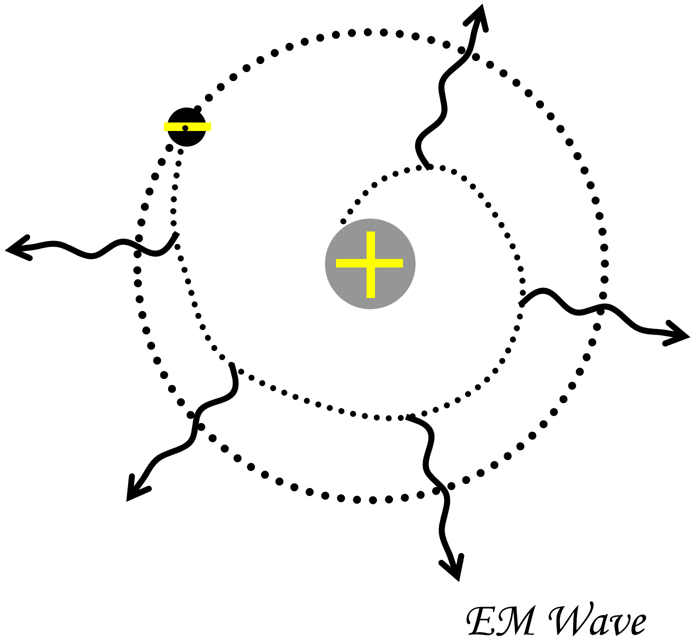


... What if there are more than two electrons ? ...

... Quantum condition fails ...

... Self-contradiction in terms of Heisenberg uncertainty principle ...

$$(\Delta p)(\Delta x) \geq \frac{h}{4\pi}$$



✓ Circumferential motion of charged particles should emit <u>EM wave</u>

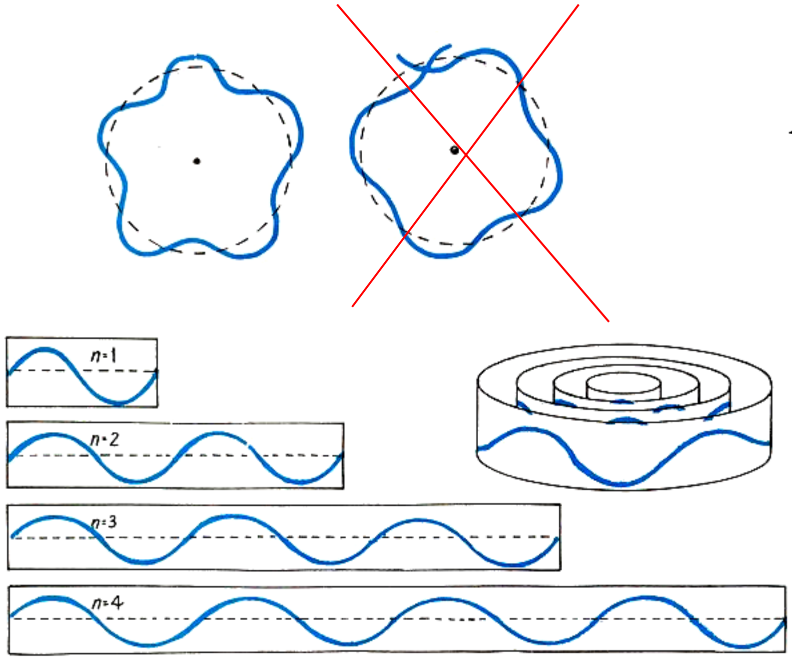
✓ Discontinuous emission spectra cannot be understood

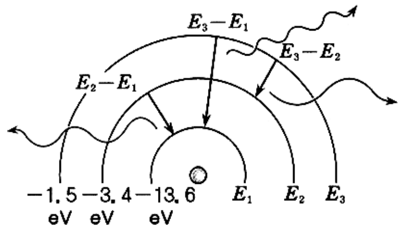
Bohr's model + Wave-mechanical model

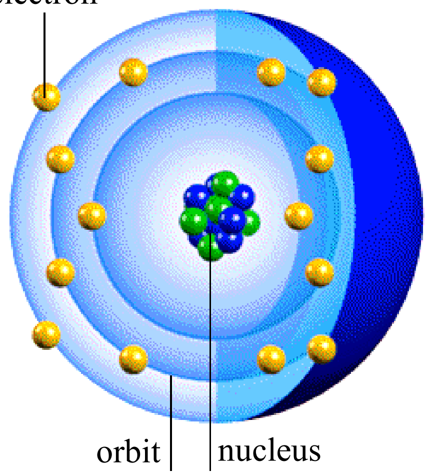
To resolve the discontinuous emission spectra...

... Therefore, in discussing the motion of an electron of known energy or momentum about a nucleus, it is necessary to speak only in terms of <u>the probability of finding that electron at any particular position</u> ...

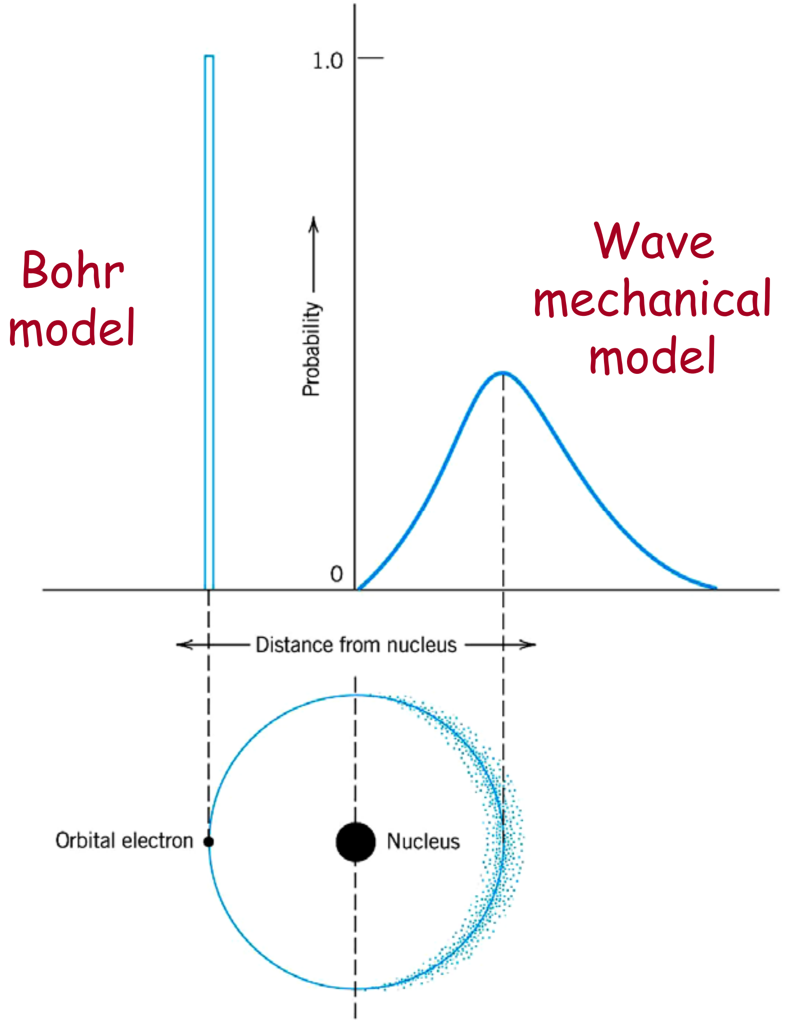
(파동역학모델: 전자는 파동성과 입자성을 동시에 갖는다 가정,
전자 = 입자 → 전자의 위치 확률분포 혹은 전자구름)

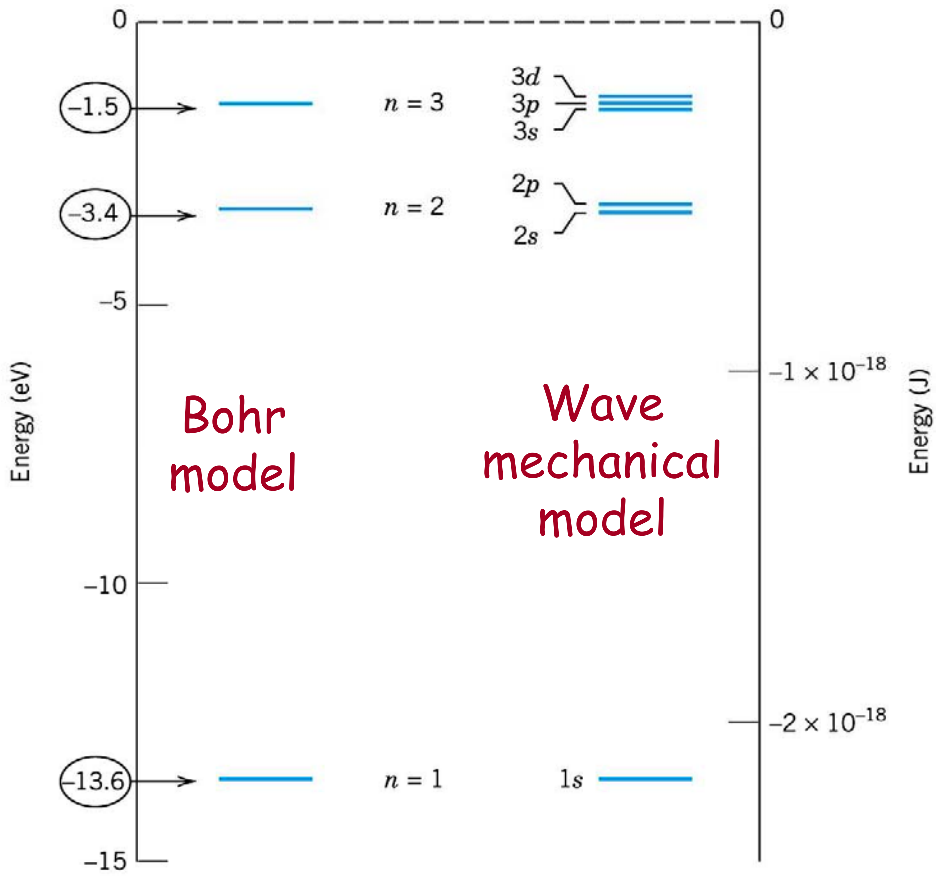






Bohr vs. wave mechanical model



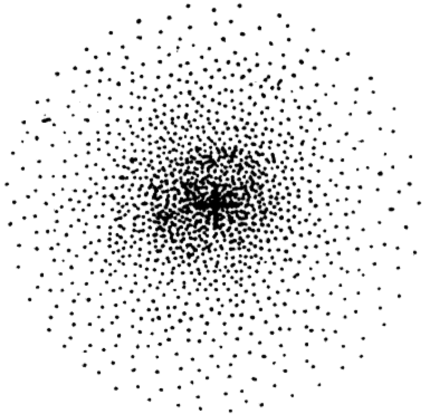


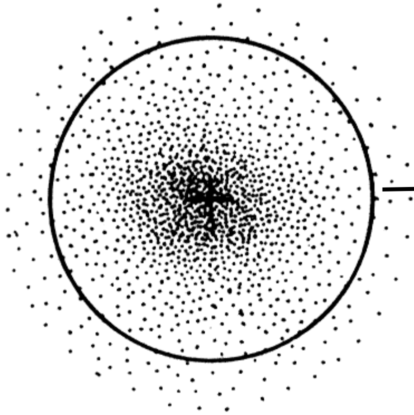
Electron position is described by
a probability distribution
or electron cloud

Bohr energy levels to be separated
into electron subshells
described by quantum numbers

Orbital concept

Imagine & take a picture of an electron confined in an atom with single room for it ...

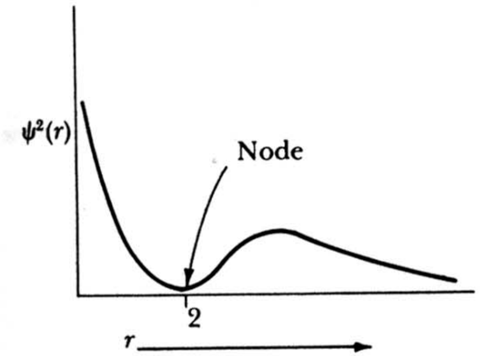


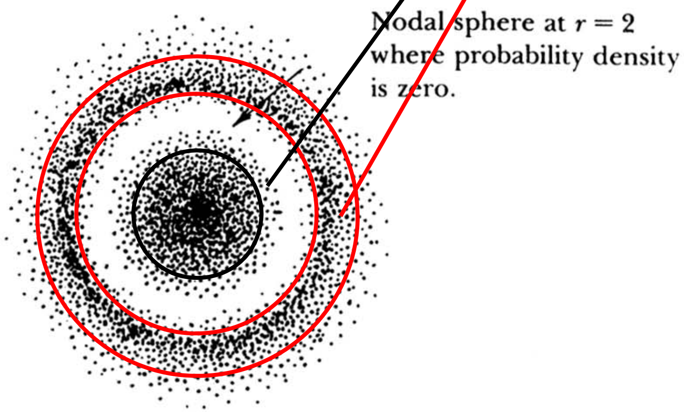


" orbital "

, which cannot be defined by a discrete line but a region of a volume due to Heisenberg uncertainty principle

Then, what if there are two available rooms for an electron ...





Electronic Structure

- Electrons have wavelike and particulate properties.
  (원자의 모든 전자는 양자수 (quantum #)라고 하는 4개의 숫자로 정의)
  - This means that electrons are in orbitals defined by a probability.
  - Each orbital at discrete energy level determined by quantum numbers.

Quantum #	Designation
n = principal (energy level-shell)	K, L, M, N, O (1, 2, 3, etc.)
ℓ = subsidiary (orbitals)	s, p, d, f (0, 1, 2, 3,…, n-1)
m_l = magnetic	1, 3, 5, 7 ($-\ell$ to $+\ell$)
m_s = spin	½, -½

Quantum numbers (양자수)

- n principal quantum number 1, 2, 3, 4, --- (K, L, M, N, ---)
  - Determines the effective volume of an electron orbital
  - Distance of an electron from the nucleus, position of an electron
- l Angular (azimuthal) quantum number 0, 1, 2, 3, 4, ---, (n-1) (s, p, d, f)
  - Determines the angular momentum of the electron
  - Shape of electron subshell, shape of electron distribution
- m_l magnetic quantum number 0, $\pm$1, $\pm$2, ---, $\pm$l
  - Determines the orientation of the orbital
- m_s spin quantum number ½, -½

- Pauli exclusion principle (파울리의 배타원리: 하나의 준위에 최대 스핀방향이 다른 2개 이하의 전자포함)
  - No two interacting entities can have the same set of the quantum numbers …

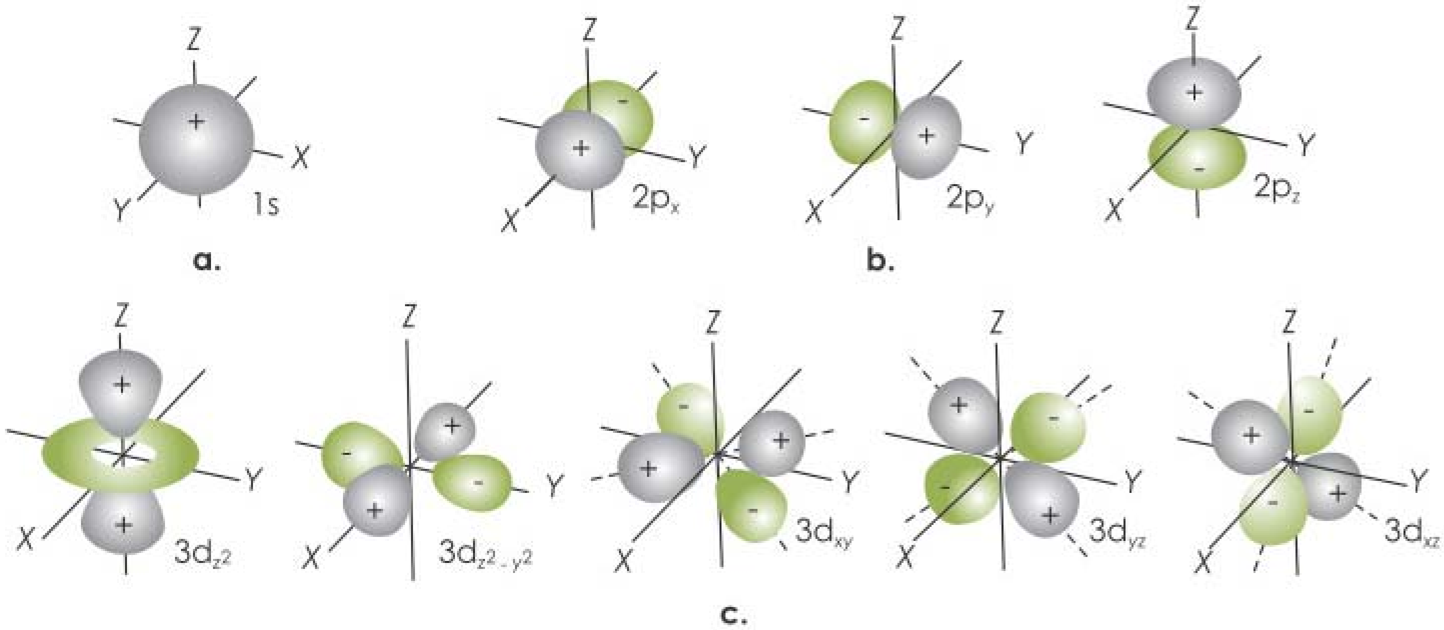
    → Each orbital will hold up to two electrons There can never be more than one electron in the same quantum state
  - Only one electron can be in a particular quantum state at a given time
  - Each electron state cannot hold more than two electrons with opposite spins

Meaning of quantum numbers

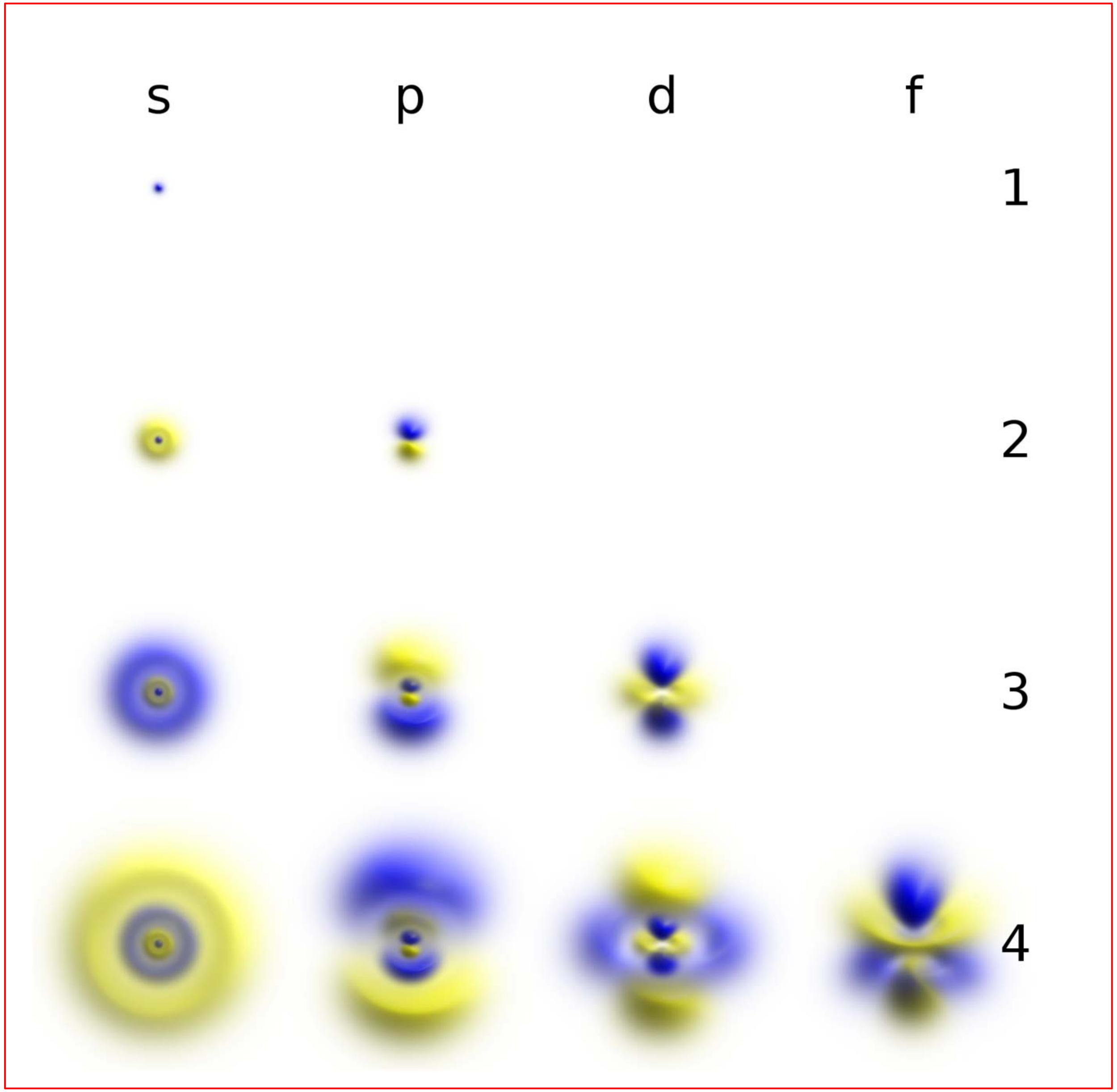
n determines the size

l determines the shape

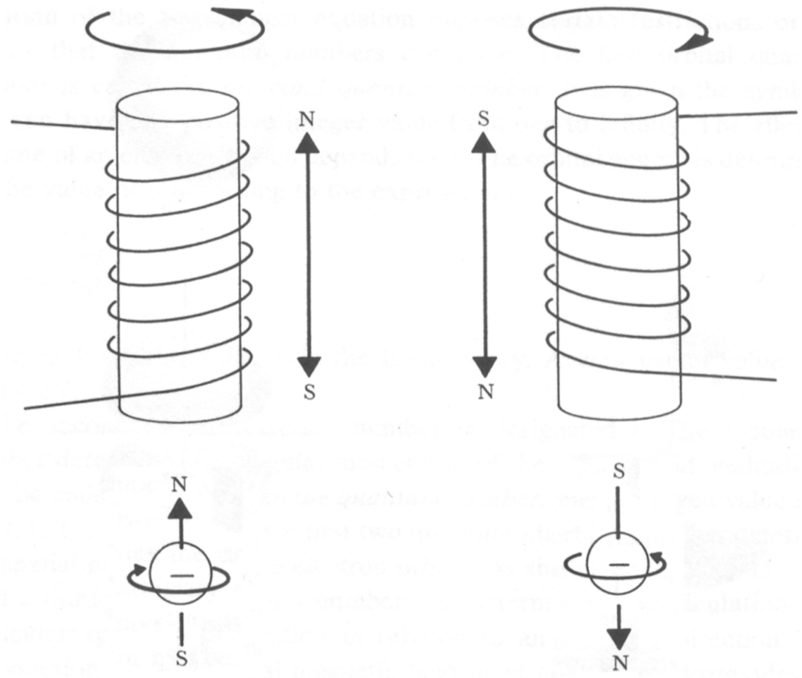
m_l determines the orientation



3-dimensional view of electron orbitals



Additional quantum number



Electron spin : $m_s = \pm \frac{\hbar}{2}$

Therefore, complete
description of
an electron requires
4 quantum numbers

Pauli exclusion principle

... No two interacting entities can have the same set of the quantum # ...

→ Each orbital will hold up to two electrons

Electron Configurations
(원자의 전자배위 혹은 전자구조)

- Valence electrons – those in unfilled shells
- Filled shells more stable
- Valence electrons (원자가전자) are most available for bonding and tend to control the chemical properties

  – example: C (atomic number = 6)

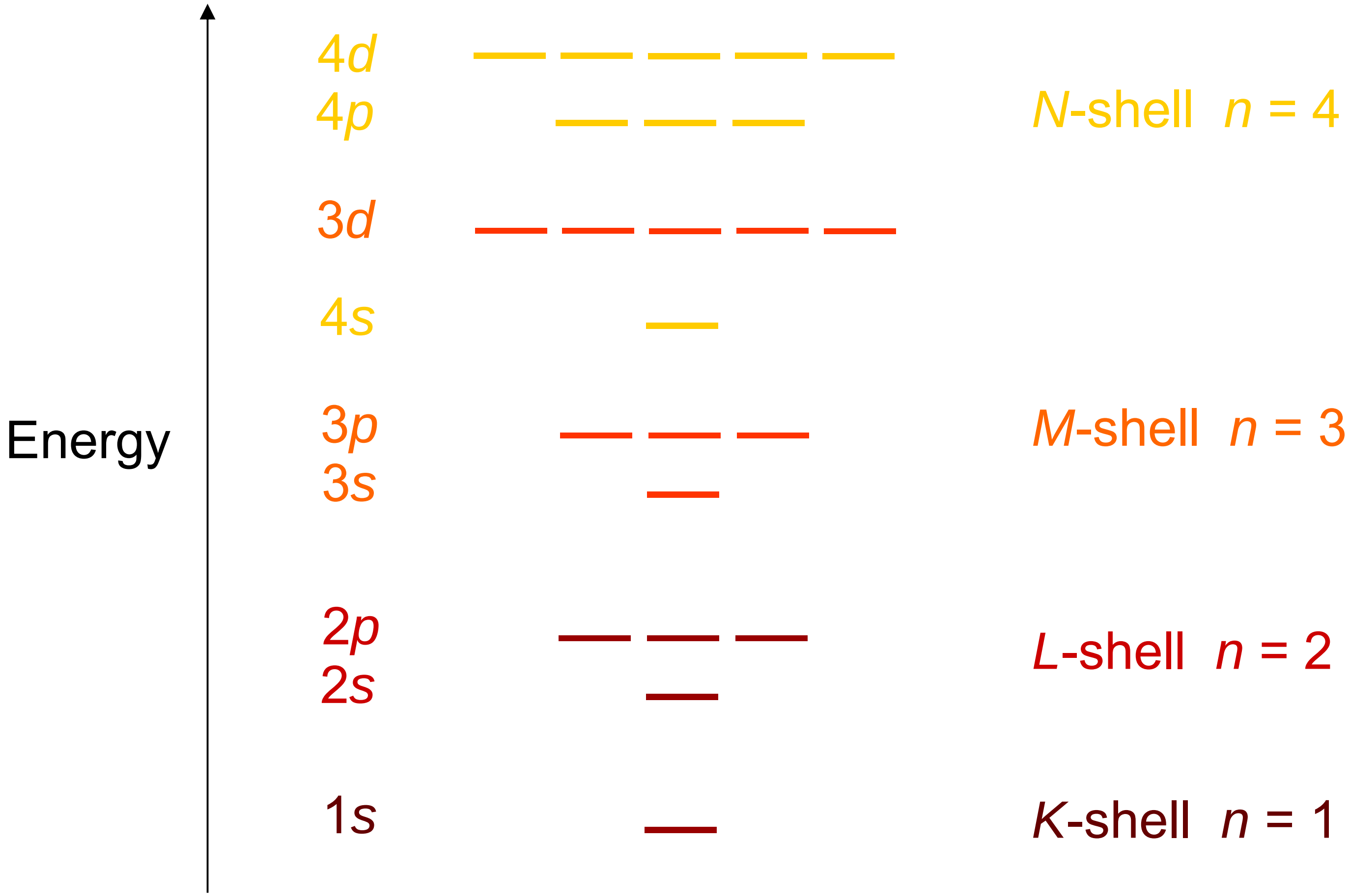
$1s^2$ $2s^2\ 2p^2$

valence electrons

Electron Energy States

Electrons...

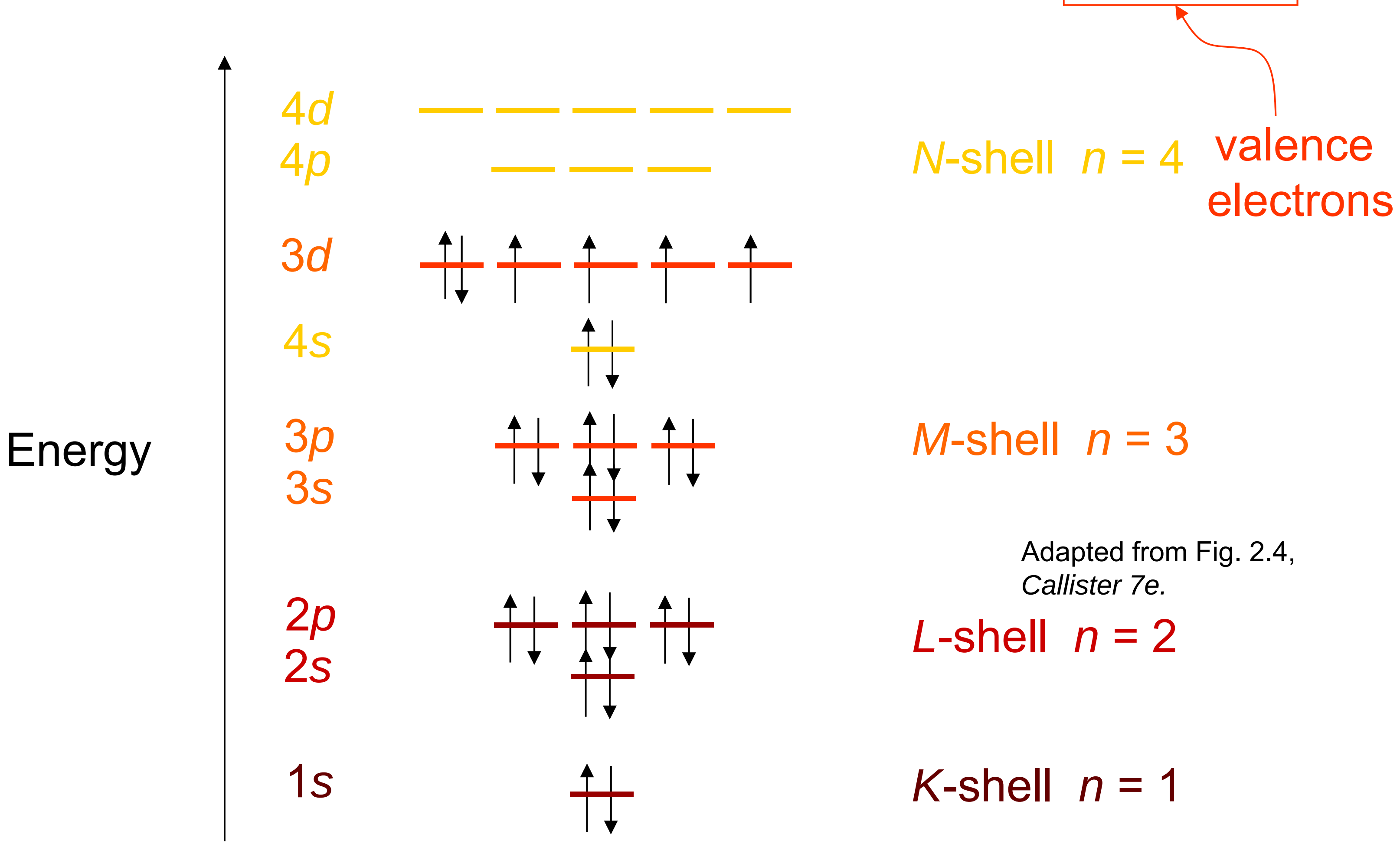
- have discrete energy states
- tend to occupy lowest available energy state.



Adapted from Fig. 2.4, *Callister 7e.*

Electronic Configurations

ex: Fe - atomic # = 26 $1s^2$ $2s^2\,2p^6$ $3s^2\,3p^6$ $3d^6$ $4s^2$



Adapted from Fig. 2.4, *Callister 7e.*

The complete set of quantum numbers for each of the 11 electrons in sodium

Subshell	Electron	n	l	m_l	m_s
$3s^1$	electron 11	$n=3$	$l=0$	$m_l=0$	$m_s=+\frac{1}{2}$ or $-\frac{1}{2}$
$2p^6$	electron 10	$n=2$	$l=1$	$m_l=+1$	$m_s=-\frac{1}{2}$
	electron 9	$n=2$	$l=1$	$m_l=+1$	$m_s=+\frac{1}{2}$
	electron 8	$n=2$	$l=1$	$m_l=0$	$m_s=-\frac{1}{2}$
	electron 7	$n=2$	$l=1$	$m_l=0$	$m_s=+\frac{1}{2}$
	electron 6	$n=2$	$l=1$	$m_l=-1$	$m_s=-\frac{1}{2}$
	electron 5	$n=2$	$l=1$	$m_l=-1$	$m_s=+\frac{1}{2}$
$2s^2$	electron 4	$n=2$	$l=0$	$m_l=0$	$m_s=-\frac{1}{2}$
	electron 3	$n=2$	$l=0$	$m_l=0$	$m_s=+\frac{1}{2}$
$1s^2$	electron 2	$n=1$	$l=0$	$m_l=0$	$m_s=-\frac{1}{2}$
	electron 1	$n=1$	$l=0$	$m_l=0$	$m_s=+\frac{1}{2}$

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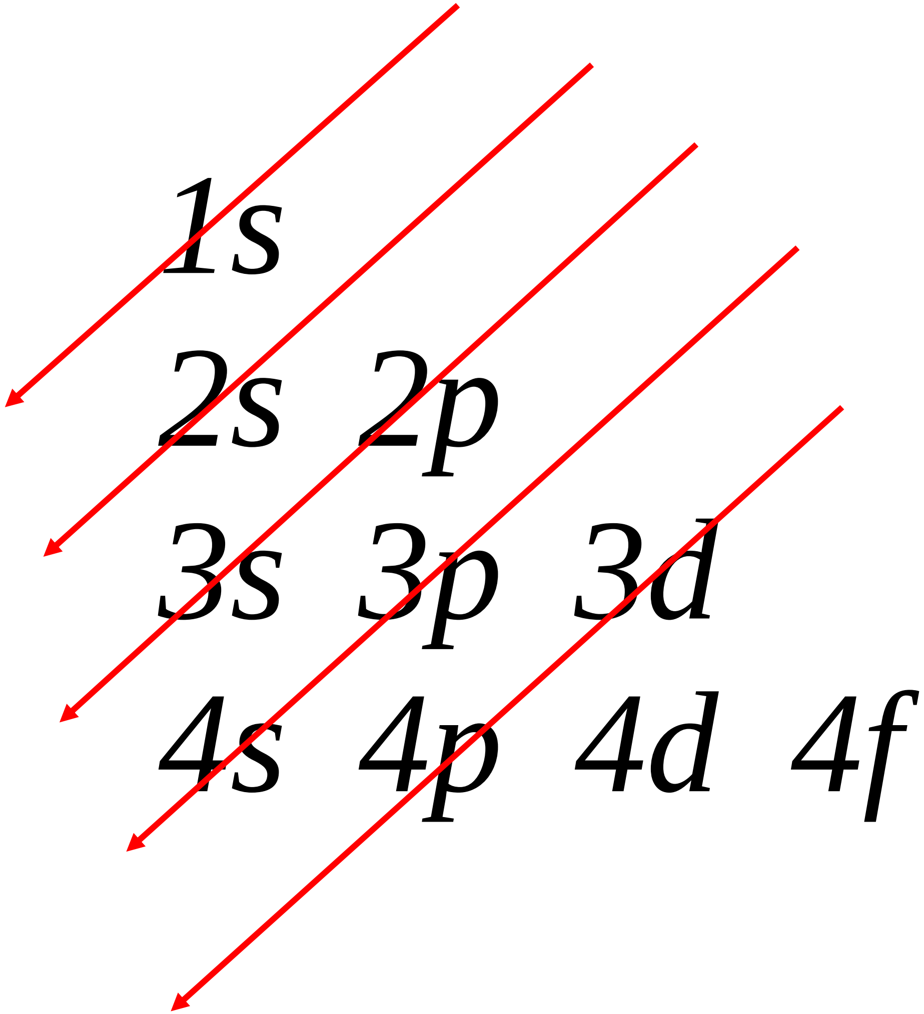
Stable Electron Configurations

- Stable electron configurations...
  - have complete s and p subshells
  - tend to be *non-reactive* (불활성).

Z	Element	Configuration
2	He	$1s^2$
10	Ne	$1s^2 2s^2 2p^6$
18	Ar	$1s^2 2s^2 2p^6 3s^2 3p^6$
36	Kr	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$



1s^1
1s^2
2s^1
2s^2
2p^1
.
.
.
2p^6
3s^1
3s^2
3p
4s
3d
4p

SURVEY OF ELEMENTS

- 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)

Adapted from Table 2.2, *Callister 7e.*

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

Chapter 2.4 모든 원소는 주기율표 상의 전자 배위에 의해 분류

Periodic Table of the Elements

KCS 대한화학회 KOREAN CHEMICAL SOCIETY
화학이 지구를 더 푸르게

Current ACS and IUPAC preferred.

Symbol / Atomic number / Name / Atomic weight / Electron arrangement: **O** 8, Oxygen, 15.9994, $2S^22P^4$

[a]Mass number of most stable or best-known isotope
[b]Mass of the isotope of longest half-life

Atomic weights are based on carbon-12. Atomic weights in parentheses indicate the most stable or best-known isotope.

Period	1 (IA)	2 (IIA)	3 (IIIB)	4 (IVB)	5 (VB)	6 (VIB)	7 (VIIB)	8 (VIIIB)	9 (VIIIB)	10 (VIIIB)	11 (IB)	12 (IIB)	13 (IIIA)	14 (IVA)	15 (VA)	16 (VIA)	17 (VIIA)	18 (VIIIA)
1	**H** 1 Hydrogen 1.00794 $1s^1$																	**He** 2 Helium 4.002602 $1s^2$
2	**Li** 3 Lithium 6.941 $2s^1$	**Be** 4 Beryllium 9.01218 $2s^2$											**B** 5 Boron 10.81 $2s^22p^1$	**C** 6 Carbon 12.011 $2s^22p^2$	**N** 7 Nitrogen 14.0067 $2s^22p^3$	**O** 8 Oxygen 15.9994 $2s^22p^4$	**F** 9 Fluorine 18.99840 $2s^22p^5$	**Ne** 10 Neon 21.1797 $2s^22p^6$
3	**Na** 11 Sodium 22.98977 $3s^1$	**Mg** 12 Magnesium 24.305 $3s^2$											**Al** 13 Aluminum 26.98154 $3s^23p^1$	**Si** 14 Silicon 28.086 $3s^23p^2$	**P** 15 Phosphorus 30.97376 $3s^23p^3$	**S** 16 Sulfur 32.06 $3s^23p^4$	**Cl** 17 Chlorine 35.453 $3s^23p^5$	**Ar** 18 Argon 39.948 $3s^23p^6$
4	**K** 19 Potassium 39.098 $4s^1$	**Ca** 20 Calcium 40.08 $4s^2$	**Sc** 21 Scandium 44.9559 $3d^14s^2$	**Ti** 22 Titanium 47.90 $3d^24s^2$	**V** 23 Vanadium 50.9415 $3d^34s^2$	**Cr** 24 Chromium 51.996 $3d^54s^1$	**Mn** 25 Manganese 54.9380 $3d^54s^2$	**Fe** 26 Iron 55.845 $3d^64s^2$	**Co** 27 Cobalt 58.9332 $3d^74s^2$	**Ni** 28 Nickel 58.69 $3d^84s^2$	**Cu** 29 Copper 63.546 $3d^{10}4s^1$	**Zn** 30 Zinc 65.409 $3d^{10}4s^2$	**Ga** 31 Gallium 69.72 $3d^{10}4s^24p^1$	**Ge** 32 Germanium 72.61 $3d^{10}4s^24p^2$	**As** 33 Arsenic 74.9216 $3d^{10}4s^24p^3$	**Se** 34 Selenium 78.96 $3d^{10}4s^24p^4$	**Br** 35 Bromine 79.904 $3d^{10}4s^24p^5$	**Kr** 36 Krypton 83.80 $3d^{10}4s^24p^6$
5	**Rb** 37 Rubidium 85.4678 $5s^1$	**Sr** 38 Strontium 87.62 $5s^2$	**Y** 39 Yttrium 88.9059 $4d^15s^2$	**Zr** 40 Zirconium 91.22 $4d^25s^2$	**Nb** 41 Niobium 92.9064 $4d^45s^1$	**Mo** 42 Molybdenum 95.94 $4d^55s^1$	**Tc** 43 Technetium 98.9062[b] $4d^55s^2$	**Ru** 44 Ruthenium 101.07 $4d^75s^1$	**Rh** 45 Rhodium 102.9055 $4d^85s^1$	**Pd** 46 Palladium 106.4 $4d^{10}$	**Ag** 47 Silver 107.868 $4d^{10}5s^1$	**Cd** 48 Cadmium 112.411 $4d^{10}5s^2$	**In** 49 Indium 114.82 $4d^{10}5s^25p^1$	**Sn** 50 Tin 118.71 $4d^{10}5s^25p^2$	**Sb** 51 Antimony 121.760 $4d^{10}5s^25p^3$	**Te** 52 Tellurium 127.60 $4d^{10}5s^25p^4$	**I** 53 Iodine 126.9045 $4d^{10}5s^25p^5$	**Xe** 54 Xenon 131.293 $4d^{10}5s^25p^6$
6	**Cs** 55 Cesium 132.9054 $6s^1$	**Ba** 56 Barium 137.327 $6s^2$	**La*** 57 Lanthanum 138.9055 $5d^16s^2$	**Hf** 72 Hafnium 178.49 $4f^{14}5d^26s^2$	**Ta** 73 Tantalum 180.9479 $4f^{14}5d^36s^2$	**W** 74 Tungsten 183.84 $4f^{14}5d^46s^2$	**Re** 75 Rhenium 186.2 $4f^{14}5d^56s^2$	**Os** 76 Osmium 190.2 $4f^{14}5d^66s^2$	**Ir** 77 Iridium 192.22 $4f^{14}5d^76s^2$	**Pt** 78 Platinum 195.078 $4f^{14}5d^96s^1$	**Au** 79 Gold 196.9665 $4f^{14}5d^{10}6s^1$	**Hg** 80 Mercury 200.59 $4f^{14}5d^{10}6s^2$	**Tl** 81 Thallium 204.3833 $4f^{14}5d^{10}6s^26p^1$	**Pb** 82 Lead 207.2 $4f^{14}5d^{10}6s^26p^2$	**Bi** 83 Bismuth 208.9804 $4f^{14}5d^{10}6s^26p^3$	**Po** 84 Polonium (210)[a] $4f^{14}5d^{10}6s^26p^4$	**At** 85 Astatine (210)[a] $4f^{14}5d^{10}6s^26p^5$	**Rn** 86 Radon (222)[a] $4f^{14}5d^{10}6s^26p^6$
7	**Fr** 87 Francium (223)[a] $7s^1$	**Ra** 88 Radium 226.0254[b] $7s^2$	**Ac**** 89 Actinium (227)[a] $6d^17s^2$	**Rf** 104 Rutherfordium (261)[a] $5f^{14}6d^27s^2$	**Db** 105 Dubnium (262)[a] $5f^{14}6d^37s^2$	**Sg** 106 Seaborgium (266) $5f^{14}6d^47s^2$	**Bh** 107 Bohrium (264) $5f^{14}6d^57s^2$	**Hs** 108 Hassium (269) $5f^{14}6d^67s^2$	**Mt** 109 Meitnerium (268) $5f^{14}6d^77s^2$	– 110 – (269) – –	– 111 – (272) – –							

Transition elements

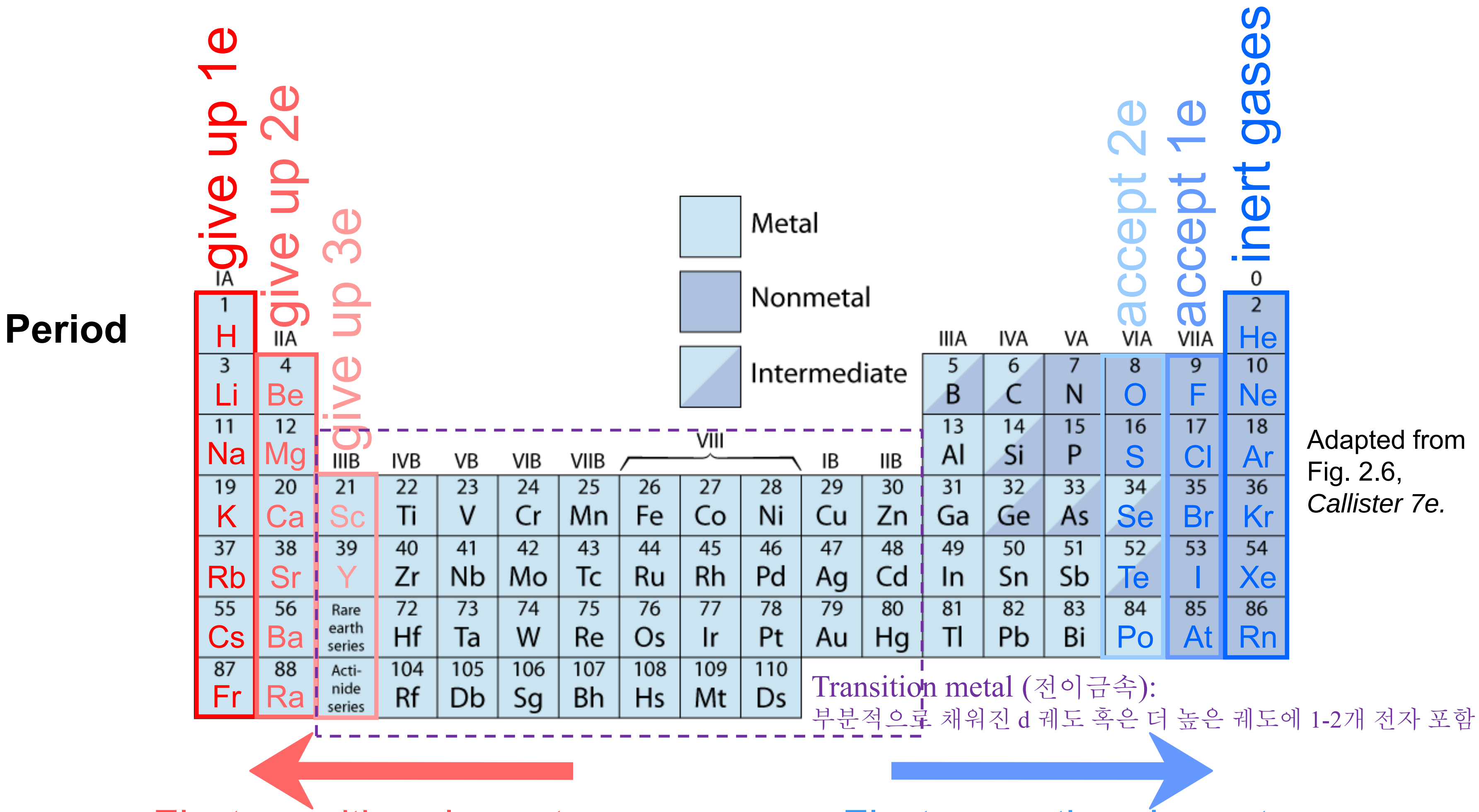
Metal | Semimetal | Nonmetal

Inner transition elements

Lanthanide series * 6	**Ce** 58 Cerium 140.116 $4f^15d^16s^2$	**Pr** 59 Praseodymium 140.90765 $4f^36s^2$	**Nd** 60 Neodymium 144.24 $4f^46s^2$	**Pm** 61 Promethium (145)[a] $4f^56s^2$	**Sm** 62 Samarium 150.4 $4f^66s^2$	**Eu** 63 Europium 151.964 $4f^76s^2$	**Gd** 64 Gadolinium 157.25 $4f^75d^16s^2$	**Tb** 65 Terbium 158.92534 $4f^96s^2$	**Dy** 66 Dysprosium 162.50 $4f^{10}6s^2$	**Ho** 67 Holmium 164.93032 $4f^{11}6s^2$	**Er** 68 Erbium 167.26 $4f^{12}6s^2$	**Tm** 69 Thulium 168.9342 $4f^{13}6s^2$	**Yb** 70 Ytterbium 173.04 $4f^{14}6s^2$	**Lu** 71 Lutetium 174.97 $4f^{14}5d^16s^2$
Actinide series ** 7	**Th** 90 Thorium 232.0381[b] $6d^27s^2$	**Pa** 91 Protactinium 231.03588 $5f^26d^17s^2$	**U** 92 Uranium 238.02891 $5f^36d^17s^2$	**Np** 93 Neptunium (237) $5f^46d^17s^2$	**Pu** 94 Plutonium (244) $5f^67s^2$	**Am** 95 Americium (243) $5f^77s^2$	**Cm** 96 Curium (247)[a] $5f^76d^17s^2$	**Bk** 97 Berkelium (247) $5f^97s^2$	**Cf** 98 Californium (251)[a] $5f^{10}7s^2$	**Es** 99 Einsteinium (251) $5f^{11}7s^2$	**Fm** 100 Fermium (257) $5f^{12}7s^2$	**Md** 101 Mendelevium (258) $5f^{13}7s^2$	**No** 102 Nobelium (259) $5f^{14}7s^2$	**Lr** 103 Lawrencium (262) $5f^{14}6d^17s^2$

The Periodic Table

- **Columns**: Similar Valence Structure_비슷한 화학적 물리적 특성



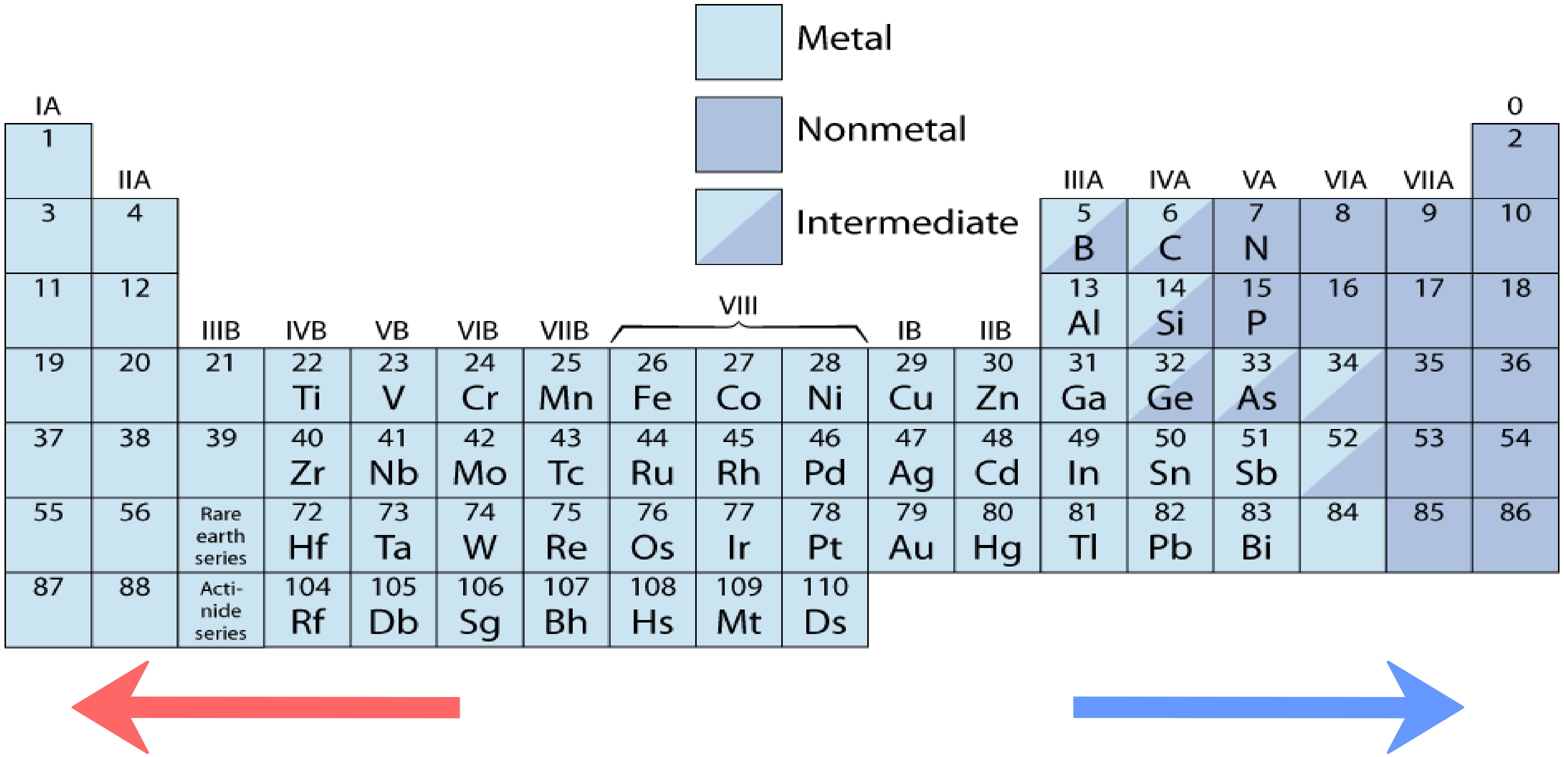
Adapted from Fig. 2.6, *Callister 7e.*

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

Electronegative elements:
Readily acquire electrons
to become - ions.

Electronegativity (전기음성도)

- Ranges from 0.7 to 4.0,
- Large values: tendency to acquire electrons.

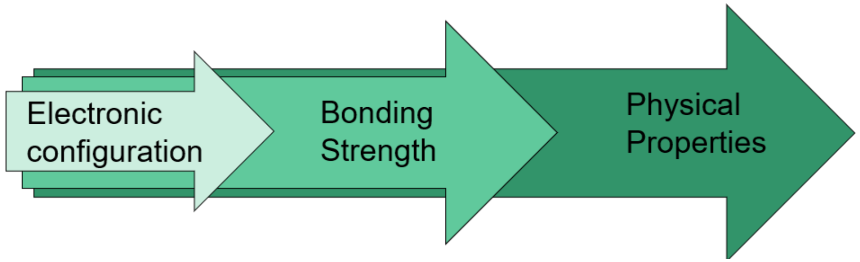


Smaller electronegativity Larger electronegativity

Adapted from Fig. 2.7, *Callister 7e.* (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

Contents for today's class

Atomic Structure



2.2 **Fundamental concepts**

- atom – electrons – 9.11×10^{-31} kg
  protons, neutrons } 1.67×10^{-27} kg

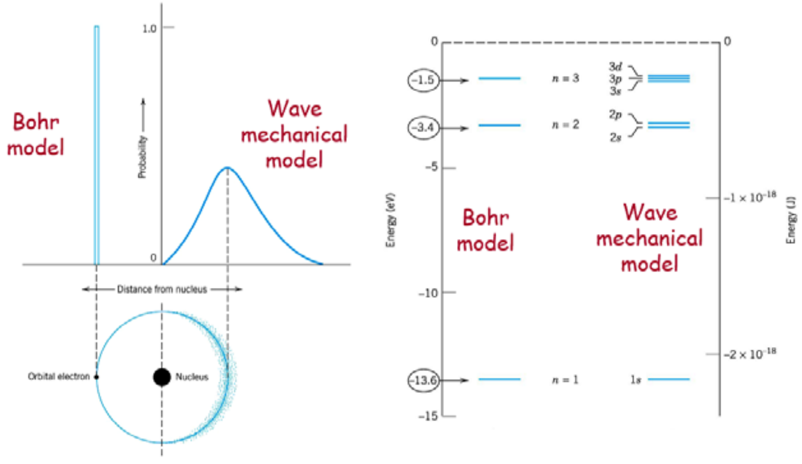
2.3 **Electrons in atoms**

a. atomic models

Bohr's model + Wave-mechanical model

전자는 파동성과 입자성을 동시에 갖는다 가정= 전자구름

Bohr vs. wave mechanical model

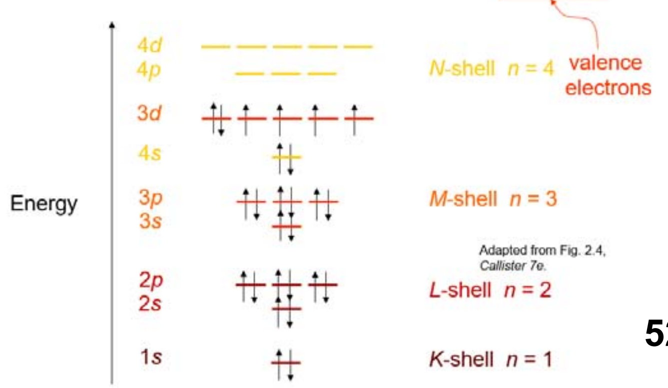


b. Quantum #s

n = principal (energy level-shell)	K, L, M, N, O (1, 2, 3, etc.)
ℓ = subsidiary (orbitals)	s, p, d, f (0, 1, 2, 3,…, n-1)
m_l = magnetic	1, 3, 5, 7 ($-\ell$ to $+\ell$)
m_s = spin	½, -½

c. Electron configurations

ex: Fe - atomic # = 26 $1s^2$ $2s^2 2p^6$ $3s^2 3p^6$ $3d^6$ $4s^2$



Adapted from Fig. 2.4, Callister 7e.

2.4 **Periodic table**

모든 원소는 주기율표 상의 전자 배위에 의해 분류

: 특성의 규칙적인 변화 양상 확인 가능