Chapter 2

Atoms, Elements, and Minerals

A mineral is:

- Solid,
- crystalline,
- has a specific chemical composition,
- and forms through geologic processes (naturally occurring)

Mineral

- Naturally occurring
  - Not synthetic, artificial
- Solid crystalline substance
  - Neither liquids nor gases
  - Atoms arranged in orderly, repeating, 3-D array
- Generally inorganic
- With a specific chemical composition
  - Fixed or within a range, limited by crystal structure

Non-Crystalline Materials

- Gases
- Organic materials
- Aqueous solutions
- Melts
- Amorphous solids ("without form"—non-crystalline)
  - Glass, opal

A rock is:

- Naturally formed
- Consolidated material
- Made of grains of one or more minerals

Rocks vs. Minerals

- A ***mineral***
  - is a ***crystalline solid***
  - is formed by *natural* geological processes
    - in the **geo**sphere (most minerals)
    - in the **hydro**sphere (e.g., salt)
    - in the **bio**sphere (e.g., calcite)
    - In the **atmo**sphere (e.g., water ice)
  - has a ***specific chemical composition***
  - has consistent *physical and chemical properties*
- A ***crystal***
  - is a mineral with ***"shape" (form)*** properties
- A ***rock***
  - is a composite of ***one or more minerals***

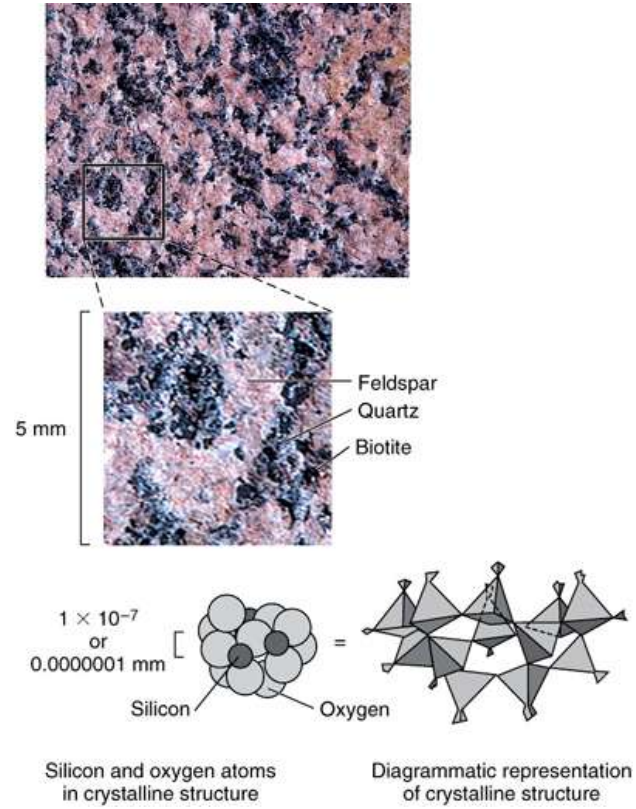
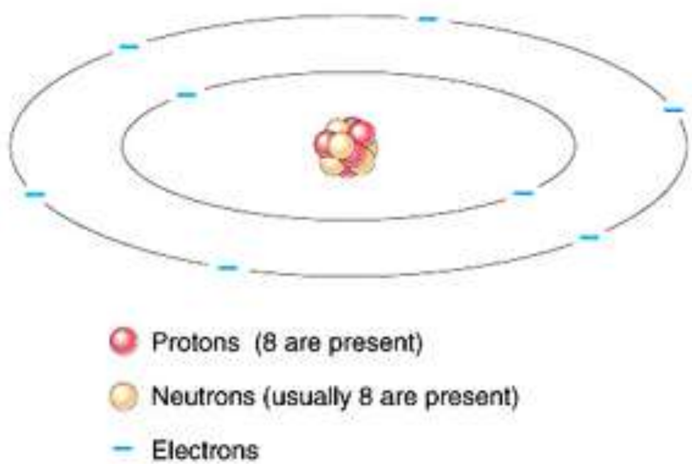


Fig. 2.1, pg. 26

An atom is:



- Smallest possible particle of an element that retains the properties of that element
- Determined by number of protons

3 most important subatomic particles

- Protons – contributes mass and a single positive electrical charge to an atom
- Neutrons – contributes mass to an atom and is electrically neutral
- Electrons – single, negative electrical charge that contributes virtually no mass to an atom

Atomic Structure

- *Nucleus* of an atom
  - has ***Protons*** (+1 charge) - determines the element
  - ***may have Neutrons*** (0 charge)
  - is a ***tiny*** volume at atom's center
  - is nearly ***all of the atom's mass***
- *Electrons* (-1 charge)
  - orbit **Nucleus** in discrete shells (energy levels)
    - Shells are most of volume of an atom
  - only a ***tiny fraction of the atom's mass***
- **Atoms**
  - **Neutral**
    - Number of electrons and protons **equal**
  - **Ions**
    - Number of electrons and protons **unequal**
- **Chemical** *(vs. nuclear)* **reactions**
  - involve ***only outermost shell - (valence) electrons***

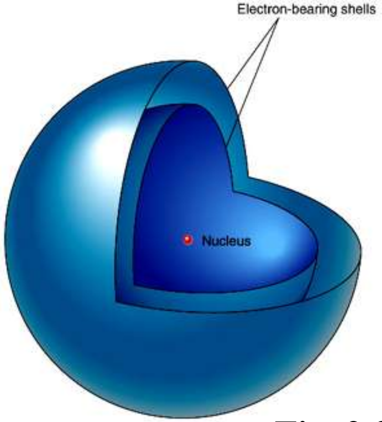


Fig. 2.3, pg. 28

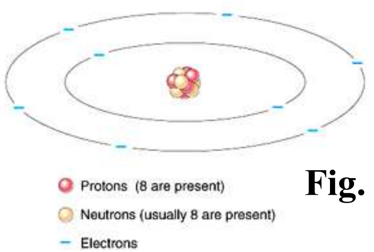
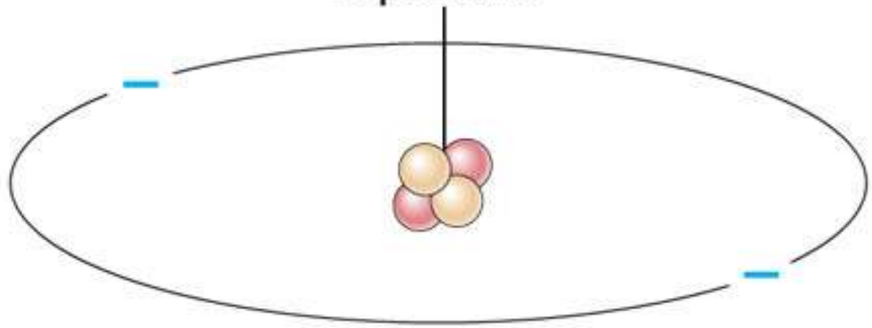
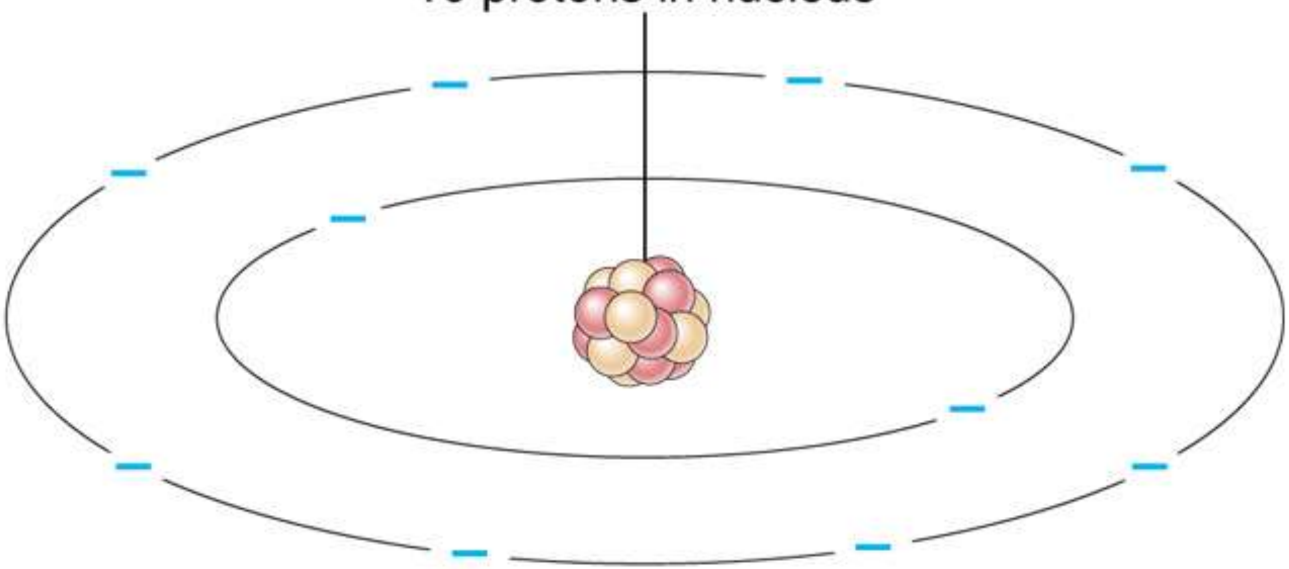


Fig. 2.5, pg. 29



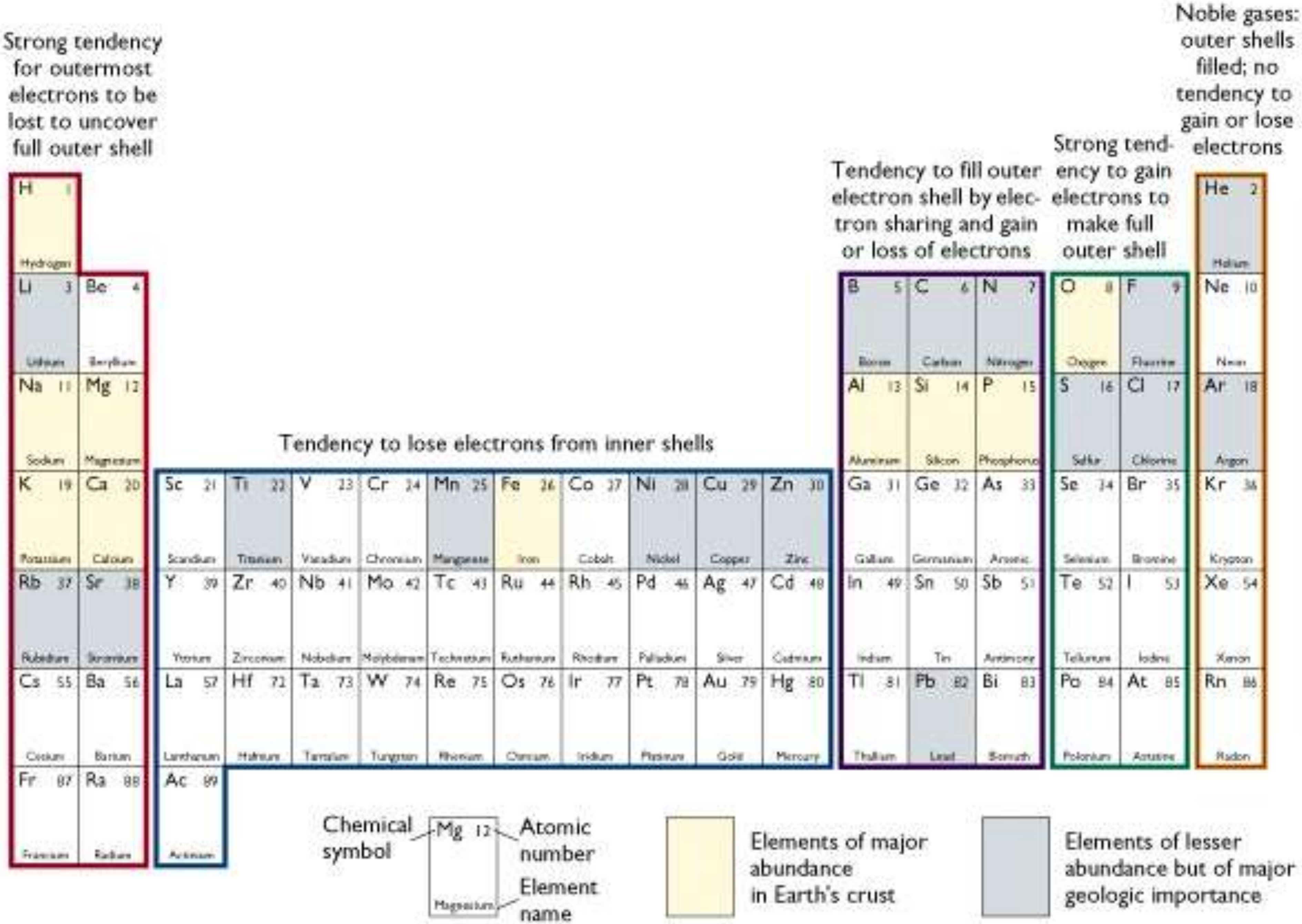
A Helium



B Neon

Atomic number

- number of protons in an atom
- determine atom's characteristics


Strong tendency for outermost electrons to be lost to uncover full outer shell
Noble gases: outer shells filled; no tendency to gain or lose electrons
Strong tendency to gain electrons to make full outer shell
Tendency to fill outer electron shell by electron sharing and gain or loss of electrons
Tendency to lose electrons from inner shells
H 1
He 2
Li 3
Be 4
B 5
C 6
N 7
O 8
F 9
Ne 10
Na 11
Mg 12
Al 13
Si 14
P 15
S 16
Cl 17
Ar 18
K 19
Ca 20
Sc 21
Ti 22
V 23
Cr 24
Mn 25
Fe 26
Co 27
Ni 28
Cu 29
Zn 30
Ga 31
Ge 32
As 33
Se 34
Br 35
Kr 36
Rb 37
Sr 38
Y 39
Zr 40
Nb 41
Mo 42
Tc 43
Ru 44
Rh 45
Pd 46
Ag 47
Cd 48
In 49
Sn 50
Sb 51
Te 52
I 53
Xe 54
Cs 55
Ba 56
La 57
Hf 72
Ta 73
W 74
Re 75
Os 76
Ir 77
Pt 78
Au 79
Hg 80
Tl 81
Pb 82
Bi 83
Po 84
At 85
Rn 86
Fr 87
Ra 88
Ac 89
Chemical symbol
Atomic number
Element name
Elements of major abundance in Earth's crust
Elements of lesser abundance but of major geologic importance

Atomic mass controlled by:

- Number of protons
- Plus
- Number of neutrons

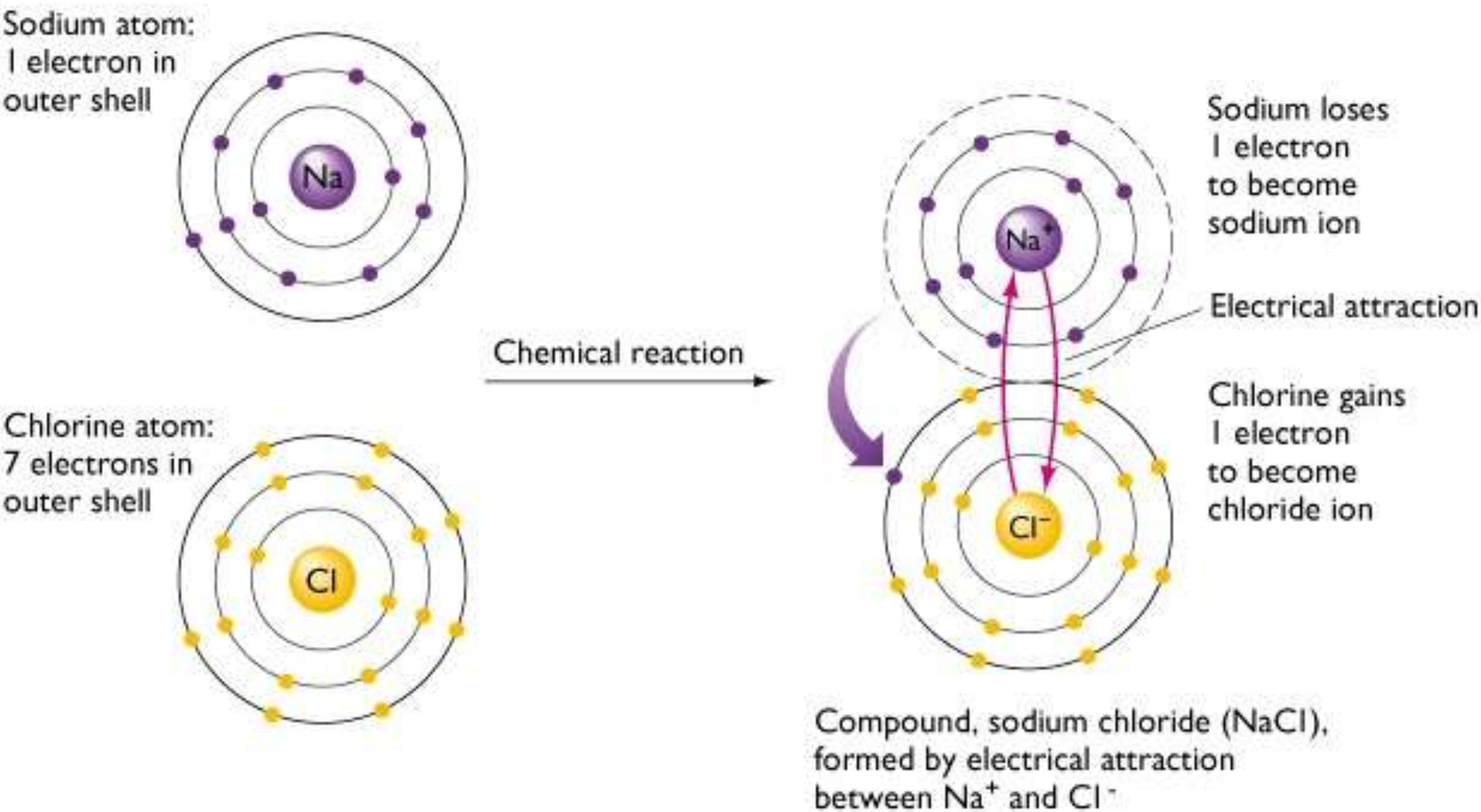
Ion =

- Electrically charge atom or group of atoms
  - Ex. = SO_4^{-2},
  - Ex. CO_3^{-2}
  - Ex. Cl^{-}, Na^{+}

Types of ions

- Cations +
- Anions -

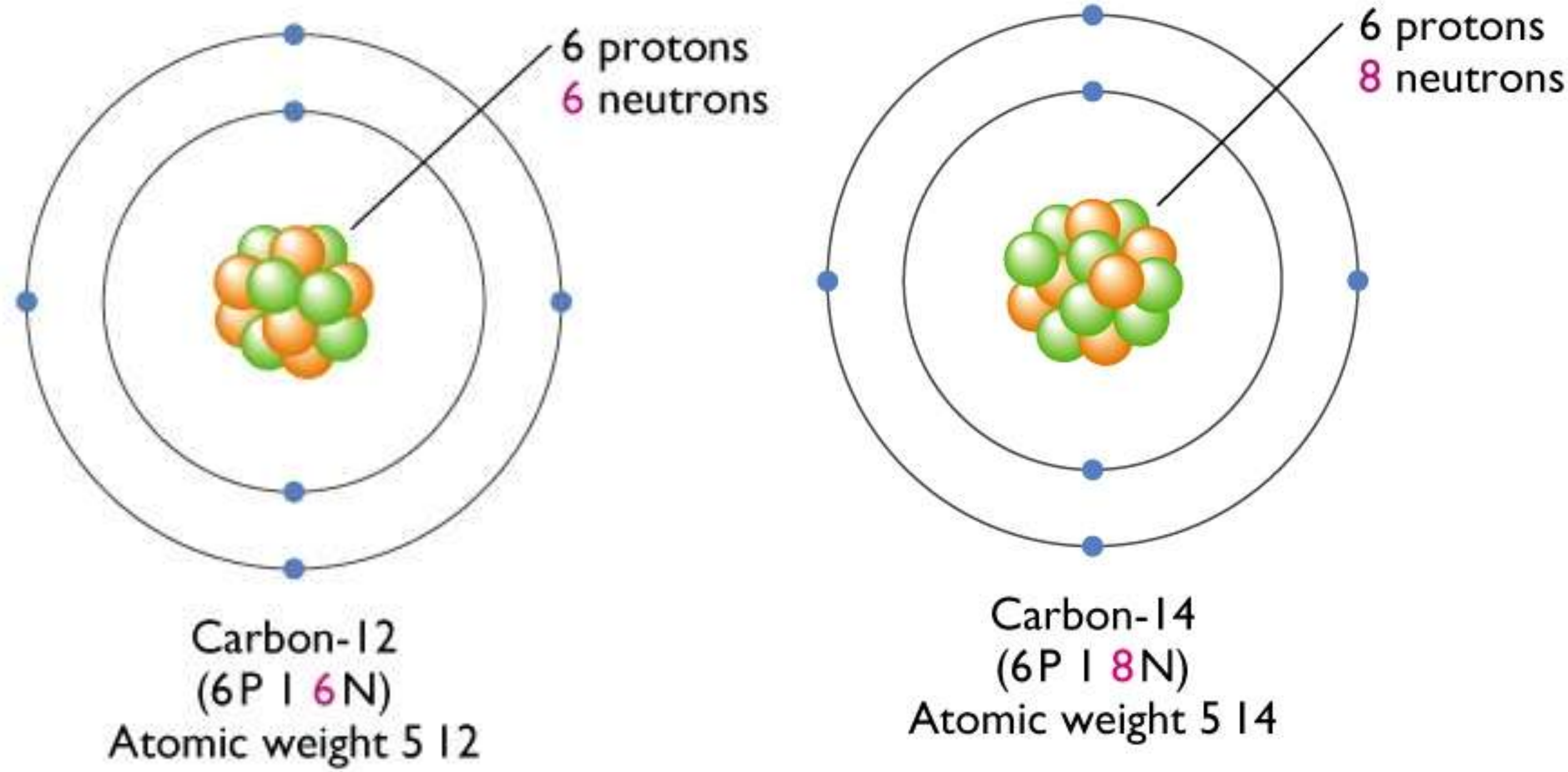
Chemical reactions construct materials

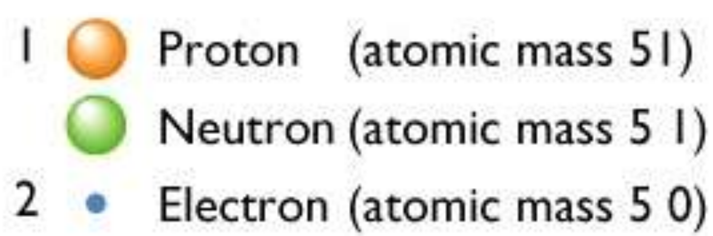


electrons

Isotopes =

- atoms of the same element that have different numbers of neutrons, but the same number of protons
- Examples = O 16 (8 neutrons), O 18 (10 neutrons)
- Unstable isotopes – decay to different element – radioactivity geiger counter





Atomic make-up

- Electrons key for chemistry

Isotopes

- Elements
  - determined ***by the number of protons in the nucleus !***
    - Carbon (C) = 6 protons ***- Always!***
    - Sodium (Na) = 11 protons ***- Always!***
    - Chlorine (Cl) = 17 protons ***- Always!***
- Number of neutrons can vary for an Element
  - ***Isotopes***
    - Carbon-12 … 6 protons, 6 neutrons
    - Carbon-13 … 6 protons, 7 neutrons
    - Carbon-14 … 6 protons, 8 neutrons
- Isotopes are a # *change in neutrons*.. ***in the nucleus!***

Isotopes

- Can only have a limited number o
  - additional neutrons in the nucleus
  - isotopes for each Element
    - heavier (larger) Elements have more
      - room in the nucleus
      - isotopes (generally)
- Isotope's nucleus may be
  - ***Stable***
    - all of their protons and neutrons retained over time
    - can be used to track climate changes
  - ***Unstable*** or ***radioactive***
    - spontaneously lose particles from their nuclei ***(fission!)***
    - proton loss means ***the Isotope turns into a new Element!***
    - major source of Earth's heat!

2 common types of atomic bonds

- Ionic bond – bonding due to the attraction between positivgely charged ions and negatively charged ions – opposites attract
- Covalent bond – bonding due to the sharing of electrons by adjacent atoms

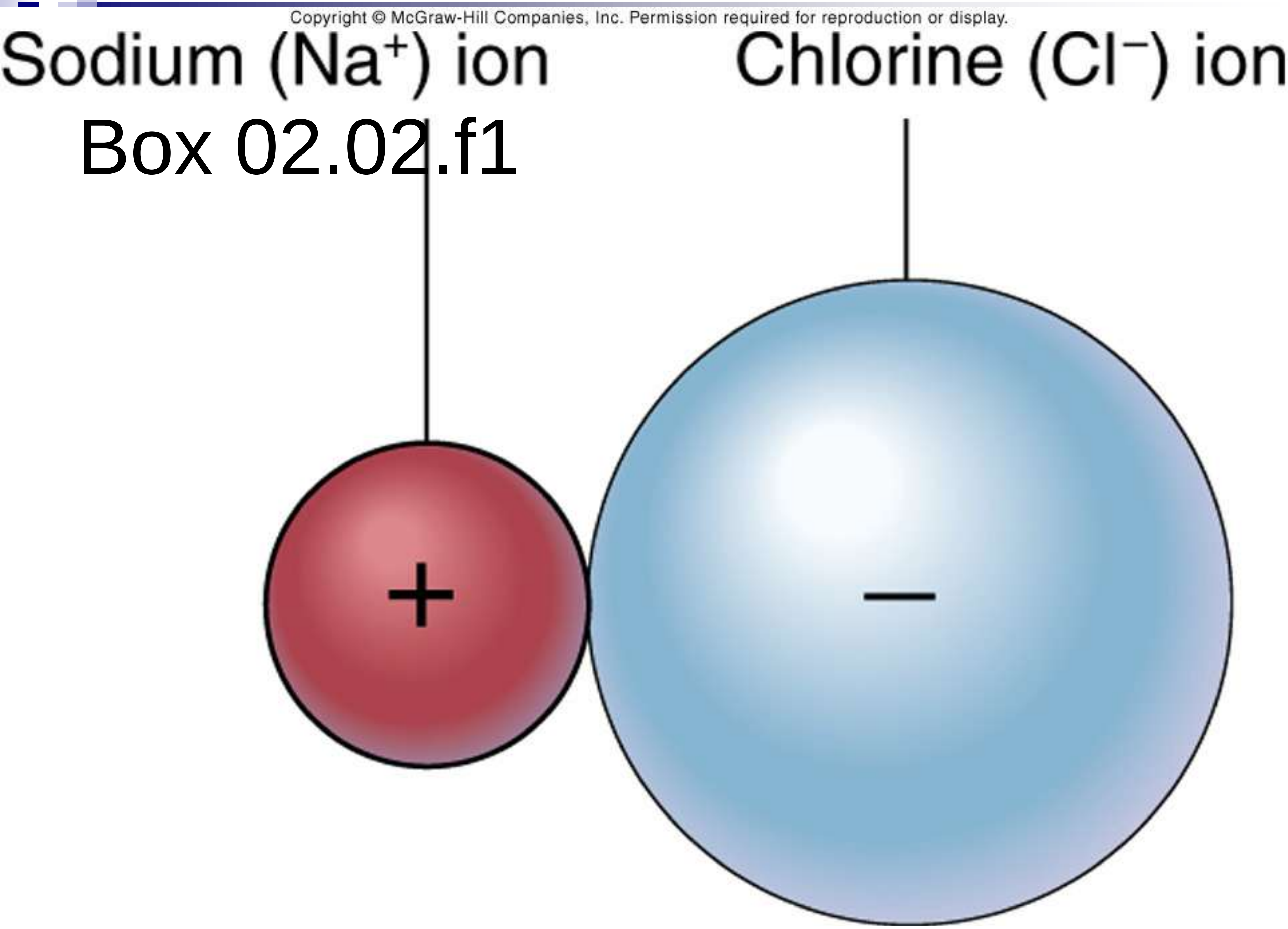
Chemical Bonds:
Important in both minerals and fluids

- Types and characteristics
  - Ionic
  - Covalent
  - Metallic
  - Van der Waals
  - Hydrogen

Ionic Bonds

- Donating/accepting electrons from one atom (element) to another atom (element)
- Typical of salts
- Generally very soluble
- Dominant type of bonds in mineral structures
- On left side of Periodic Table—lose electrons

Box 02.02.f1



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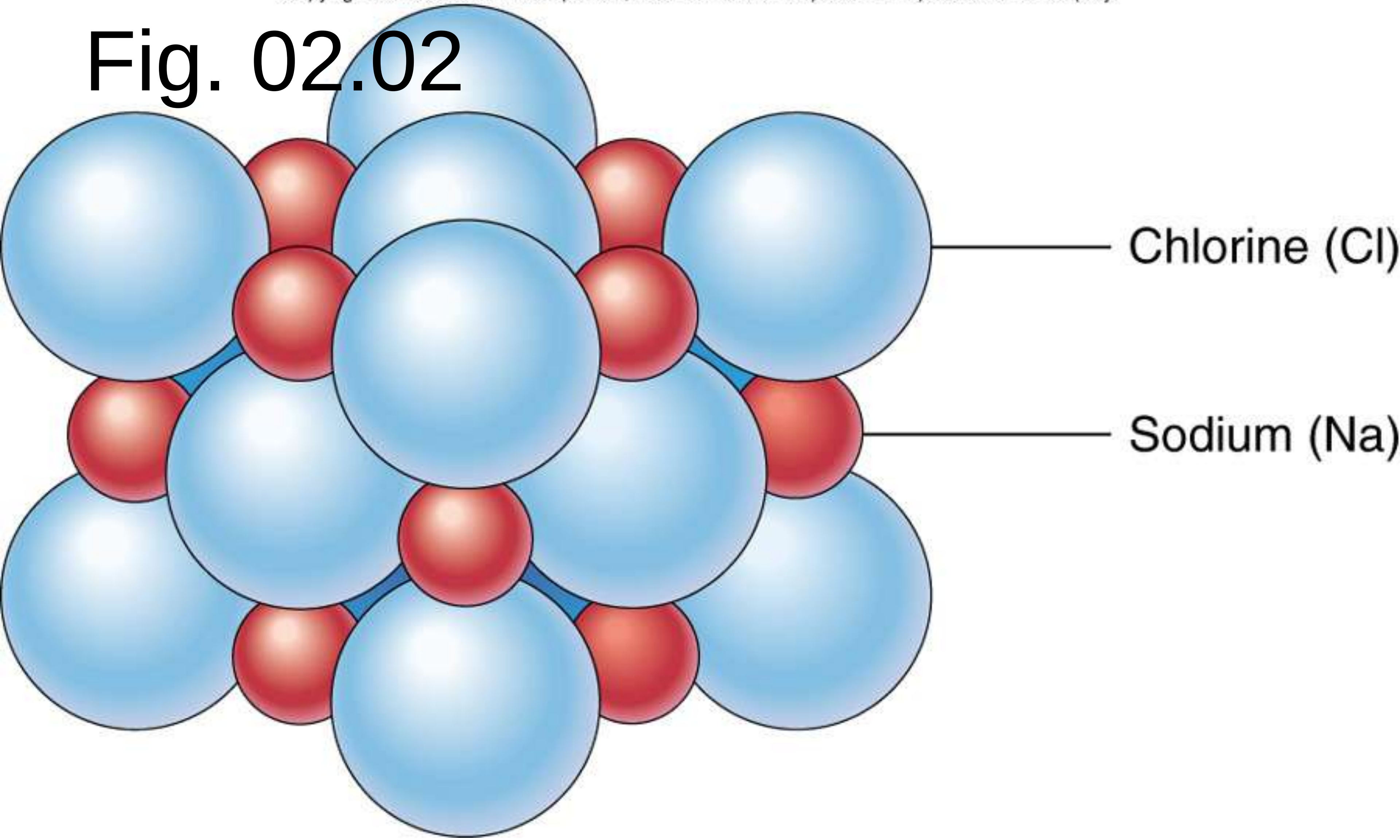
Sodium (Na^+) ion
Chlorine (Cl^-) ion
+
−

Fig. 02.02



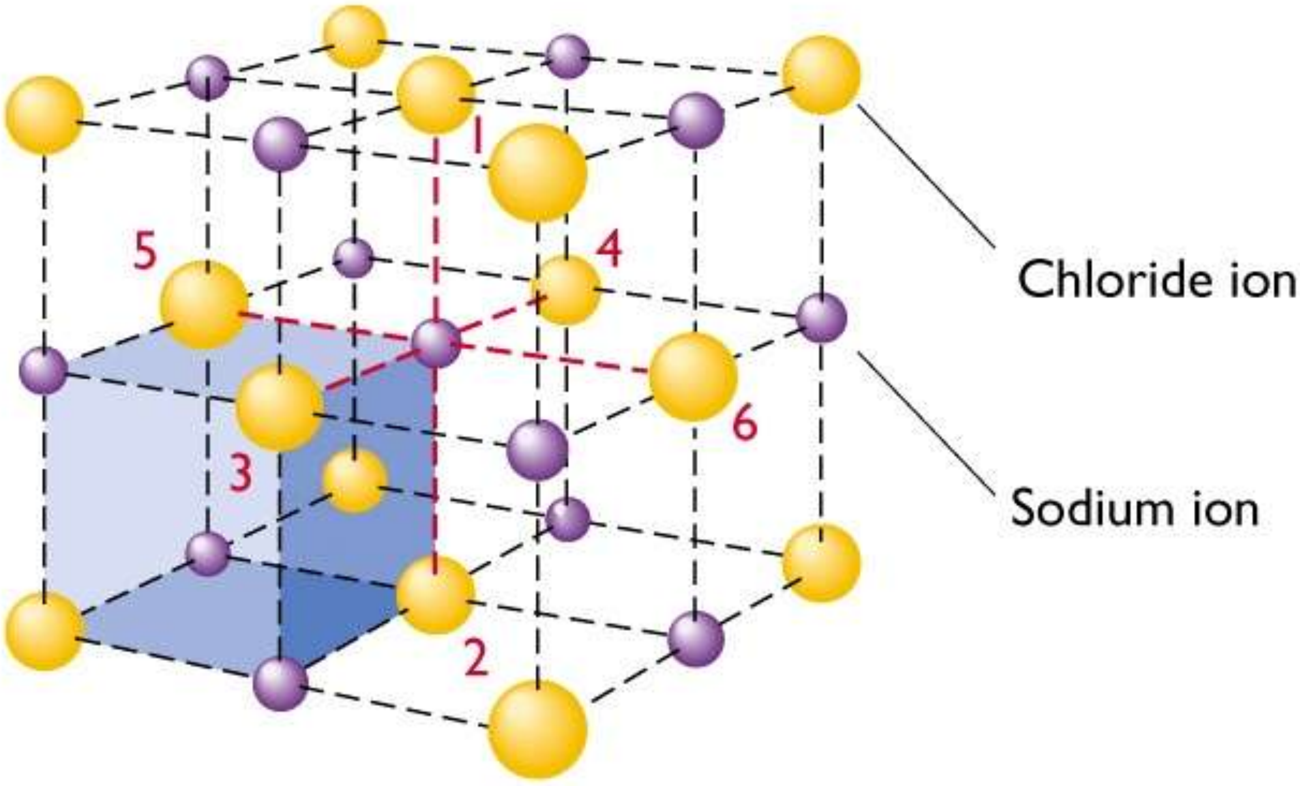
Covalent Bonds

- Localized sharing electrons (e.g., diamond)
- Generally stronger than ionic bonds (minerals less soluble)

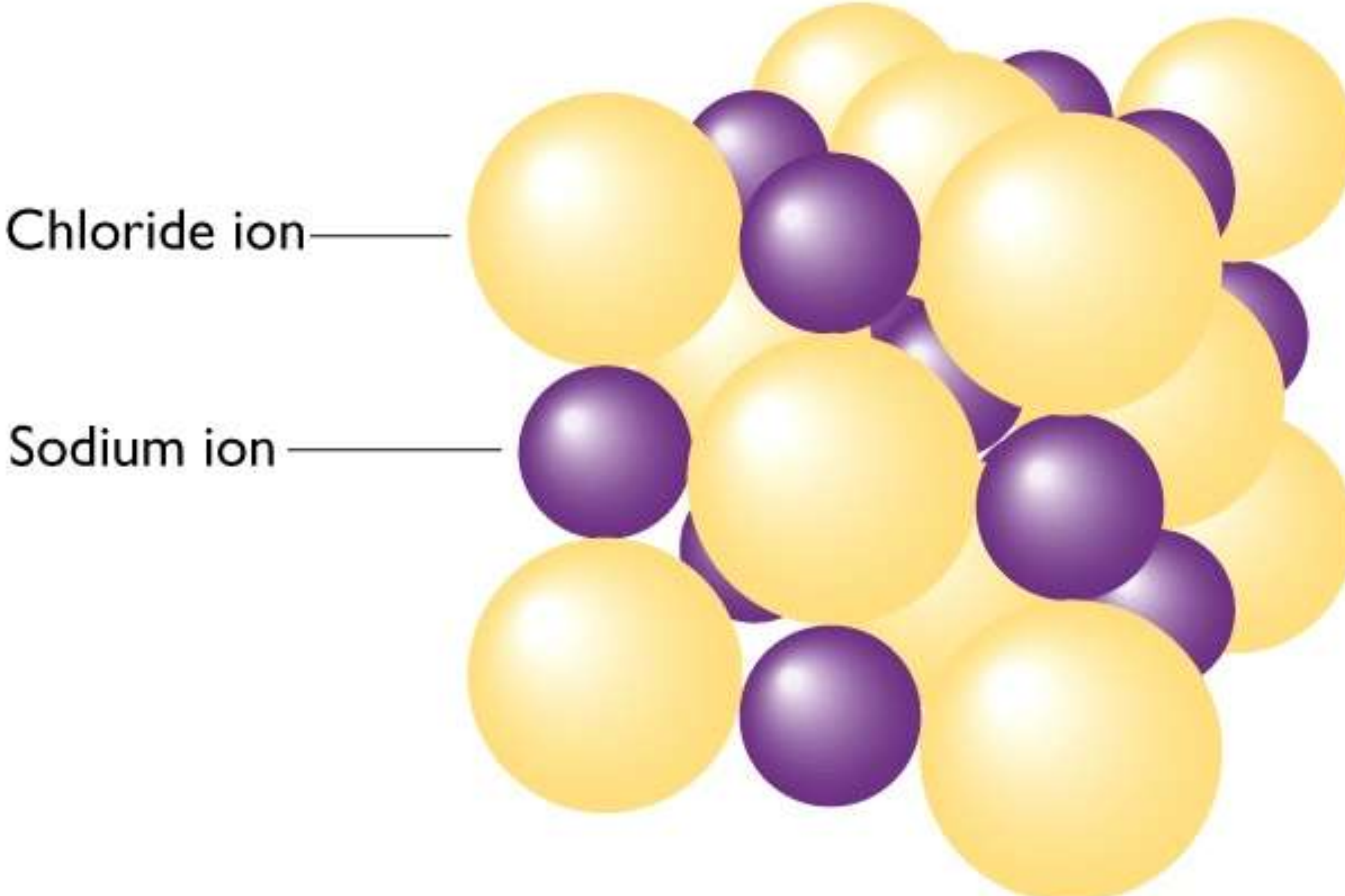
Metallic Bonds

- Also shared electrons but delocalized—not tied to a particular site
- A kind of covalent bond
- Important for thermal and electrical conductivity
- Sheen—absorb and re-emit light by reflection

Mineral structures & properties



- Crystal structure of halite (NaCl, common salt)
- Octahedron, 6 sides in 3-D; 6 Cl about 1 Na



- Halite, a chloride

Major classes of minerals

- Elements
- Sulfides – S
- Oxides – O
- Carbonates – CO_3
- Sulfates - SO_4
- Phosphates PO_4
- Silicates SiO_4

*Key Rock-forming Minerals**

Group	Mineral group / Formula type	Rock type
Non-silicates	Hematite — Fe_2O_3	Sedimentary
	Magnetite — Fe_3O_4	Igneous
	Halite — NaCl	Chemical sedimentary
	Calcite — $CaCO_3$	Chemical sedimentary & metamorphic
	Dolomite — $CaMg(CO_3)_2$	Chemical sedimentary & metamorphic
	Gypsum — $CaSO_4.2H_2O$	Chemical sedimentary
Silicates	Quartz — framework (SiO_2)	Clastic sedimentary & igneous
	Feldspars — framework (Na-K-Ca-Al)	Clastic sedimentary & igneous
	Micas (muscovite, biotite) — sheet (K-Al-Fe-Mg)	Metamorphic & igneous
	Clay group — sheet (K-Na-Al-Fe-Mg)	Sedimentary
	Amphiboles— double chain (Na-Ca-Mg-Fe-Al)	Igneous and metamorphic
	Pyroxenes — single chain (Ca-Mg-Fe-Na-Al)	Igneous and metamorphic
	Olivine — isolated SiO_4 (Mg-Fe)	Igneous and metamorphic
	Garnet — isolated SiO_4 (Ca-Mg-Fe-Al)	Metamorphic

* *What is most important:*
(1) the mineral groups,
(2) their systematic distribution in different rock types,
(3) the differences in composition and structure type

Non-Silicate Minerals

- Carbonates
  - Contain **CO_3** in their structures (e.g., calcite - $CaCO_3$)
- Sulfates
  - Contain **SO_4** in their structures (e.g., gypsum - $CaSO_4 \cdot 2H_2O$)
- Sulfides
  - Contain **S (but no O)** in their structures (e.g., pyrite - FeS_2)
- Oxides
  - Contain **O**, but ***not bonded to Si, C or S*** (e.g., hematite - Fe_2O_3)
- Native elements
  - ***Composed entirely of one element*** (e.g., diamond - C; gold - Au)

The Periodic Table of the Elements

Appendix D, pg. 549

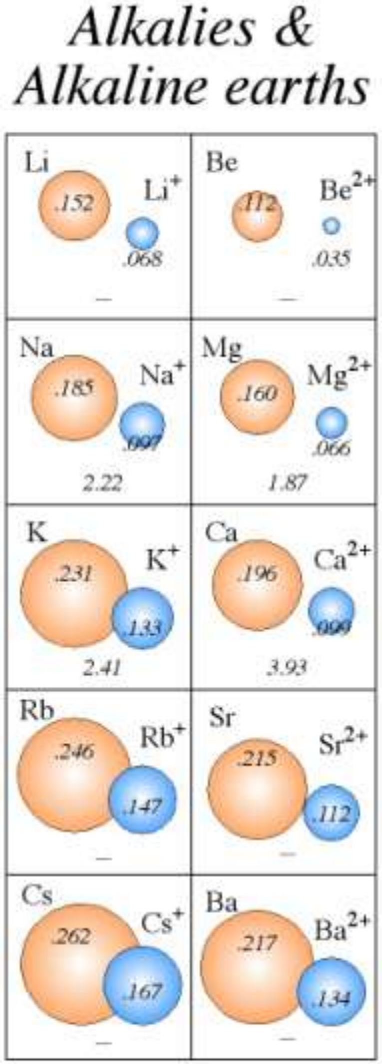
Light Metals · Heavy Metals · Nonmetals

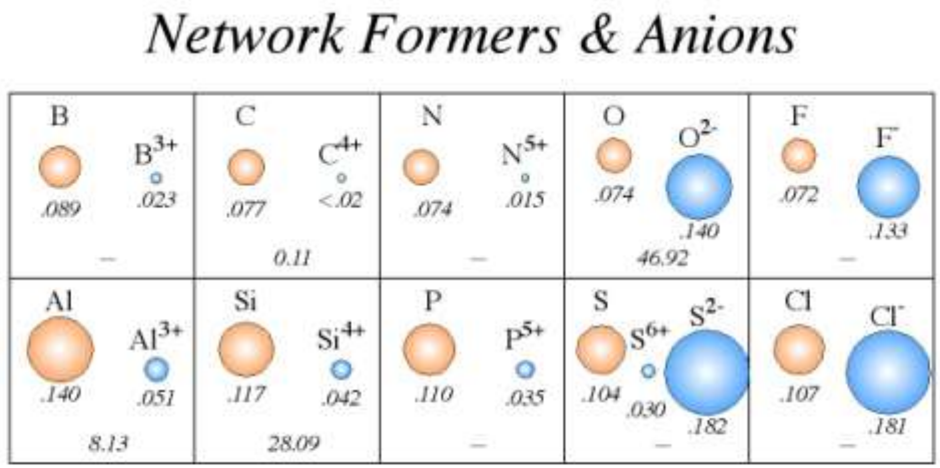
I A	II A	III B	IV B	V B	VI B	VII B	VIII B	VIII B	VIII B	I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1 *H* 1.0080																	2 *He* 4.003
3 *Li* 6.939	4 *Be* 9.012											5 *B* 10.81	6 *C* 12.011	7 *N* 14.007	8 *O* 15.9994	9 *F* 18.998	10 *Ne* 20.183
11 *Na* 22.990	12 *Mg* 24.31											13 *Al* 26.98	14 *Si* 28.09	15 *P* 30.974	16 *S* 32.064	17 *Cl* 35.453	18 *Ar* 39.948
19 *K* 39.102	20 *Ca* 40.08	21 *Sc* 44.96	22 *Ti* 47.90	23 *V* 50.94	24 *Cr* 52.00	25 *Mn* 54.94	26 *Fe* 55.85	27 *Co* 58.93	28 *Ni* 58.71	29 *Cu* 63.54	30 *Zn* 65.37	31 *Ga* 69.72	32 *Ge* 72.59	33 *As* 74.92	34 *Se* 78.96	35 *Br* 79.909	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* (99)	44 *Ru* 101.1	45 *Rh* 102.90	46 *Pd* 106.4	47 *Ag* 107.870	48 *Cd* 112.40	49 *In* 114.82	50 *Sn* 118.69	51 *Sb* 121.75	52 *Te* 127.60	53 *I* 126.90	54 *Xe* 131.30
55 *Cs* 132.91	56 *Ba* 137.34	57 TO 71	72 *Hf* 178.49	73 *Ta* 180.95	74 *W* 183.85	75 *Re* 186.2	76 *Os* 190.2	77 *Ir* 192.2	78 *Pt* 195.09	79 *Au* 197.0	80 *Hg* 200.59	81 *Tl* 204.37	82 *Pb* 207.19	83 *Bi* 208.98	84 *Po* (210)	85 *At* (210)	86 *Rn* (222)
87 *Fr* (223)	88 *Ra* 226.05	89 TO 103															

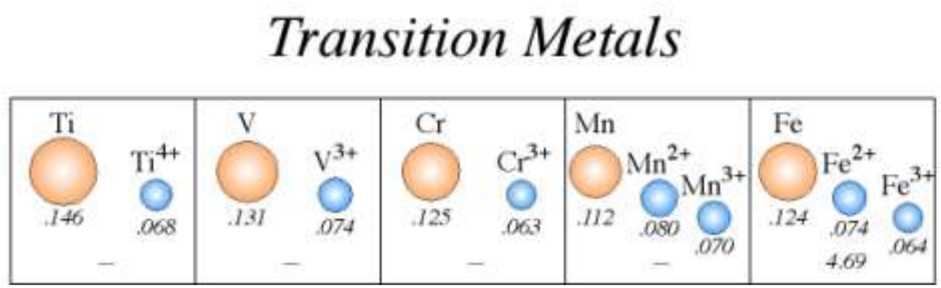
Lanthanide series	57 *La* 138.91	58 *Ce* 140.12	59 *Pr* 140.91	60 *Nd* 144.24	61 *Pm* (147)	62 *Sm* 150.35	63 *Eu* 151.96	64 *Gd* 157.25	65 *Tb* 158.92	66 *Dy* 162.50	67 *Ho* 164.93	68 *Er* 167.26	69 *Tm* 168.93	70 *Yb* 173.04	71 *Lu* 174.97
Actinide series	89 *Ac* (227)	90 *Th* 232.04	91 *Pa* (231)	92 *U* 238.03	93 *Np* (237)	94 *Pu* (242)	95 *Am* (243)	96 *Cm* (247)	97 *Bk* (249)	98 *Cf* (251)	99 *Es* (254)	100 *Fm* (253)	101 *Md* (256)	102 *No* (254)	103 *Lw* (257)

Key Parts of the Periodic Table

showing most important elements, their atomic and ionic radii, and some of their abundances in the crust of the Earth







- Relative size and charge are key features — charge balance and "coordination number"

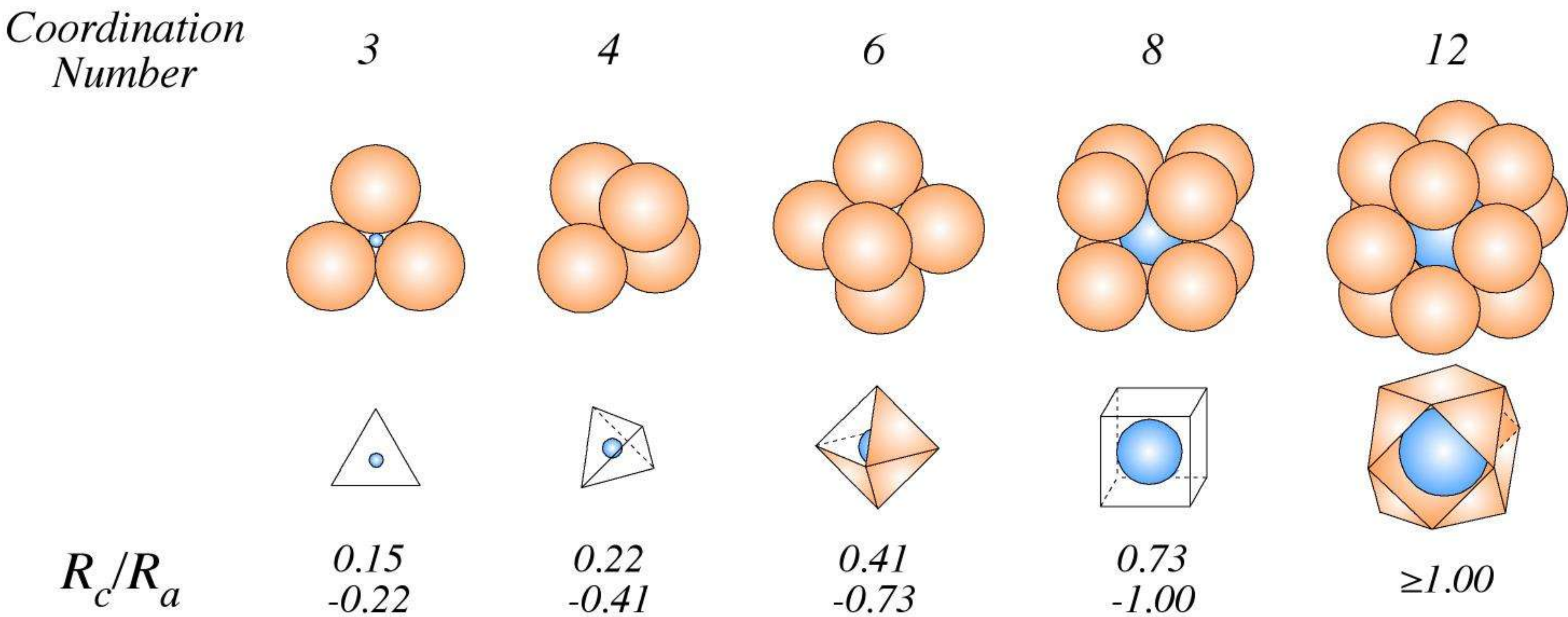
Non-silicate mineral groups

Mineral Type	Composition	Examples	Uses
Carbonates	Metallic ion(s) plus carbonate ion complex (CO_3^{2-})	Calcite ($CaCO_3$)	Cement
		Dolomite ($CaMg(CO_3)_2$)	Cement
Oxides	Metallic ion(s) plus oxygen ion (O^{2-})	Hematite (Fe_2O_3)	Iron ore
		Magnetite (Fe_3O_4)	Iron ore
		Corundum (Al_2O_3)	Gems, abrasives
		Cassiterite (SnO_2)	Tin ore
		Rutile (TiO_2)	Titanium ore
		Ilmenite ($FeTiO_3$)	Titanium ore
		Uraninite (UO_2)	Uranium ore
Sulfides	Metallic ion(s) plus sulfur (S^{2-})	Galena (PbS)	Lead ore
		Pyrite (FeS_2)	Sulfur ore
		Cinnabar (HgS)	Mercury ore
		Sphalerite (ZnS)	Zinc ore
		Molybdenite (MoS_2)	Molybdenum ore
		Chalcopyrite ($CuFeS_2$)	Copper ore
Sulfates	Metallic ion(s) plus sulfate ion (SO_4^{2-})	Gypsum ($CaSO_4 \cdot 2H_2O$)	Plaster
		Anhydrite ($CaSO_4$)	Plaster
		Barite ($BaSO_4$)	Drilling mud
Native elements	Minerals consisting of a single element	Gold (Au)	Jewelry, coins, electronics
		Silver (Ag)	Jewelry, coins, photography
		Platinum (Pt)	Jewelry, catalyst for gasoline productio
		Diamond (C)	Jewelry, drill bits, cutting tools

Apatite: $Ca_5(PO_4)_3F$ — a phosphate

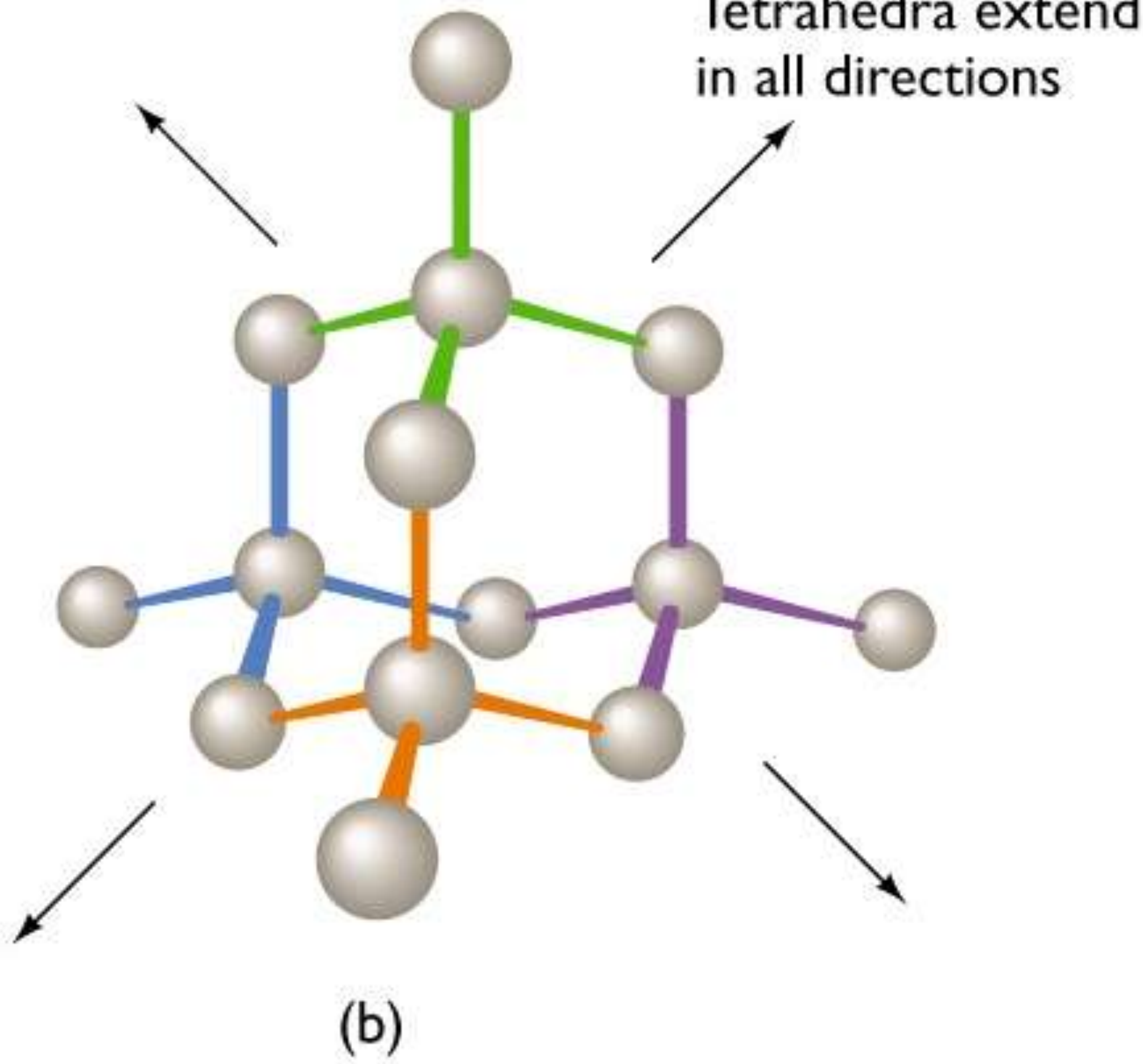
- Tetrahedral PO_4^{-3} group is the anion in phosphates
- Location of most phosphorous in rocks (an essential nutrient)
- Where is most of the phosphorous in this room? (why are calcium and fluoride important?)

Ions Cluster as "Polyhedra"



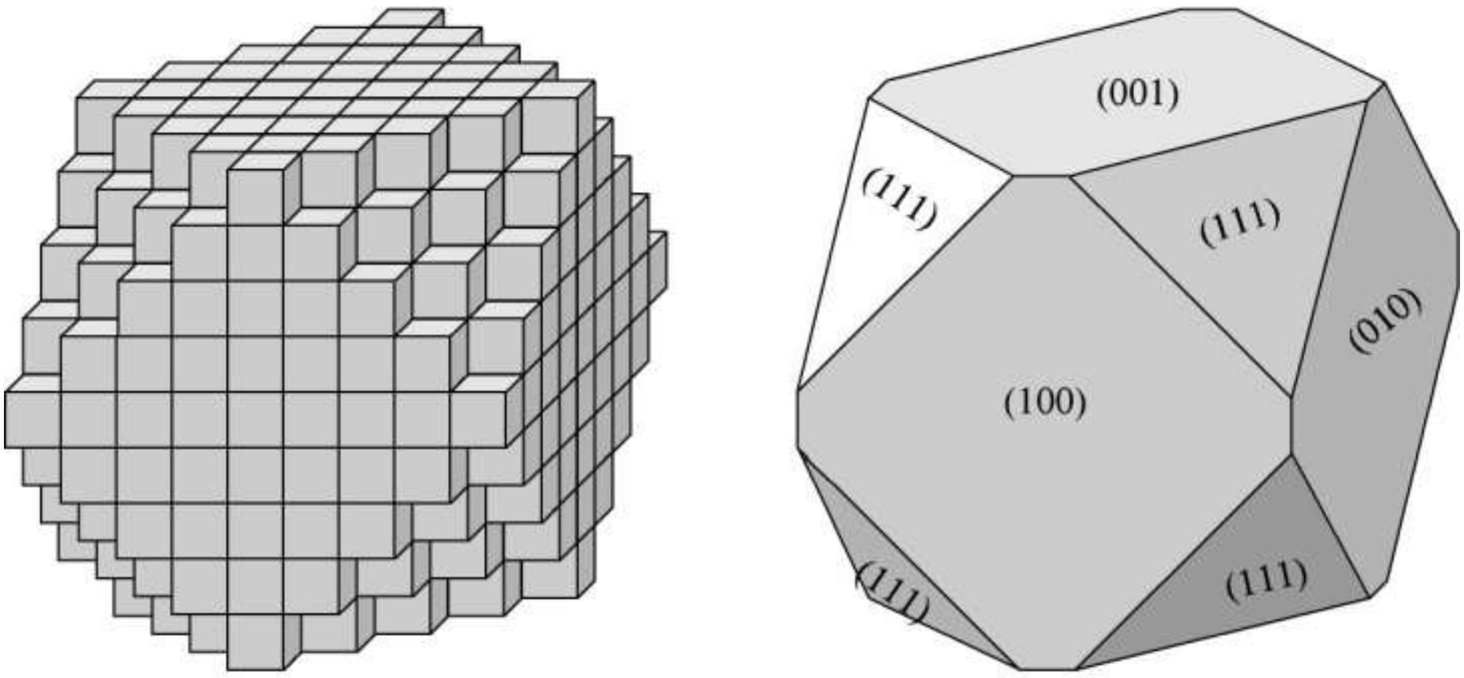
- Opposite charges attract
  - # that go around central ion depends on relative size
  - Does the central ion have + charge or — charge? Why?
- Examine the tetrahedron next (coordination # = 4)

Making a crystal from polyhedra



- Linking polyhedral units by sharing of some or all corners builds a regularly repeating 3-D structure — *a crystal structure*

Relationship of crystal form to structure



A cube-octahedron (as might be seen in galena or fluorite) showing external morphology related to unit cells

- Here, galena / halite are built up from the elementary repeat units of the crystal — note cube and octahedral faces

O Si Al Fe Ca Na K Mg Ti

Table 2.1 Crustal Abundance of Elements

Element	Symbol	Percentage by Weight	Percentage by Volume	Percentage of Atoms
Oxygen	O	46.6	93.8	60.5
Silicon	Si	27.7	0.9	20.5
Aluminum	Al	8.1	0.8	6.2
Iron	Fe	5.0	0.5	1.9
Calcium	Ca	3.6	1.0	1.9
Sodium	Na	2.8	1.2	2.5
Potassium	K	2.6	1.5	1.8
Magnesium	Mg	2.1	0.3	1.4
All other elements		1.5	—	

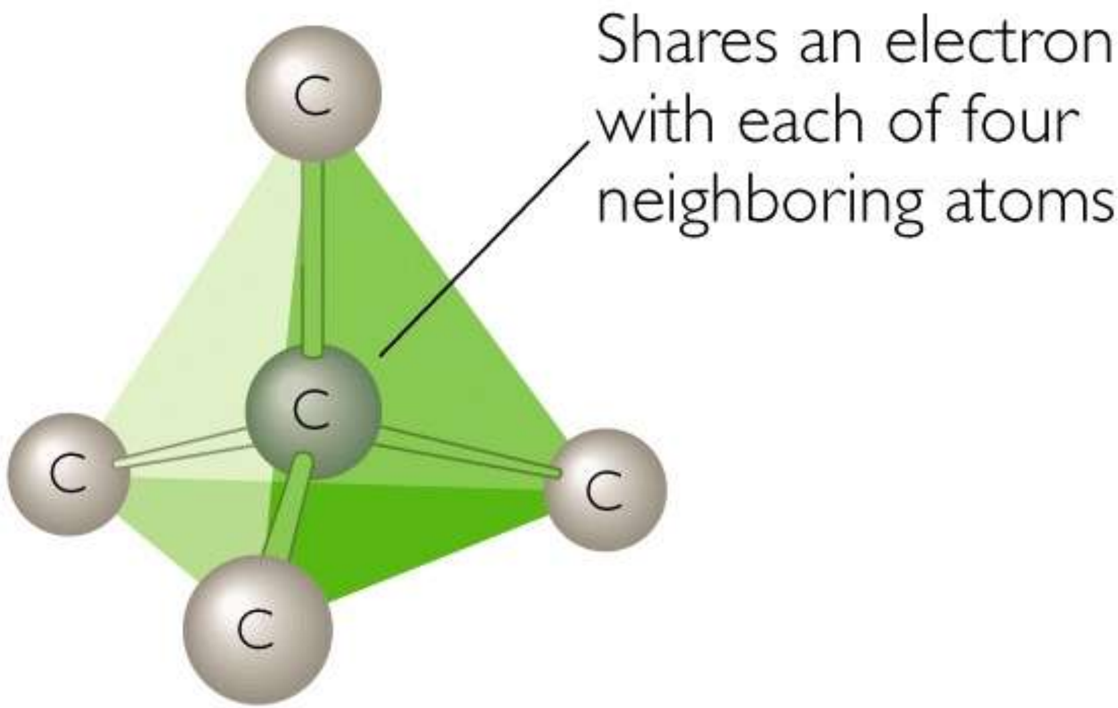
Common rock forming minerals

- Quartz
- K feldspar = orthoclase
- Plagioclase
- Hornblende
- Mica
- Calcite

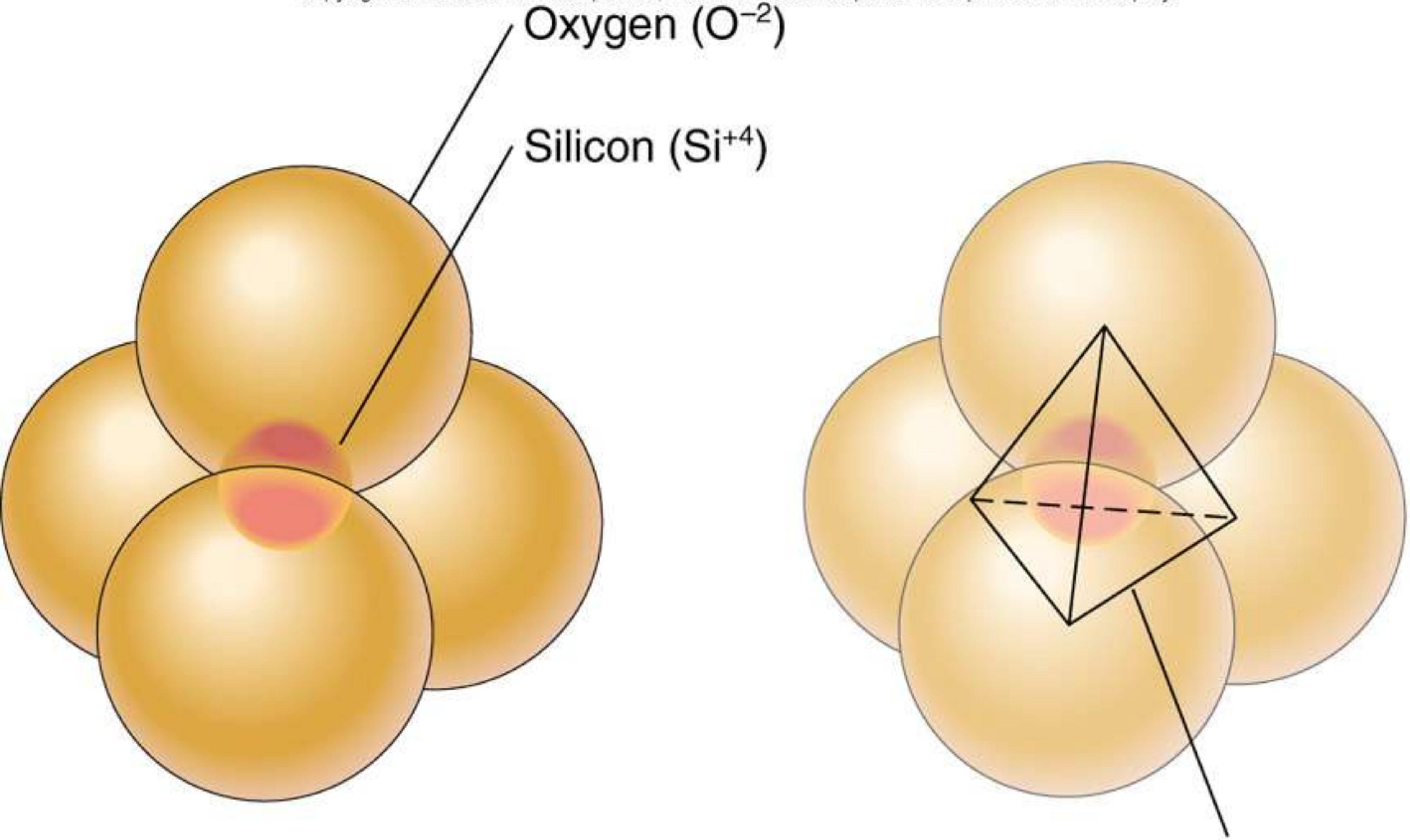



Silicon Oxygen tetrahedron

- 1 silicon,
- 4 oxygen
- SiO_4

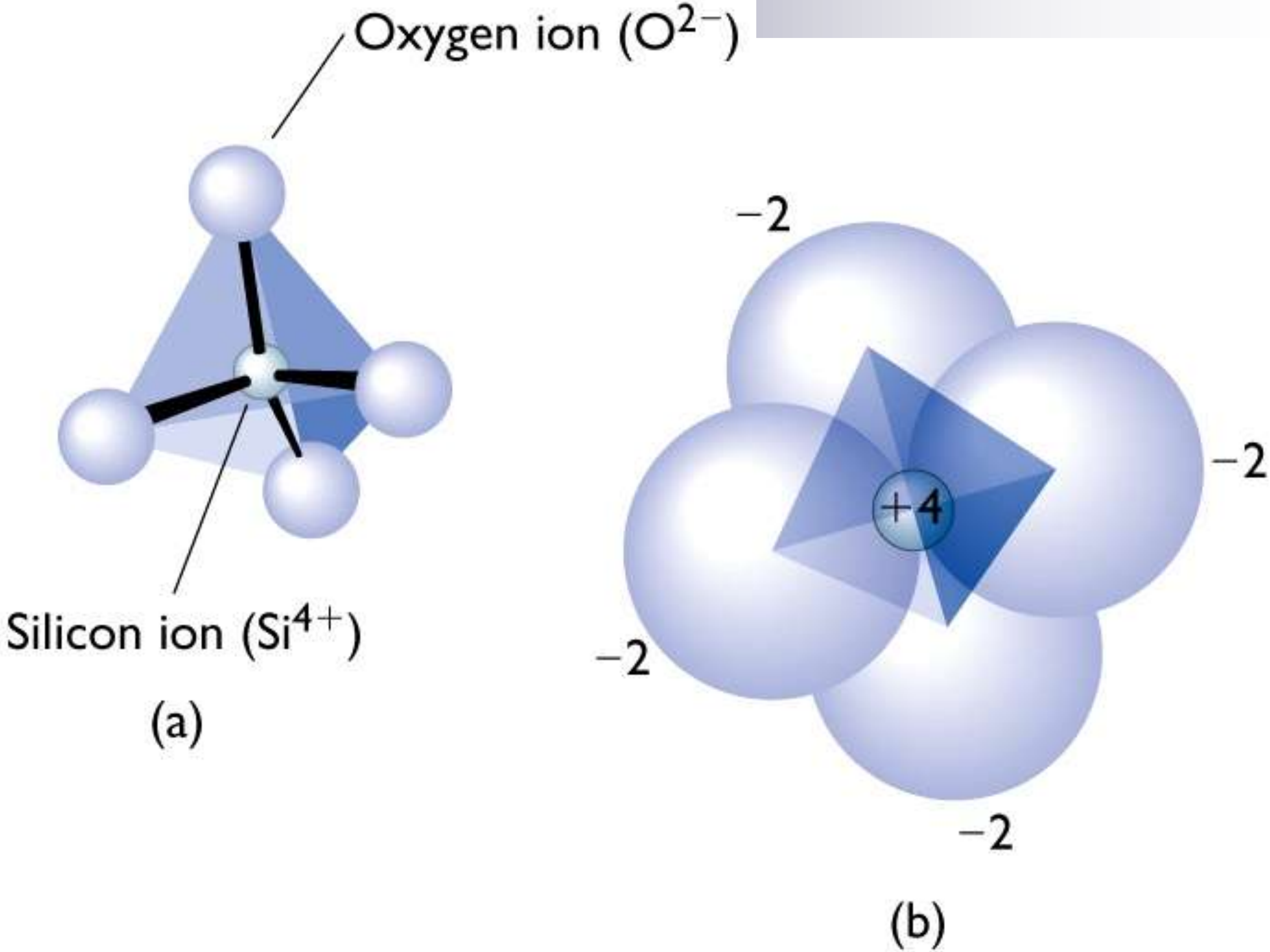


(a)



A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron


Oxygen ion (O^{2-})
Silicon ion (Si^{4+})
(a)
−2
−2
+4
−2
−2
(b)

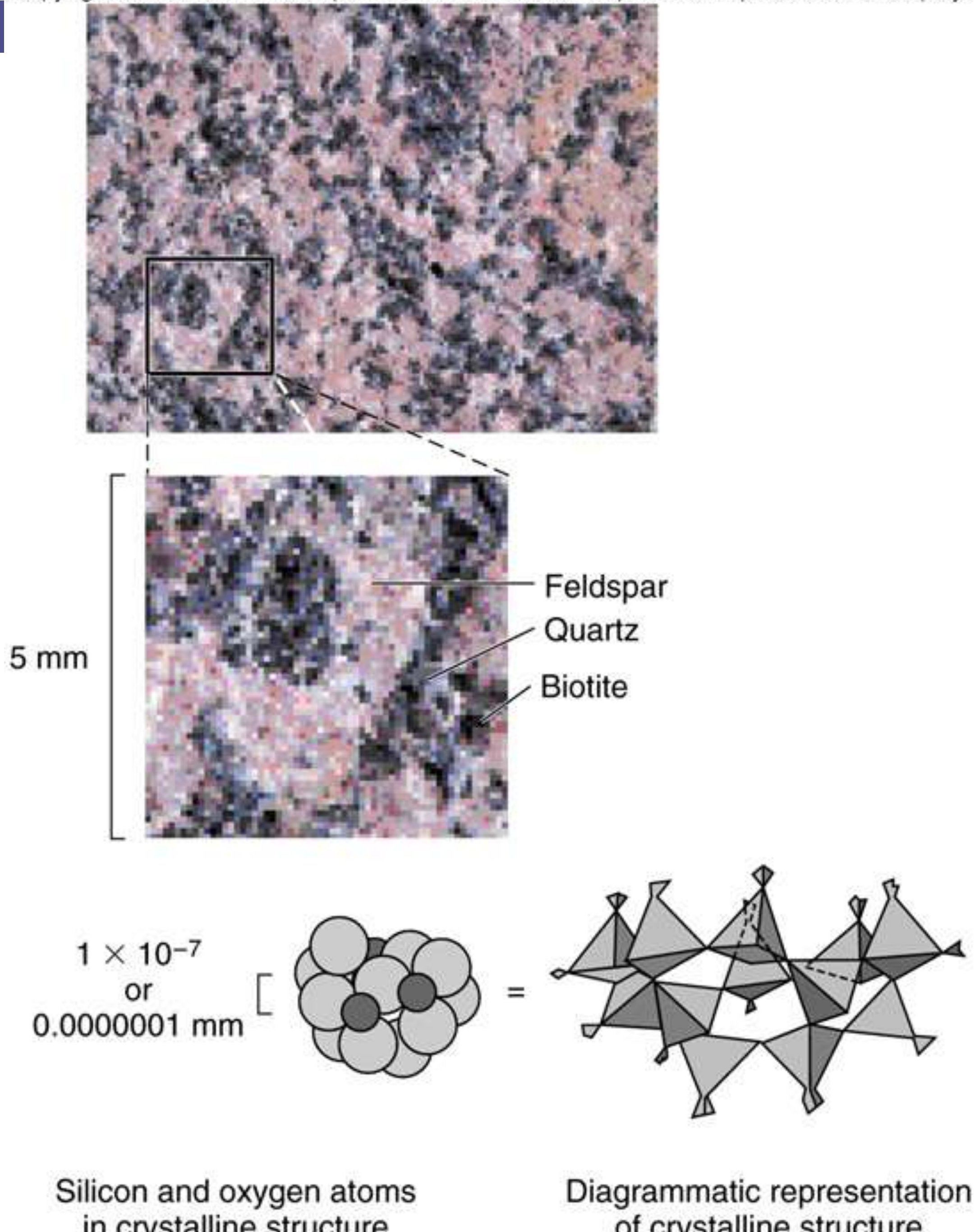
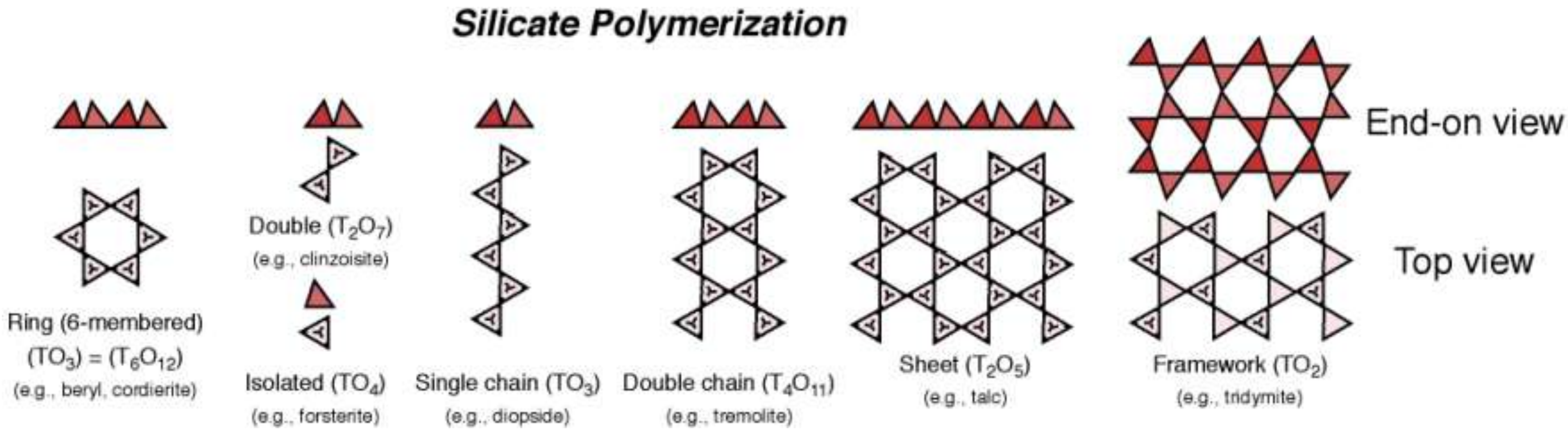


Photo by C. C. Plummer

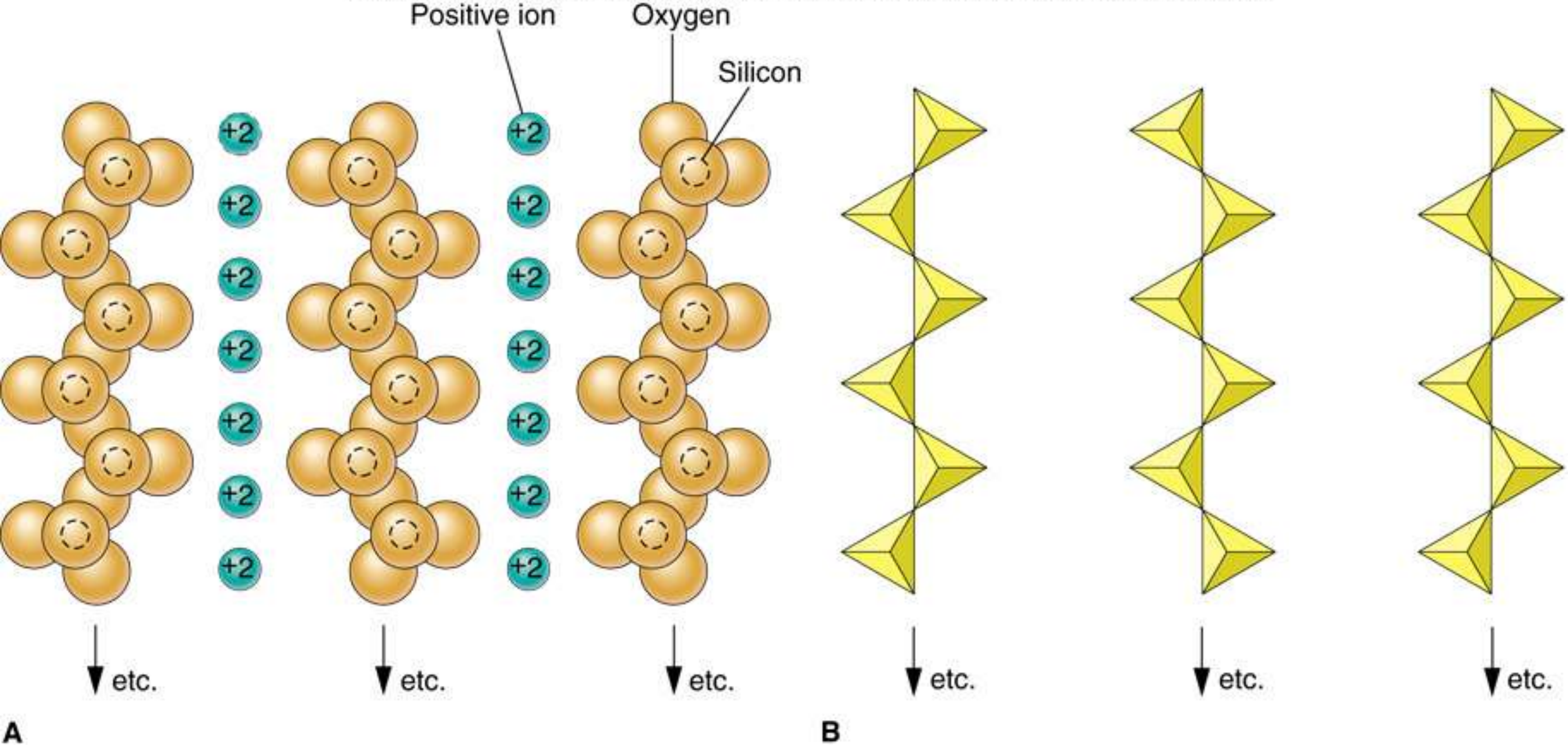
Silicate minerals

- Constructed of $SiO_4^{=}$ tetrahedra that share 0 to 4 of their corners with other tetrahedra
- With all shared, we get SiO_2 (quartz) — a “framework” silicate (3-d connections)
- With fewer shared or with some Al^{+3} for Si^{+4} we need to charge balance with other ions — typically these are Na, K, Mg, Ca, Fe, Al, H
- With fewer than 4 corners shared we get sheet, double chain, single chain & ortho silicates
- *similar relationships apply in silicate melts*

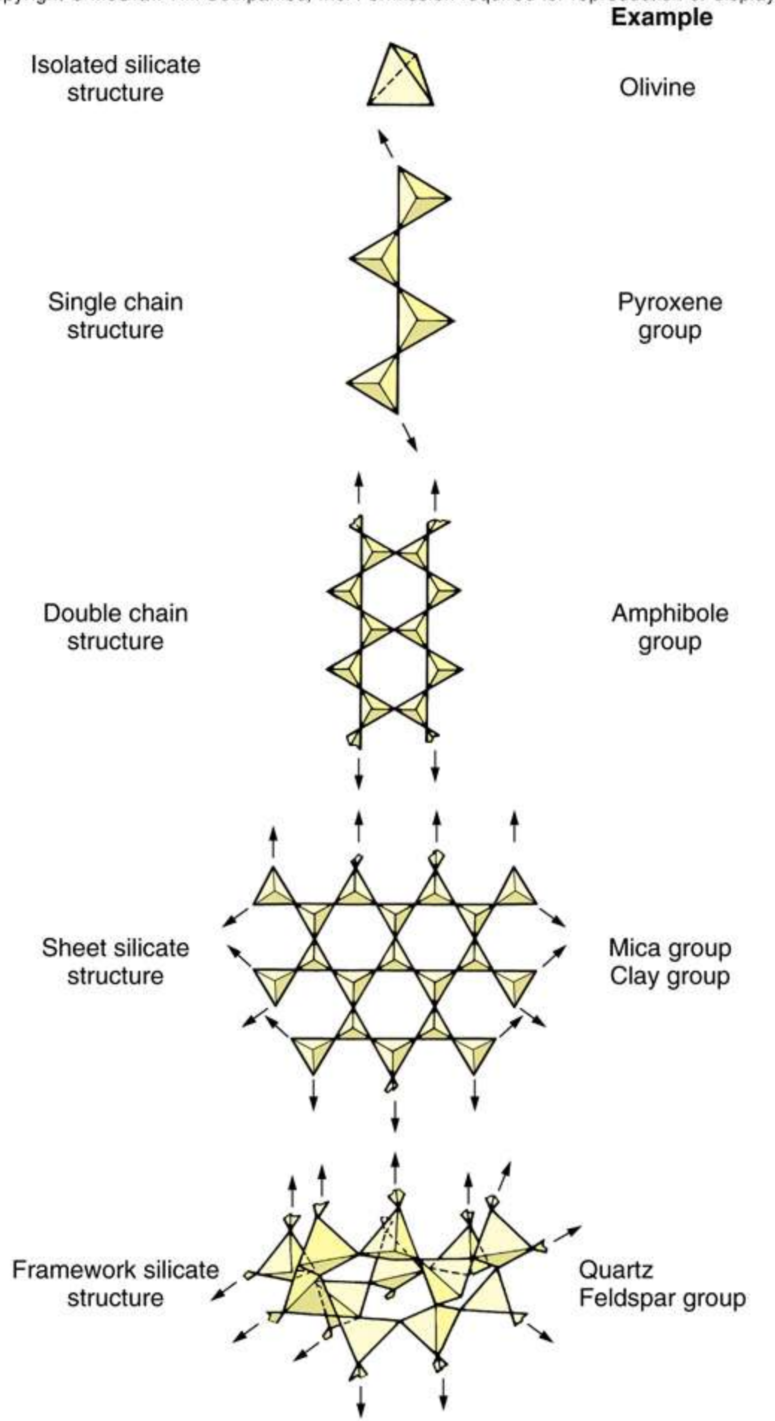


- The main groups of silicate units that make up most silicate minerals — different amounts of polymerization
  - *isolated, single & double chain, sheet, framework*
- We now look at these groups along with their related physical properties

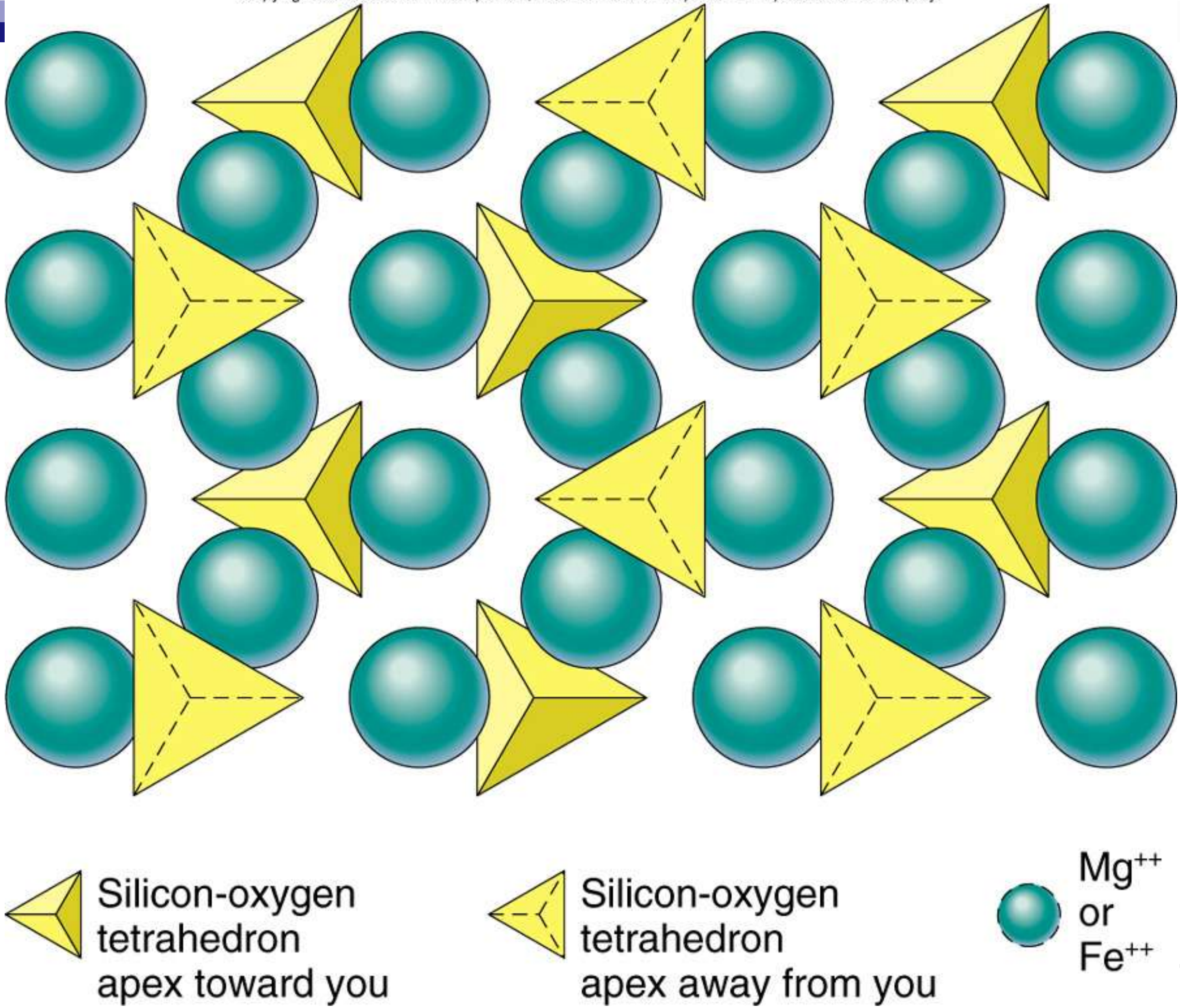
Single chains



silicates



Example
Isolated silicate structure
Olivine
Single chain structure
Pyroxene group
Double chain structure
Amphibole group
Sheet silicate structure
Mica group
Clay group
Framework silicate structure
Quartz
Feldspar group

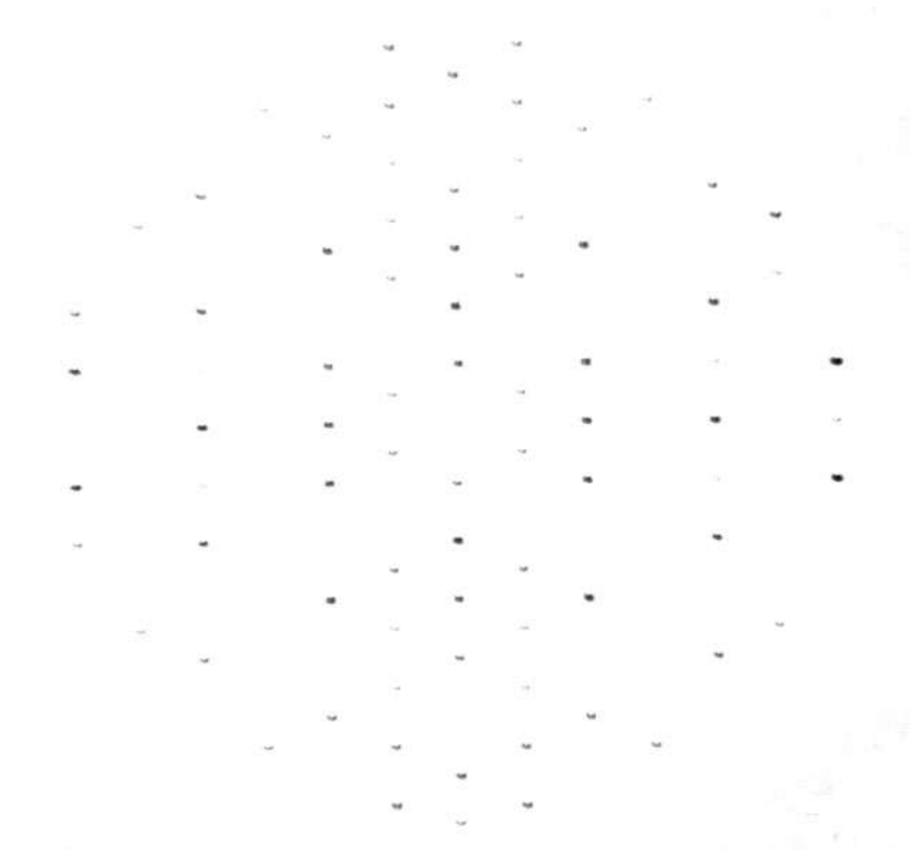


Silicon-oxygen tetrahedron apex toward you
Silicon-oxygen tetrahedron apex away from you
Mg^{++} or Fe^{++}

Physical properties

- Luster
- Cleavage
- Hardness
- Crystal form
- Color
- Streak
- fizz

Tools for Mineral Identification and Study



- Hand lens
- Petrographic microscope
- X-ray diffraction
- Electron microscopy
- Microbeam analysis

Cleavage, fracture

- Cleavage = ability of a mineral to break along preferred planes
- Fracture = the way a substance breaks when it is not controlled by cleavage – irregular surfaces (not planes)

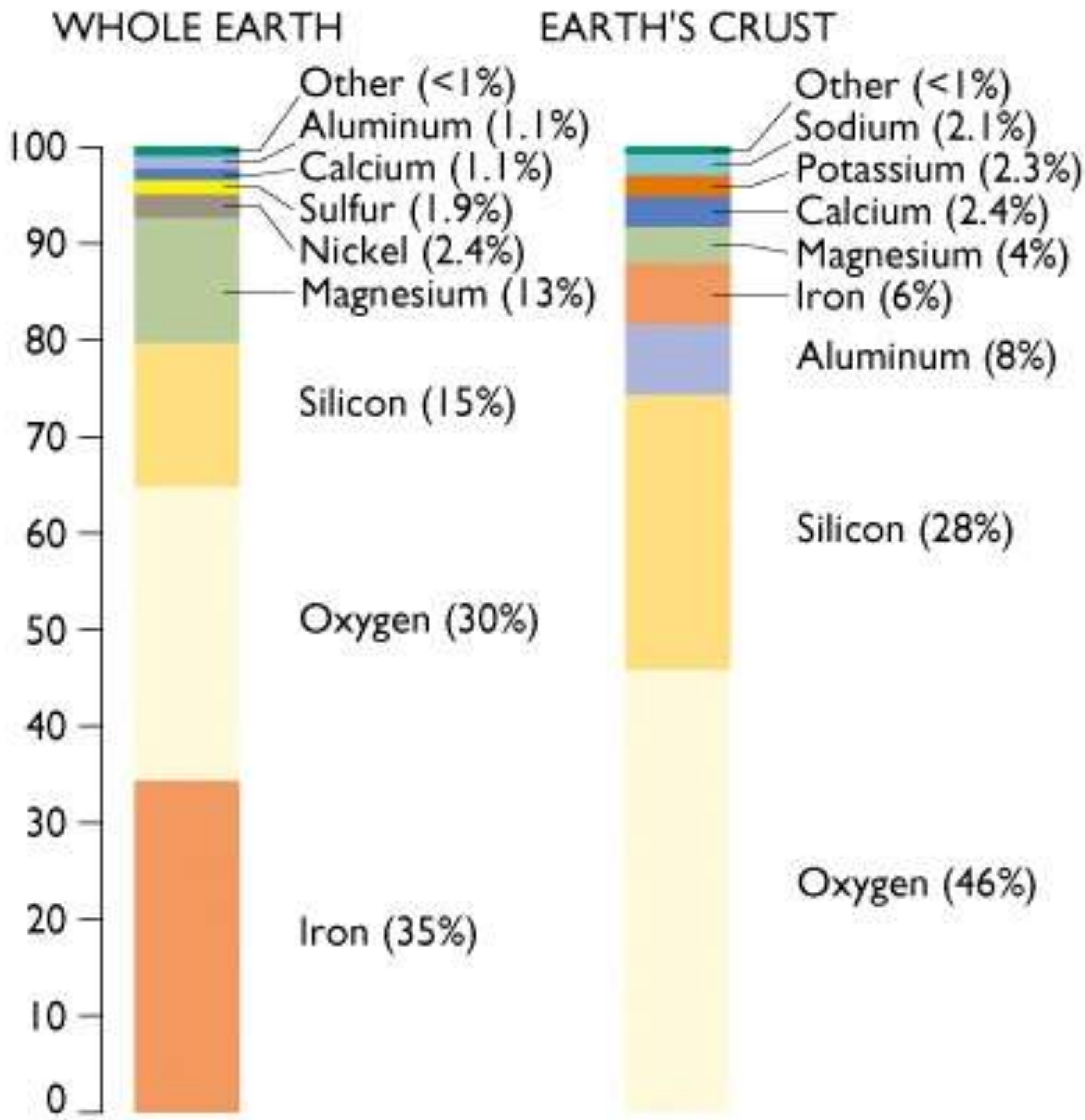
Mohs hardness scale

Table 2.3 Mohs' Hardness Scale

1. Talc
2. Gypsum
   Fingernail
3. Calcite
   Copper coin
4. Fluorite
5. Apatite
   Knife blade
   Glass
6. Feldspar
   File
7. Quartz
8. Topaz
9. Corundum
10. Diamond

streak

- Color of a pulverized substance
- Obtained from rubbing a mineral on an unglazed procelain tile
- Ex. - distinctive reddish brown streak - hematite



Chemical make-up of the solid Earth

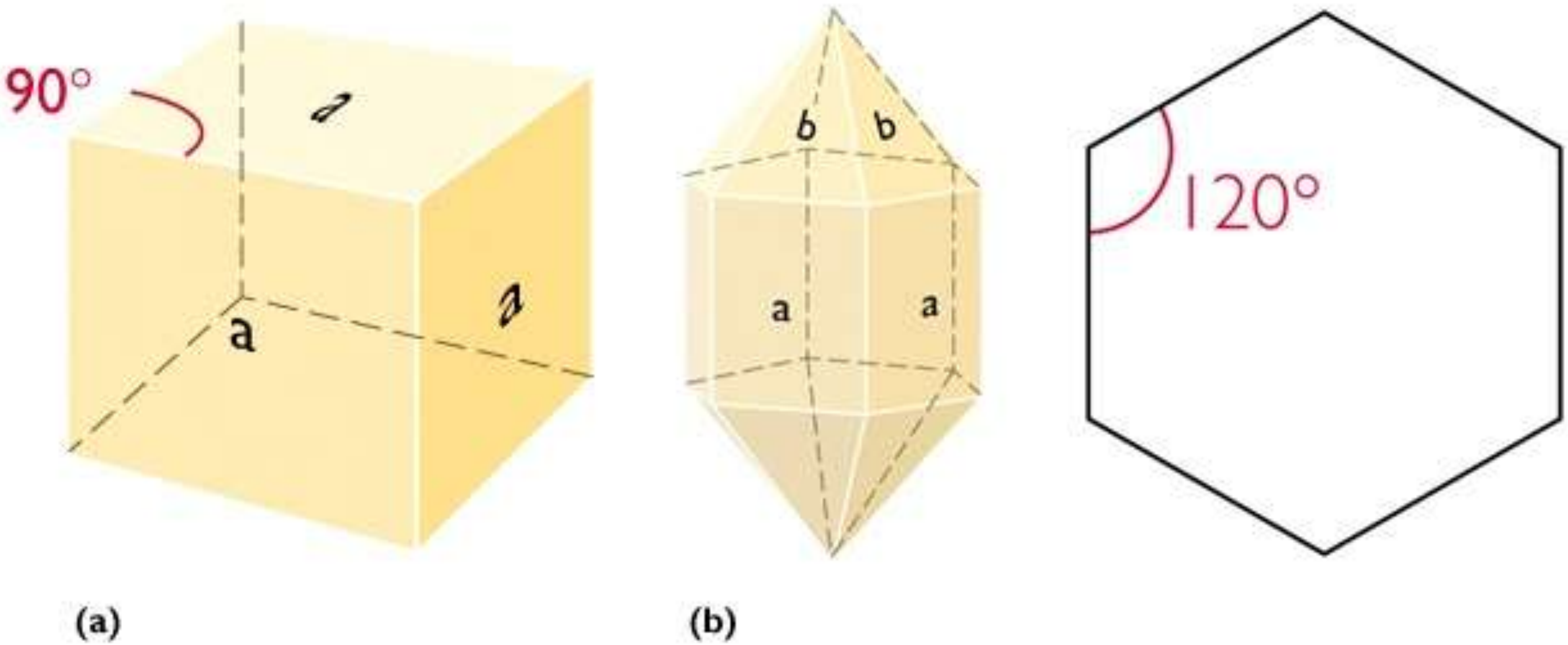
- Good to know major elements in core, mantle, crust (hint, hint...)
- These (+ H, C) are the building blocks of the common minerals that make up most rocks — the "rock-forming minerals"

(b)

- Galena (lead sulfide) and halite (common salt, sodium chloride) have the same crystal structures; thus, similar forms and cleavages (*why might other properties differ?*)

External characteristics of crystals

- Regular geometry of crystals — symmetry
  - Crystal “faces” (growth surfaces)
  - Physical properties (e.g., cleavage — planes of breaking)
- Both reflect the underlying crystal structure



- Angular relationships are key distinguishing features--not relatives sizes, elongation, etc.
- Halite 90 degrees: cubic
- Quartz 120 degrees: hexagonal

Photo by C. C. Plummer

A

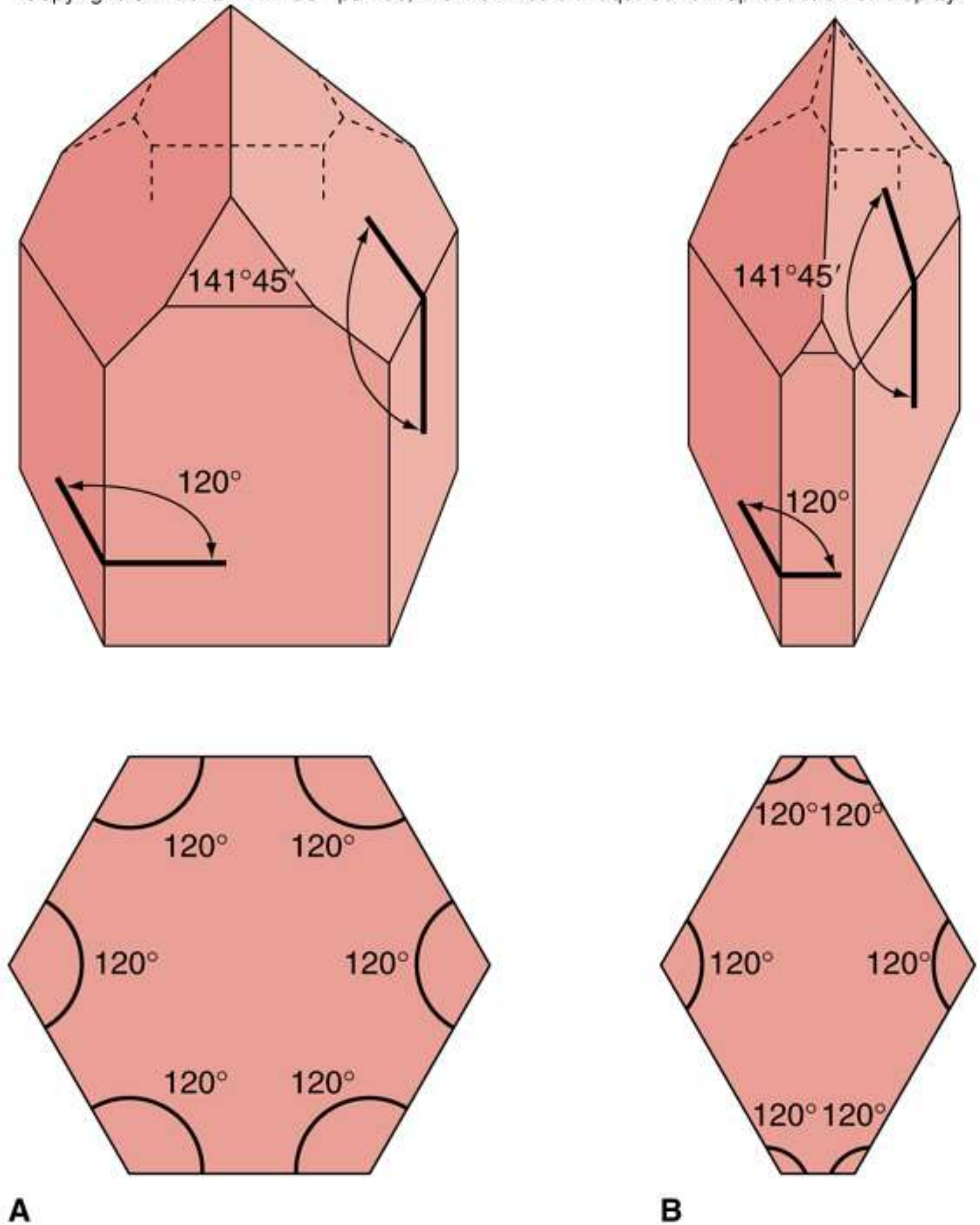
Photo by C. C. Plummer

B

Photo by C. C. Plummer

C

Photo by C. C. Plummer


141°45′
120°
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A
141°45′
120°
120°120°
120°
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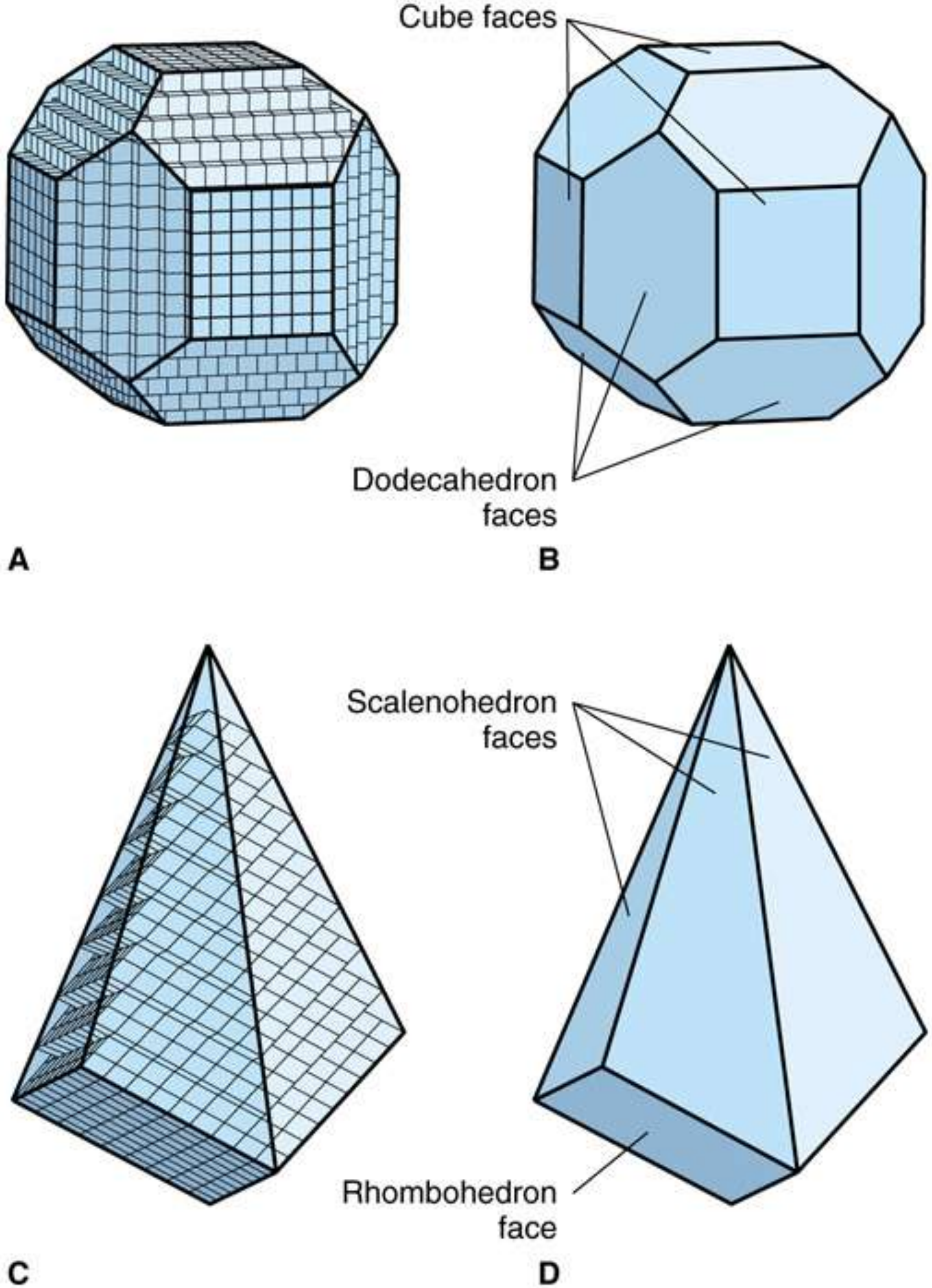
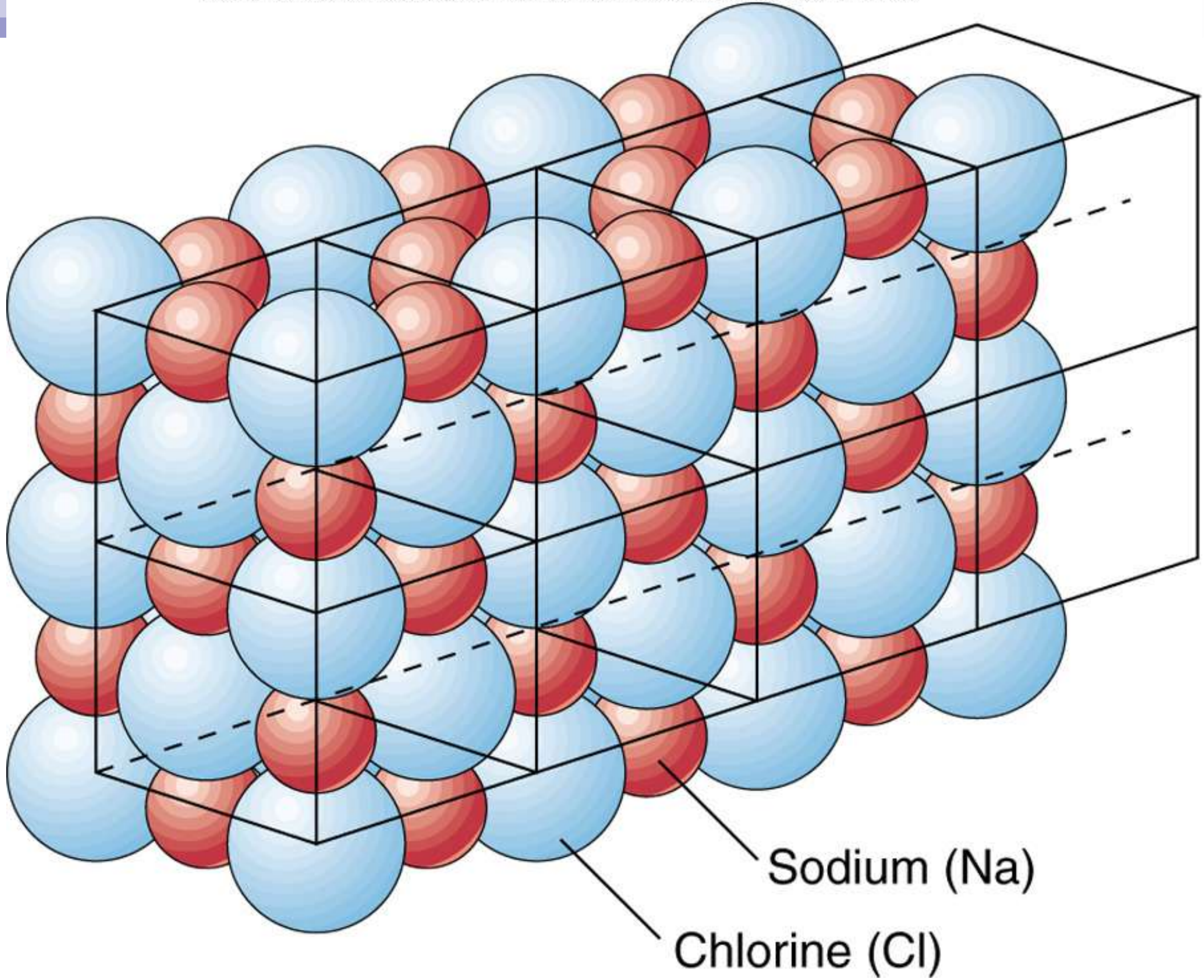
120° 120°
B


Cube faces
Dodecahedron faces
A
B
Scalenohedron faces
Rhombohedron face
C
D


Sodium (Na)
Chlorine (Cl)

A

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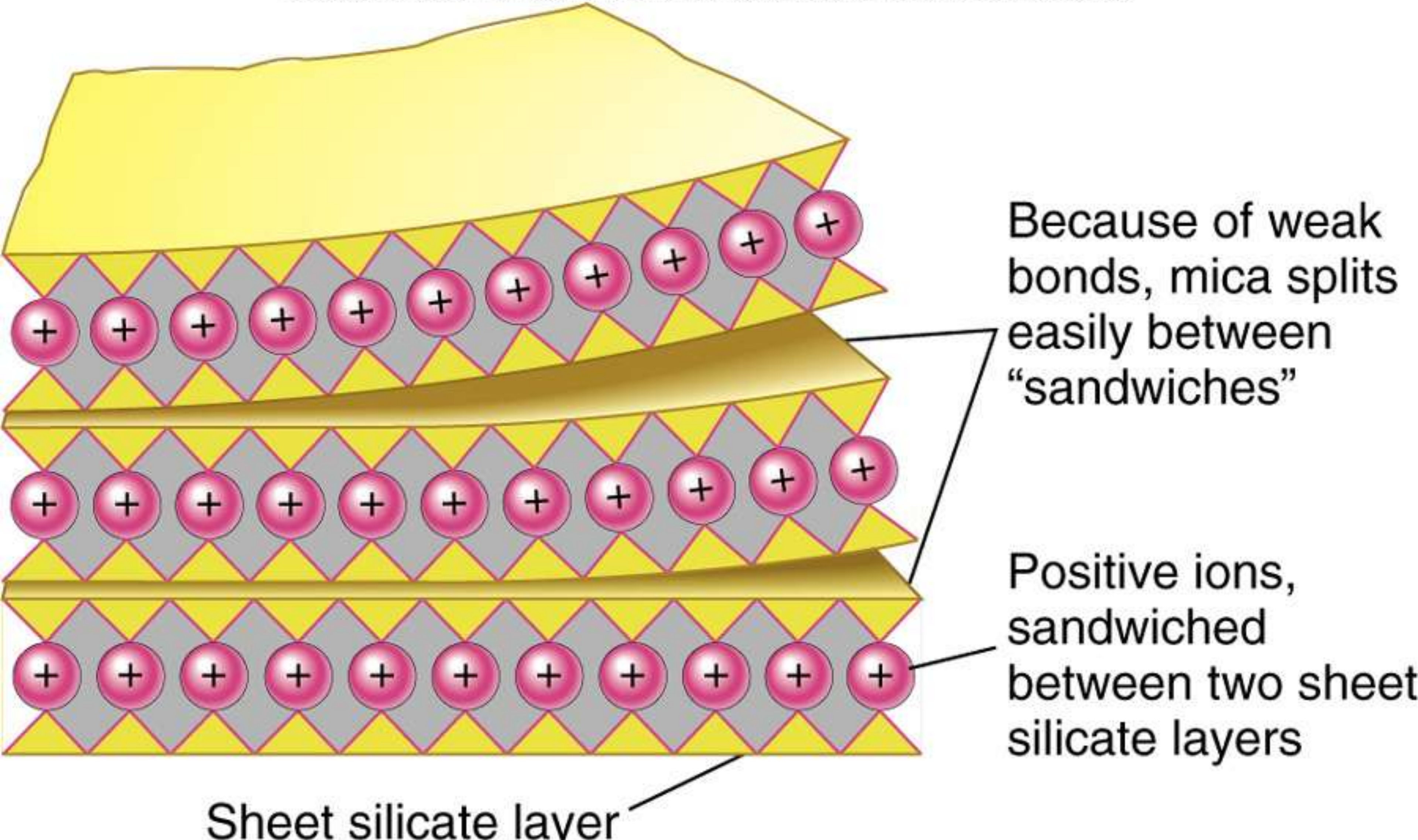
Because of weak bonds, mica splits easily between "sandwiches"
Positive ions, sandwiched between two sheet silicate layers
Sheet silicate layer

B

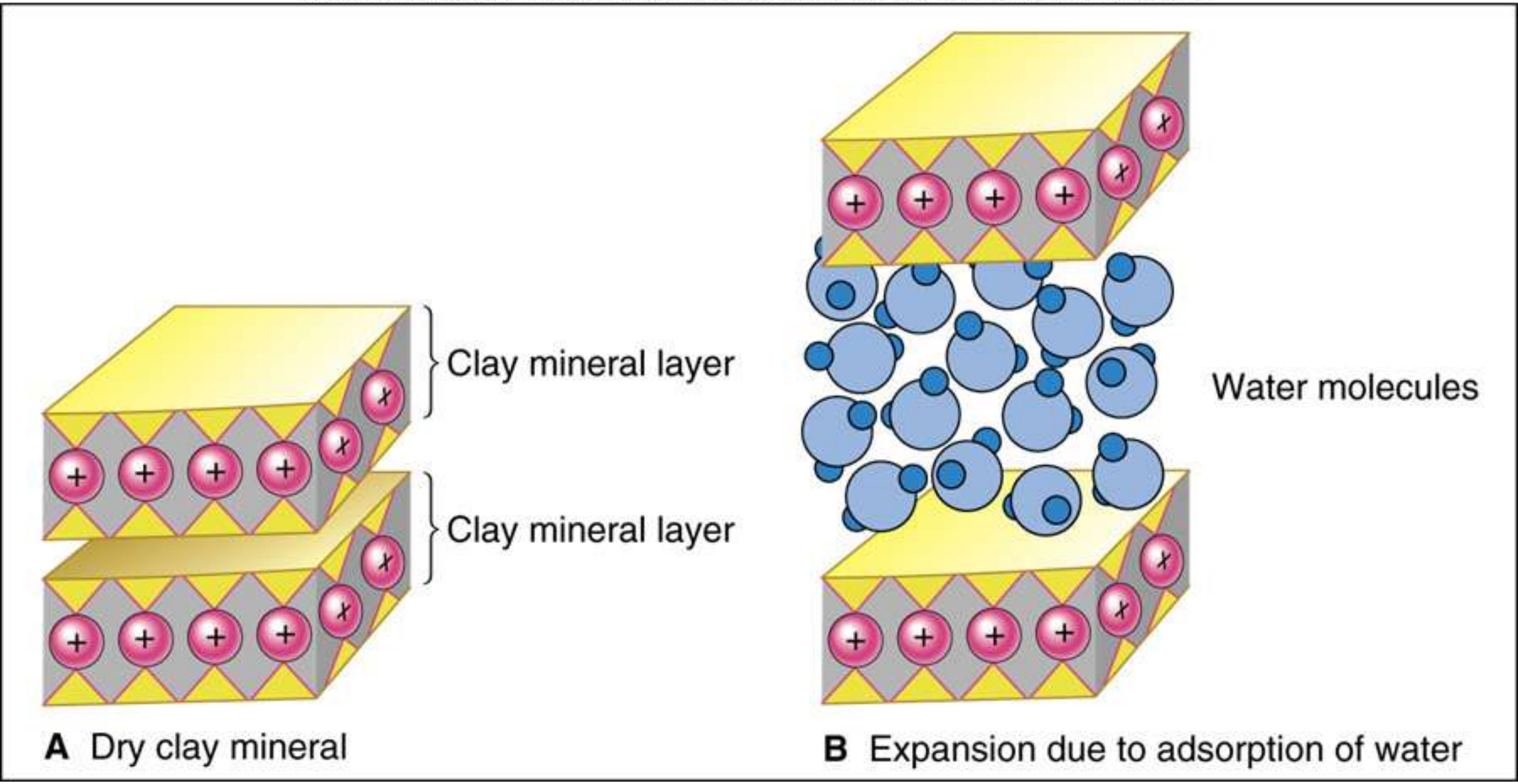
Clay mineral layer
Clay mineral layer
Water molecules
A Dry clay mineral
B Expansion due to adsorption of water

Fig. 02.21

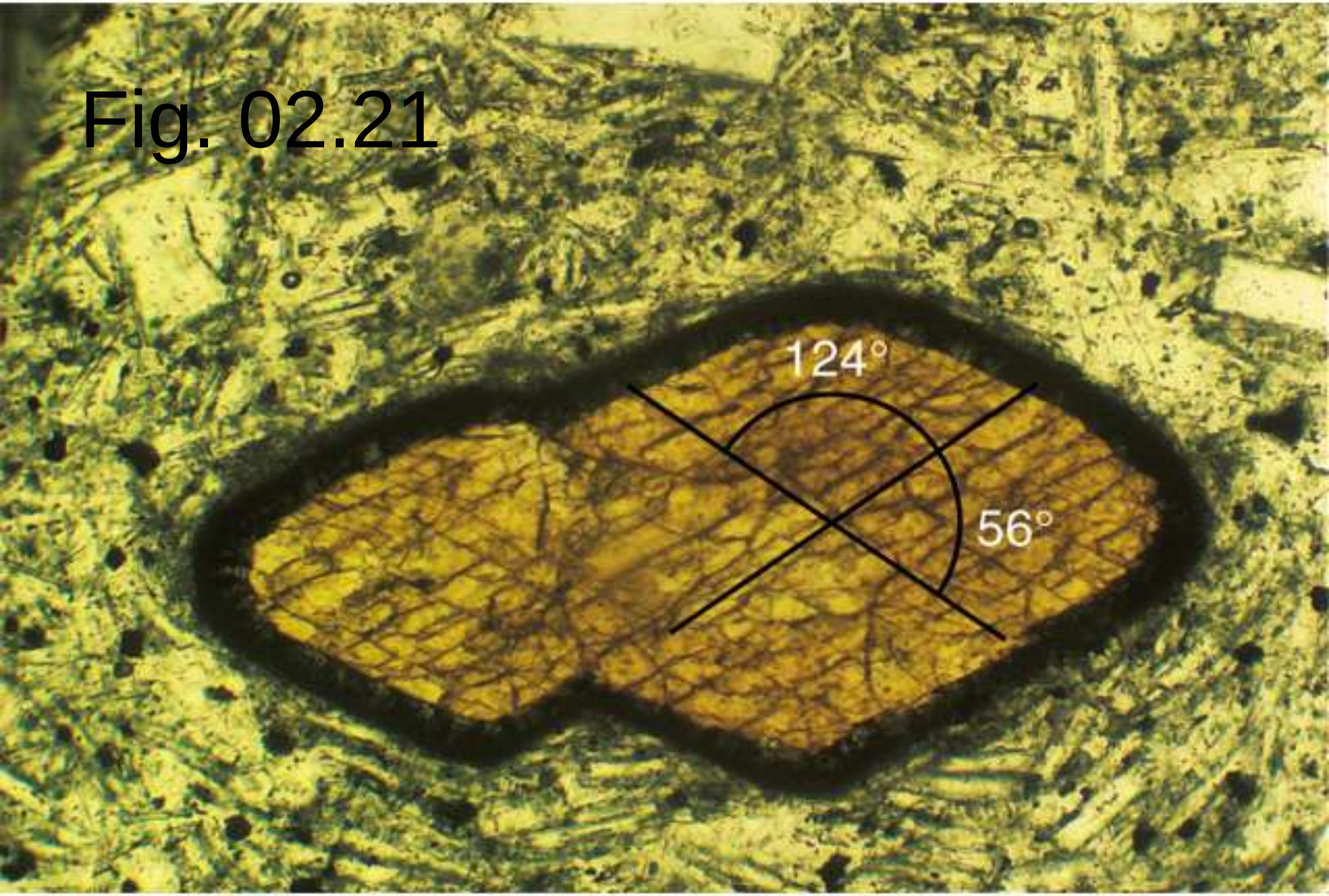

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Fig. 02.23

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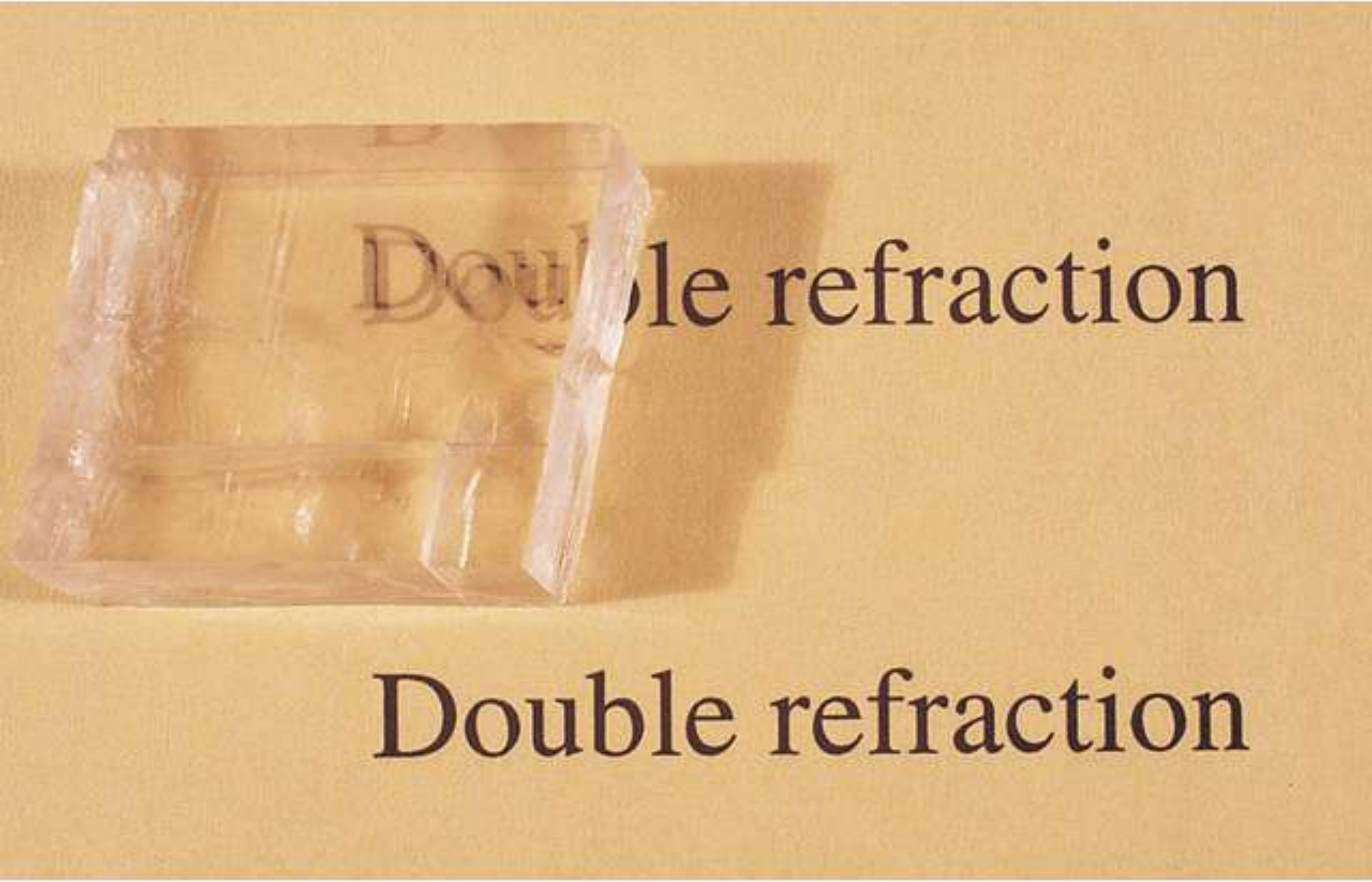

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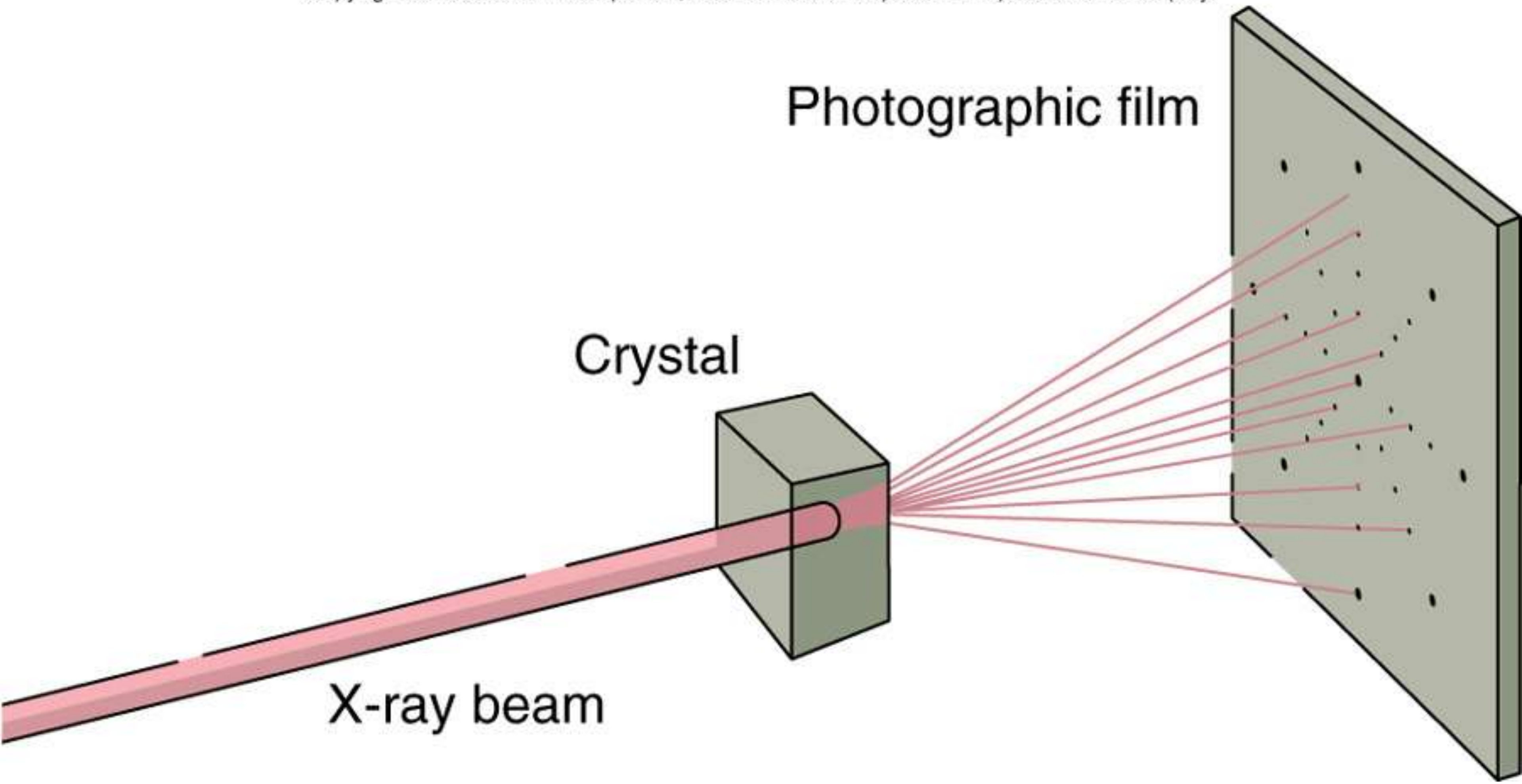
Photographic film
Crystal
X-ray beam

Table 2.2 Minerals of the Earth's Crust

Name	Chemical Composition	Type of Silicate Structure or Chemical Group
The most common rock-forming minerals. (These make up more than 90% of the Earth's crust.)		
Feldspar group		
Plagioclase	Ca and Na Al silicate	Framework silicate
Potassium feldspar (orthoclase, microcline)	K Al silicate	Framework silicate
Pyroxene group (augite most common)	Fe, Mg silicate (some with Al, Na, Ca)	Single-chain silicate
Amphibole group (hornblende most common)	Complex Fe, Mg, Al silicate hydroxide	Double-chain silicate
Quartz	Silica	Framework silicate
Mica group		
Muscovite	K Al silicate hydroxide	Sheet silicate
Biotite	K Fe, Mg Al silicate hydroxide	Sheet silicate
Other common rock-forming minerals.		
Silicates		
Olivine	Mg, Fe silicate	Isolated silicate
Garnet group	Complex silicates	Isolated silicate
Clay minerals group	Complex Al silicate hydroxides	Sheet silicate
Nonsilicates		
Calcite	$CaCO_3$	Carbonate
Dolomite	$CaMg(CO_3)_2$	Carbonate
Gypsum	$CaSO_4 \cdot 2H_2O$	Sulfate
Much less common minerals of commercial value.		
Halite	NaCl	Chloride
Diamond	C	Native element
Gold	Au (gold)	Native element
Hematite	Iron oxide (Fe_2O_3)	Oxide
Magnetite	Iron oxide (Fe_3O_4)	Oxide
Chalcopyrite	Cu, Fe sulfide	Sulfide
Sphalerite	Zn sulfide	Sulfide
Galena	Pb sulfide	Sulfide

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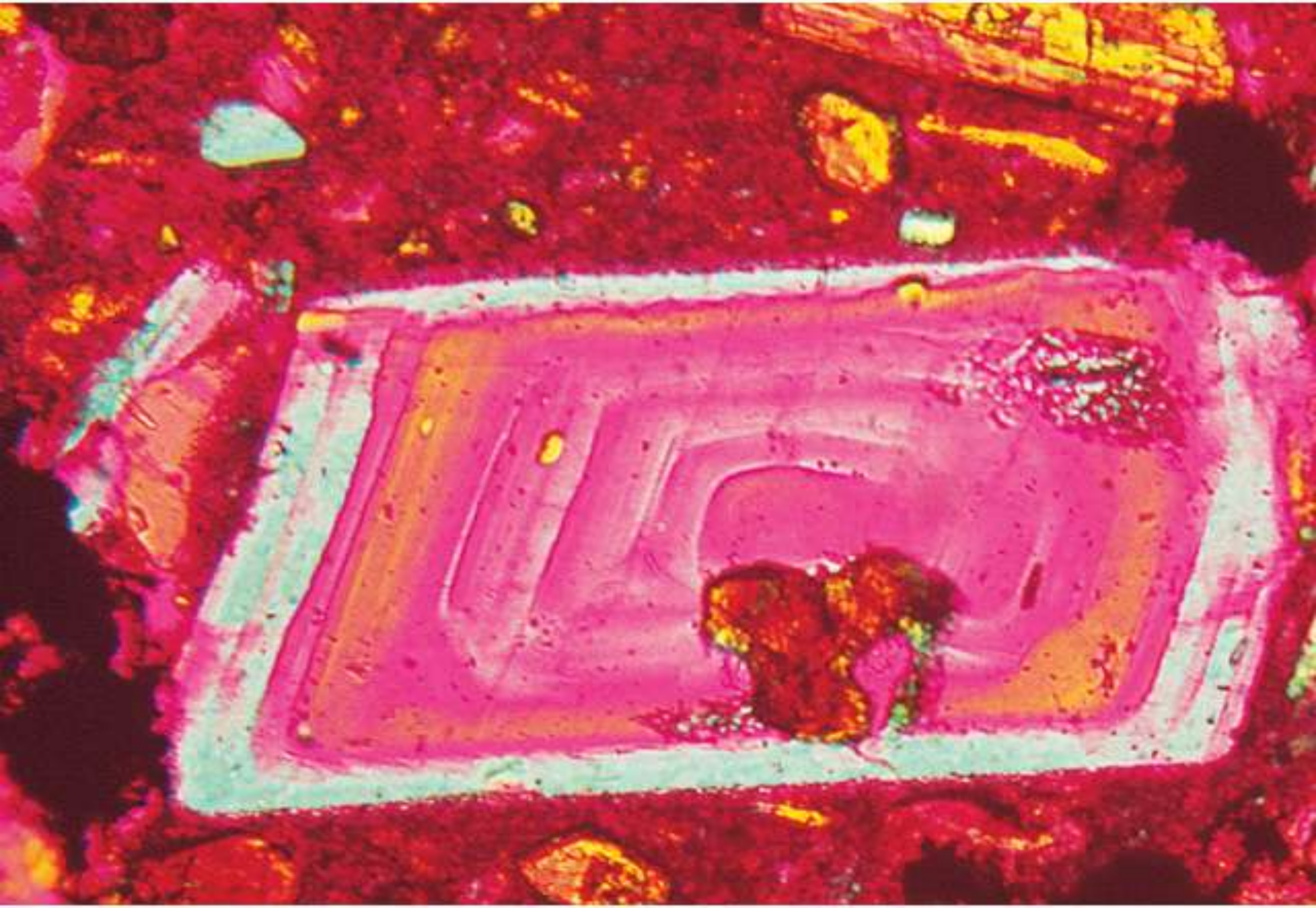

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