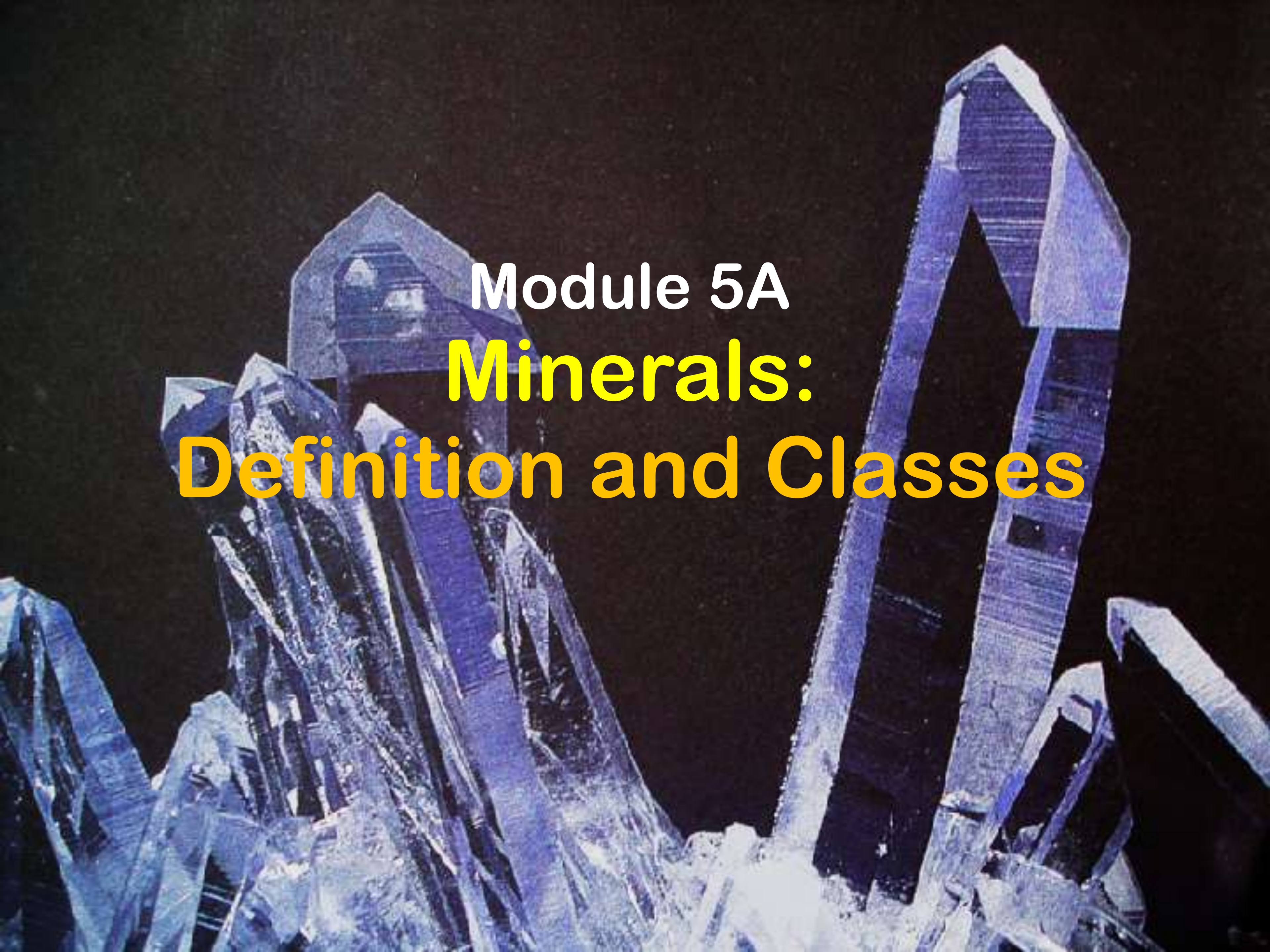


Module 5A

Minerals: Definition and Classes

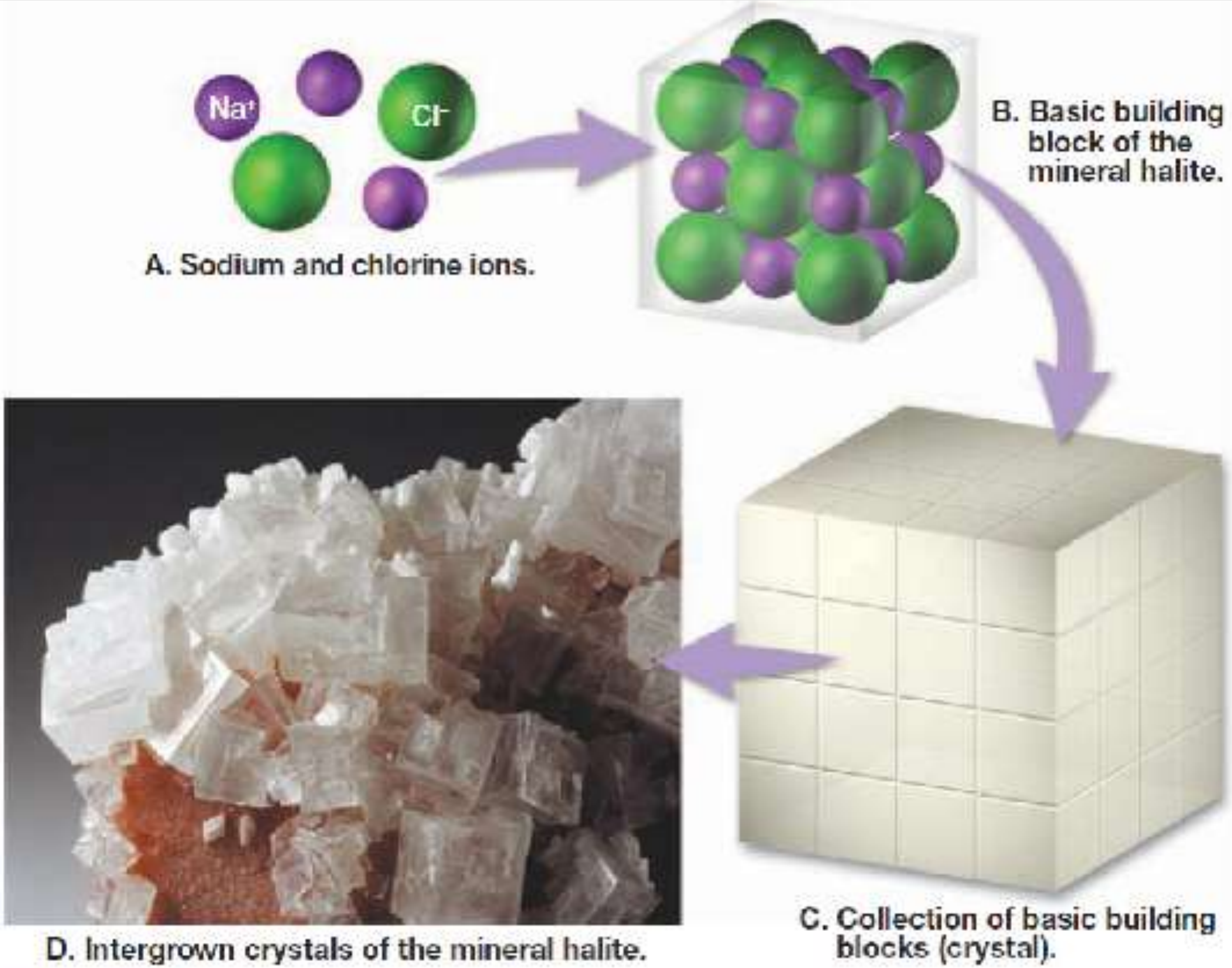
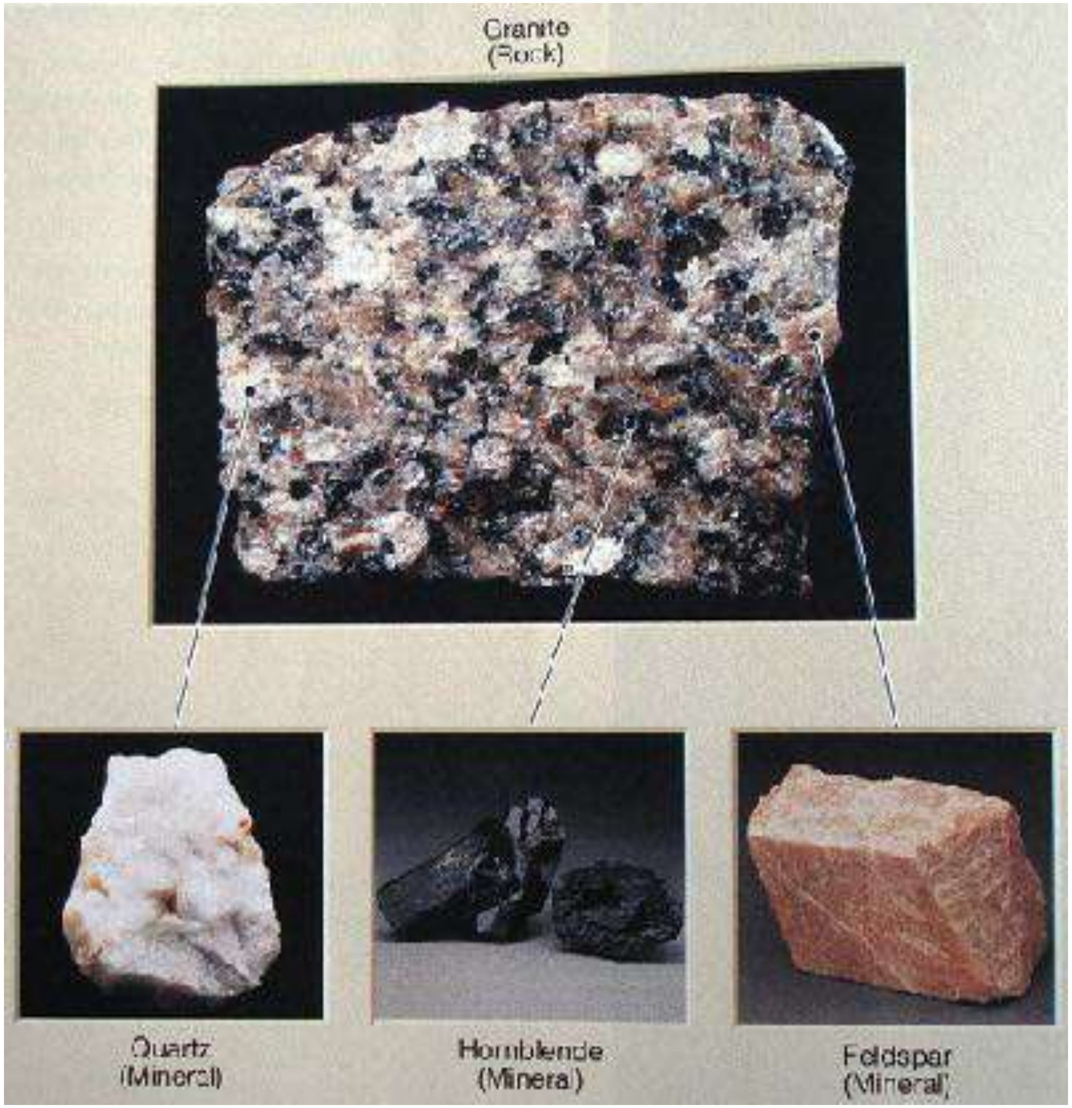


FIGURE 2.2 This diagram illustrates the orderly arrangement of sodium and chloride ions in the mineral halite. The arrangement of atoms into basic building blocks having a cubic shape results in regularly shaped cubic crystals. *(Photo by Dennis Tasa)*

(Lutgens et al, 2011)

Rock & Minerals



(Lutgens & Tarbuck, 1995)

Definition

What is a Mineral?

- A mineral is a naturally formed inorganic crystalline solid with a definite chemical composition and identifying physical properties
  - naturally formed
    - formed by geologic processes in nature, not artificial
  - inorganic
    - was never alive
  - crystalline solid
    - a solid composed of atoms arranged in a repeating orderly framework
  - definite chemical composition
    - a homogeneous chemical compound with a chemical formula
  - distinctive, identifying physical properties

Definition

What is a Mineral?

- Is water a mineral?
  - Why or why not?
- Is ice a mineral?
  - Why or why not?
- Is glass a mineral?
  - Why or why not?
- Is gold a mineral?
  - Why or why not?
- Is steel a mineral?
  - Why or why not?

Definition

- **Mineral** is a naturally occurring inorganic element or compound having orderly internal structure and characteristic chemical composition, crystal form, and physical properties

Pertanyaan:

- Apakah lampu kristal tergolong mineral?
- Bagaimana dengan tubuh kekurangan mineral? Air mineral?

Definition

- This definition includes ice as a mineral, but excludes coal, natural oil and gas. The only allowable exception to the rule that a mineral must be "solid" is native mercury (quicksilver), which is liquid.
- "Definite chemical composition" is not synonymous with 'fixed or constant composition', since many minerals have compositions which are variable between certain limits, which are defined in terms of end members: e.g. the composition of the common *olivines* is expressible in terms of the two compounds, Mg_2SiO_4 (forsterite) and Fe_2SiO_4 (fayalite). The general rule is that minor variations of composition which do not markedly alter fundamental properties are discounted

Definition

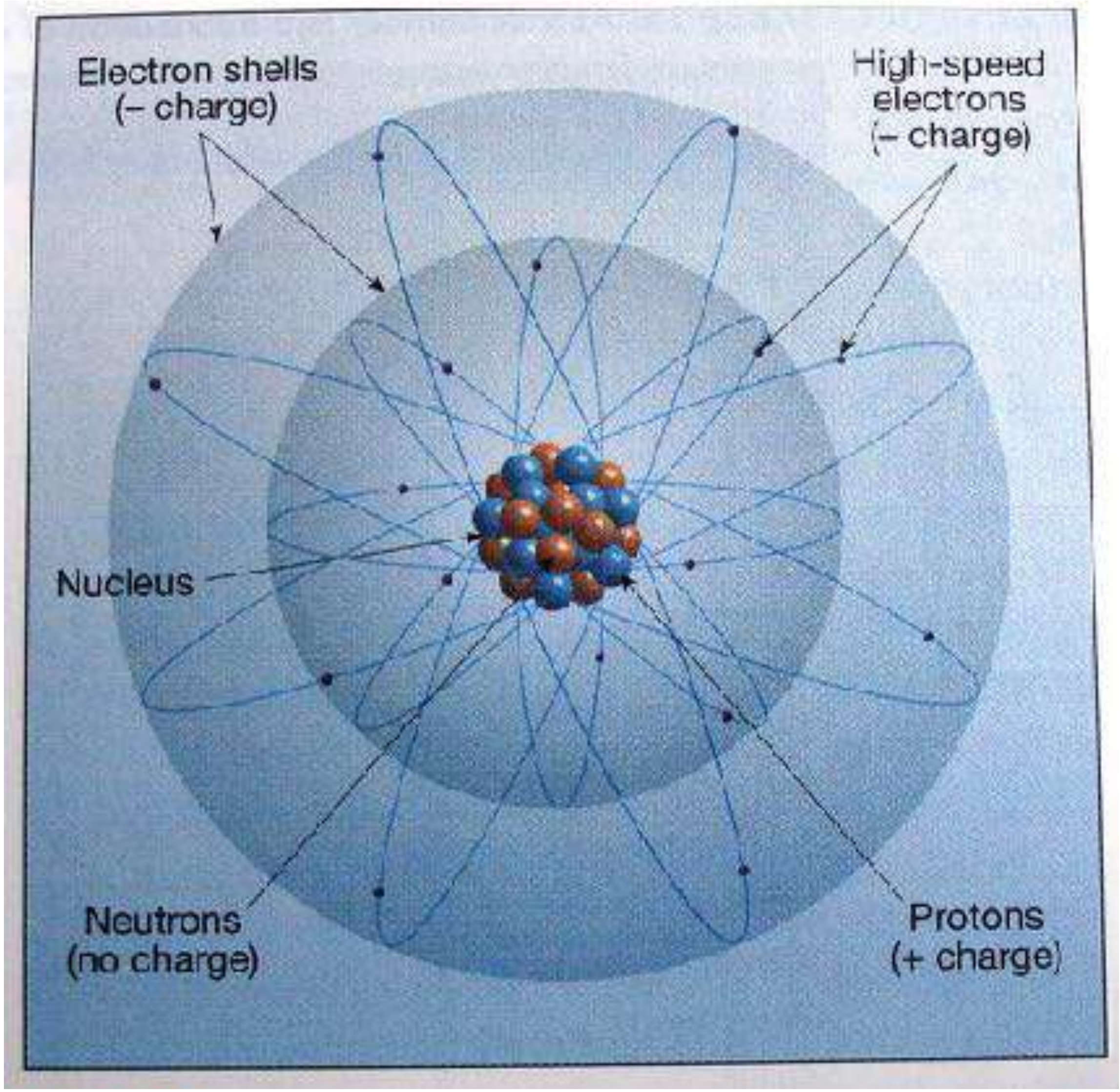
- “Structurally homogeneous” implies that the fundamental atomic structure is continuous and constant through the mineral unit, e.g. in → *silicates* the silicon-oxygen lattice will be constant in characters, although the interstitial cations may vary in different parts of the lattice
- Although strictly of “organic origin”, the constituents of many limestones, siliceous rocks, and bedded phosphate deposits are treated as though they were true mineral species

Whitten, DGA and Brooks, JRV. 1977. *The Penguin Dictionary of Geology*. Middlesex: Penguin Books. p. 293-294.

Mineral	NATURAL Iron ore (hematite)	SOLID Sand (quartz)	INORGANIC Rock salt (halite)
Nonmineral	ARTIFICIAL Cast iron (metallic iron)	LIQUID Seawater (H_2O + salts)	ORGANIC Vegetation (cellulose)
		GAS Air (oxygen)	

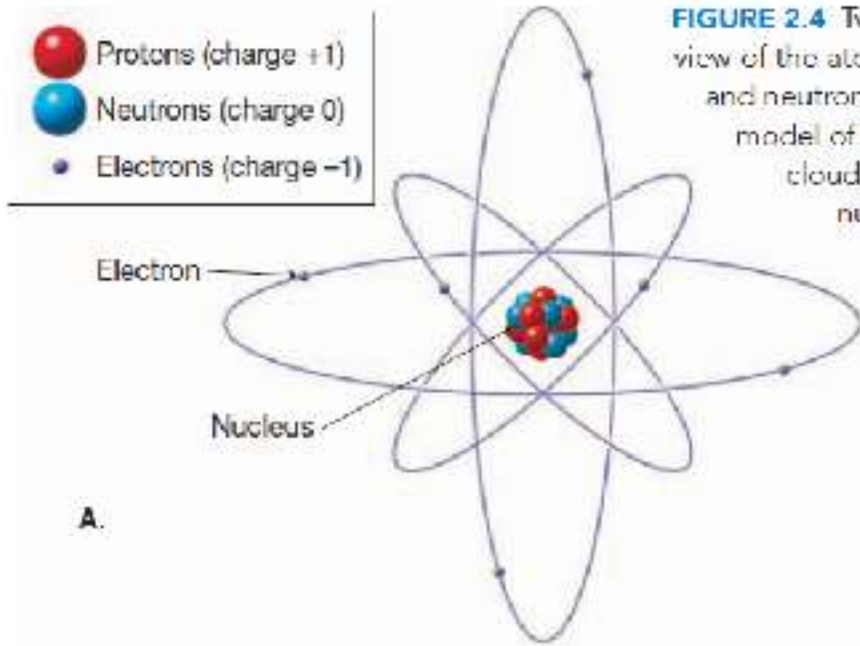
(Press & Siever, 1994)

Simplified model of an atom



(Lutgens & Tarbuck, 1995)

Two models of the atom



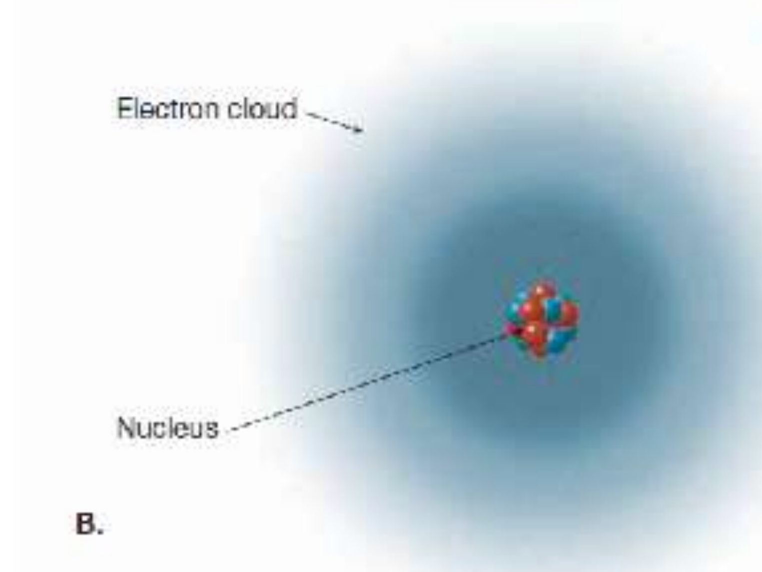


FIGURE 2.4 Two models of the atom. **A.** A very simplified view of the atom. The central nucleus consists of protons and neutrons encircled by high-speed electrons. **B.** This model of the atom shows spherically shaped electron clouds (shells) surrounding a central nucleus. The nucleus contains virtually all of the mass of the atom. The remainder of the atom is the space in which the light, negatively charged electrons reside. (The relative sizes of the nuclei shown are greatly exaggerated.)

(Lutgens et al, 2011)

TABLE 2.1 Atomic number and distribution of electrons

Element	Symbol	Atomic Number	Number of Electrons in Each Shell			
			1st	2nd	3rd	4th
Hydrogen	H	1	1			
Helium	He	2	2			
Lithium	Li	3	2	1		
Beryllium	Be	4	2	2		
Boron	B	5	2	3		
Carbon	C	6	2	4		
Nitrogen	N	7	2	5		
Oxygen	O	8	2	6		
Fluorine	F	9	2	7		
Neon	Ne	10	2	8		
Sodium	Na	11	2	8	1	
Magnesium	Mg	12	2	8	2	
Aluminum	Al	13	2	8	3	
Silicon	Si	14	2	8	4	
Phosphorus	P	15	2	8	5	
Sulfur	S	16	2	8	6	
Chlorine	Cl	17	2	8	7	
Argon	Ar	18	2	8	8	
Potassium	K	19	2	8	8	1
Calcium	Ca	20	2	8	8	2

(Lutgens & Tarbuck, 1995)

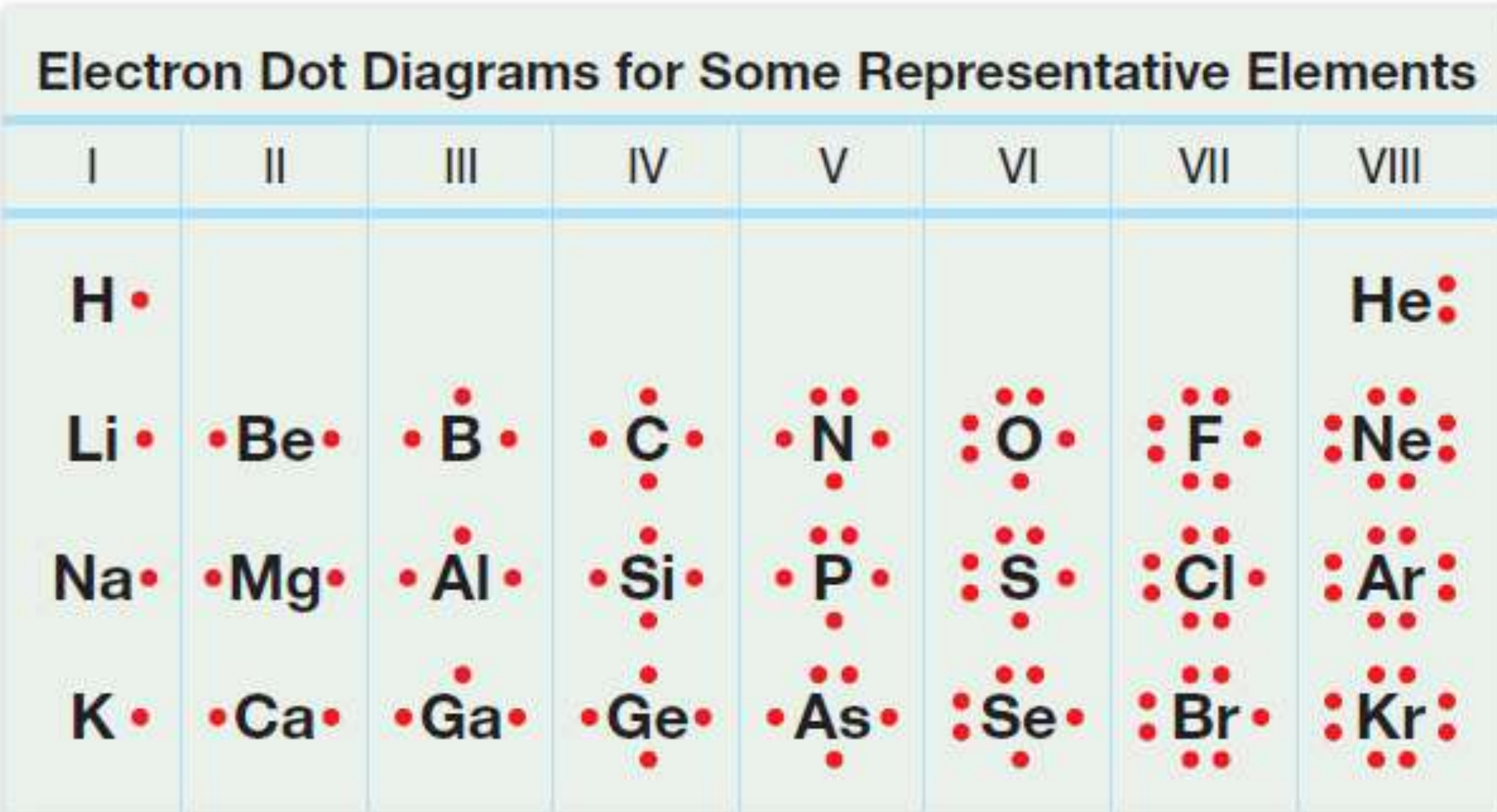
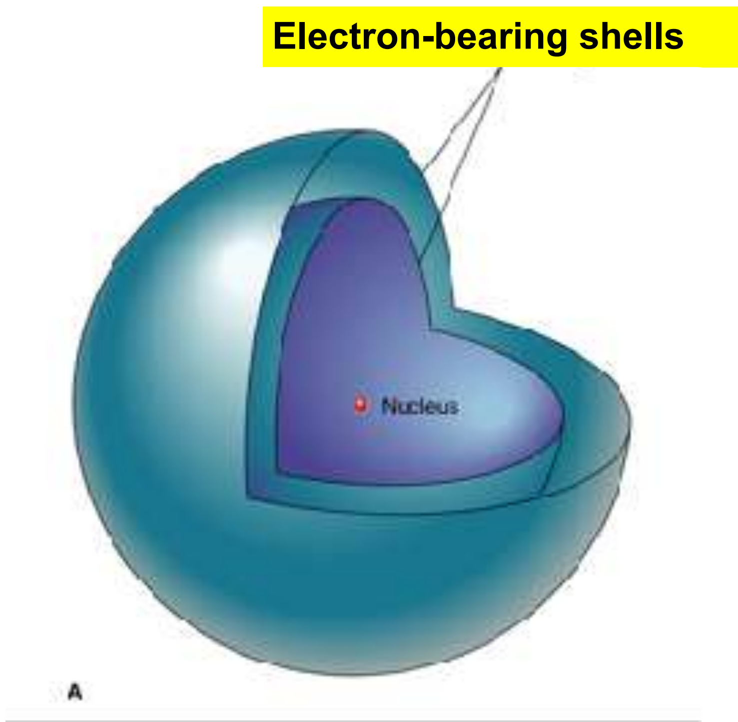


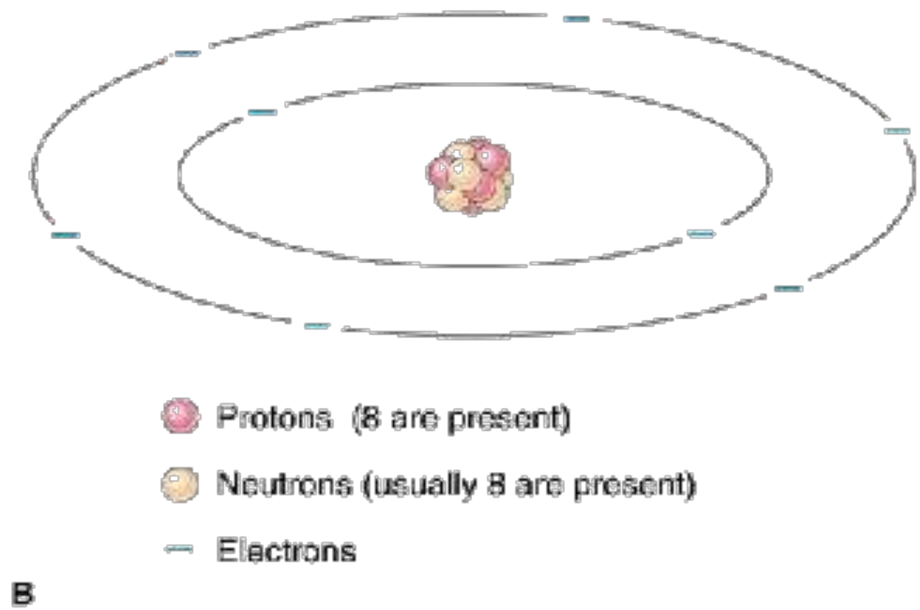
FIGURE 2.6 Dot diagrams for some representative elements. Each dot represents a valence electron found in the outermost principal shell.

(Lutgens et al, 2011)

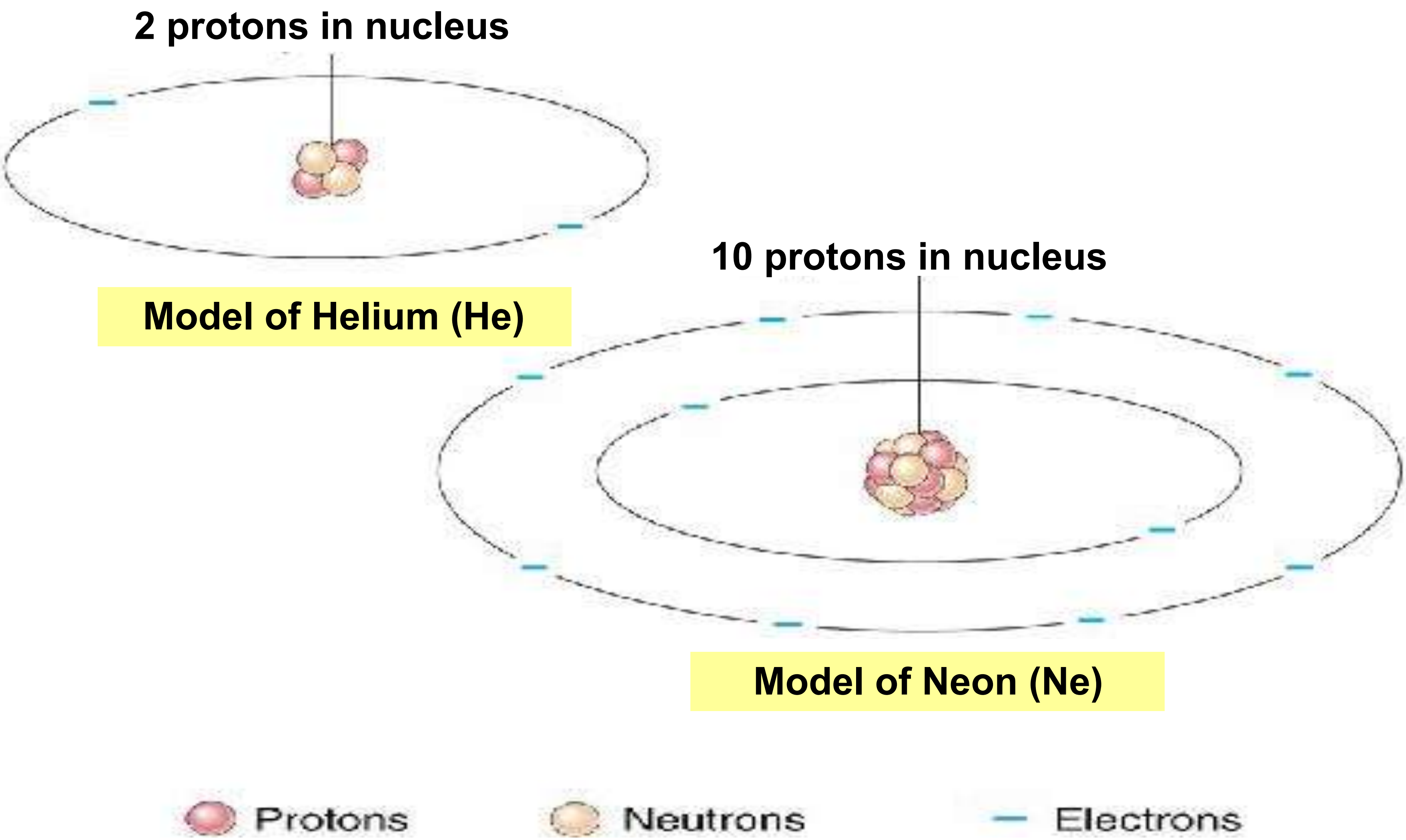
Review

Model of Oxygen

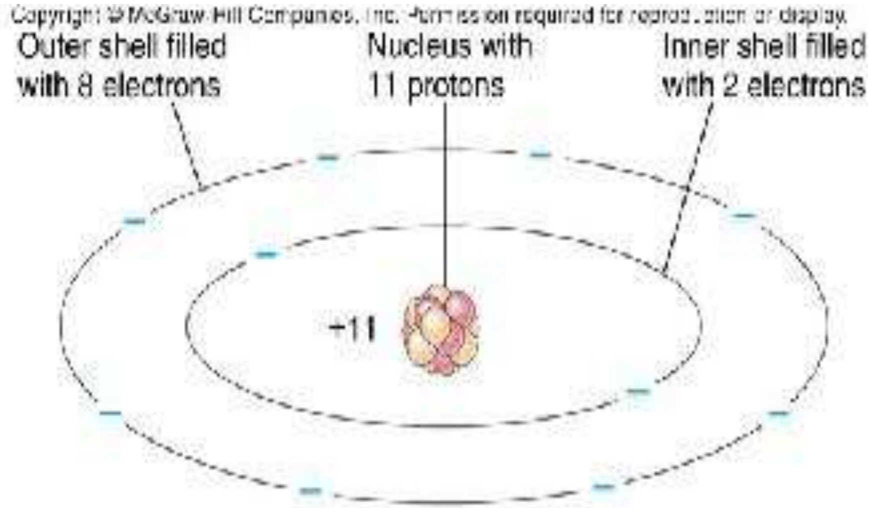




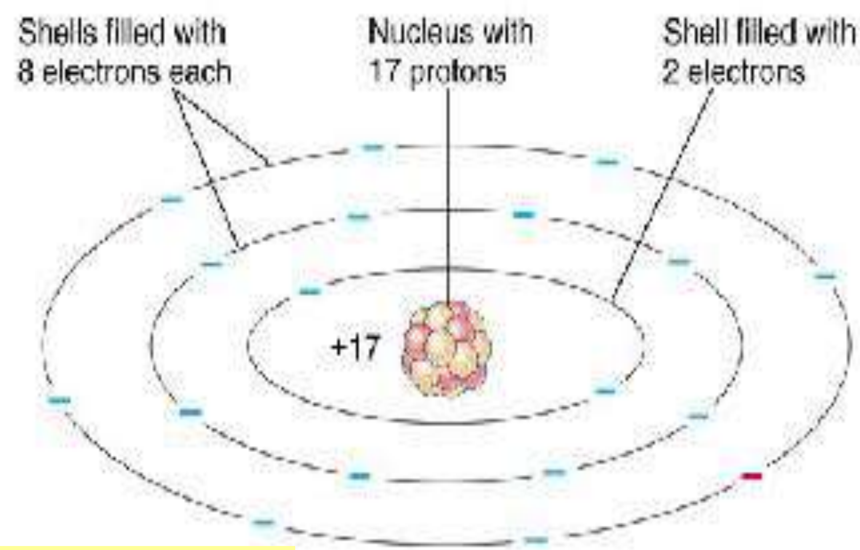
Review


2 protons in nucleus
Model of Helium (He)
10 protons in nucleus
Model of Neon (Ne)
Protons
Neutrons
Electrons

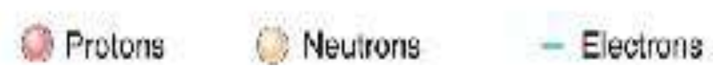
Review

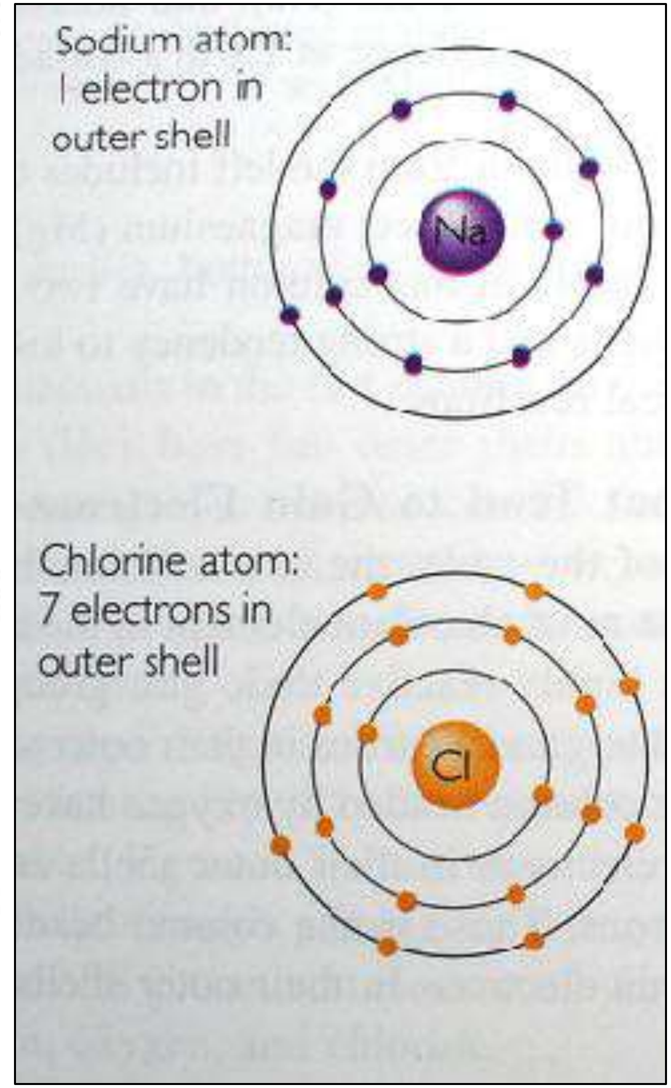


Model of Sodium (Na+)

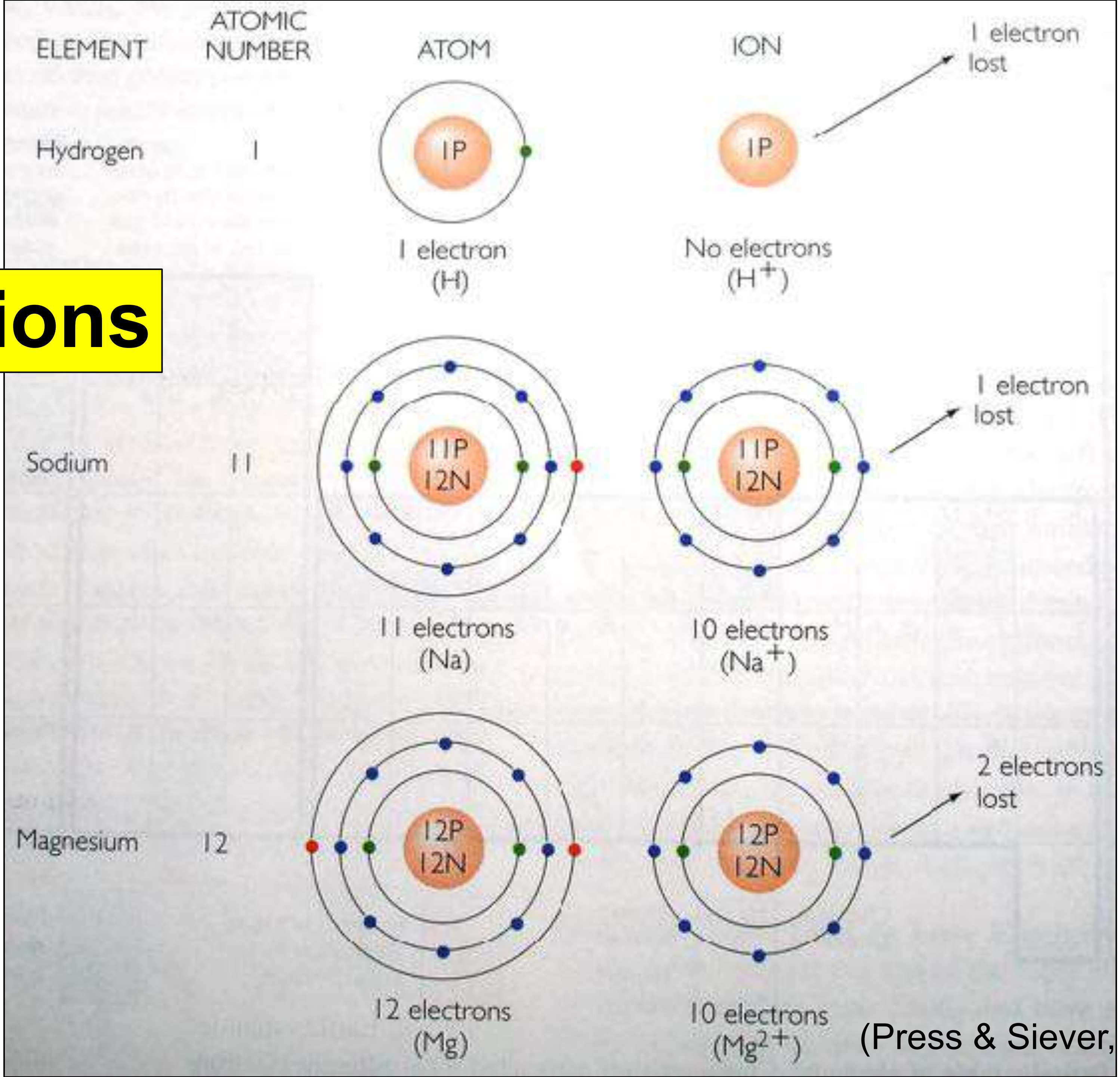


Model of Chlorine (Cl-)



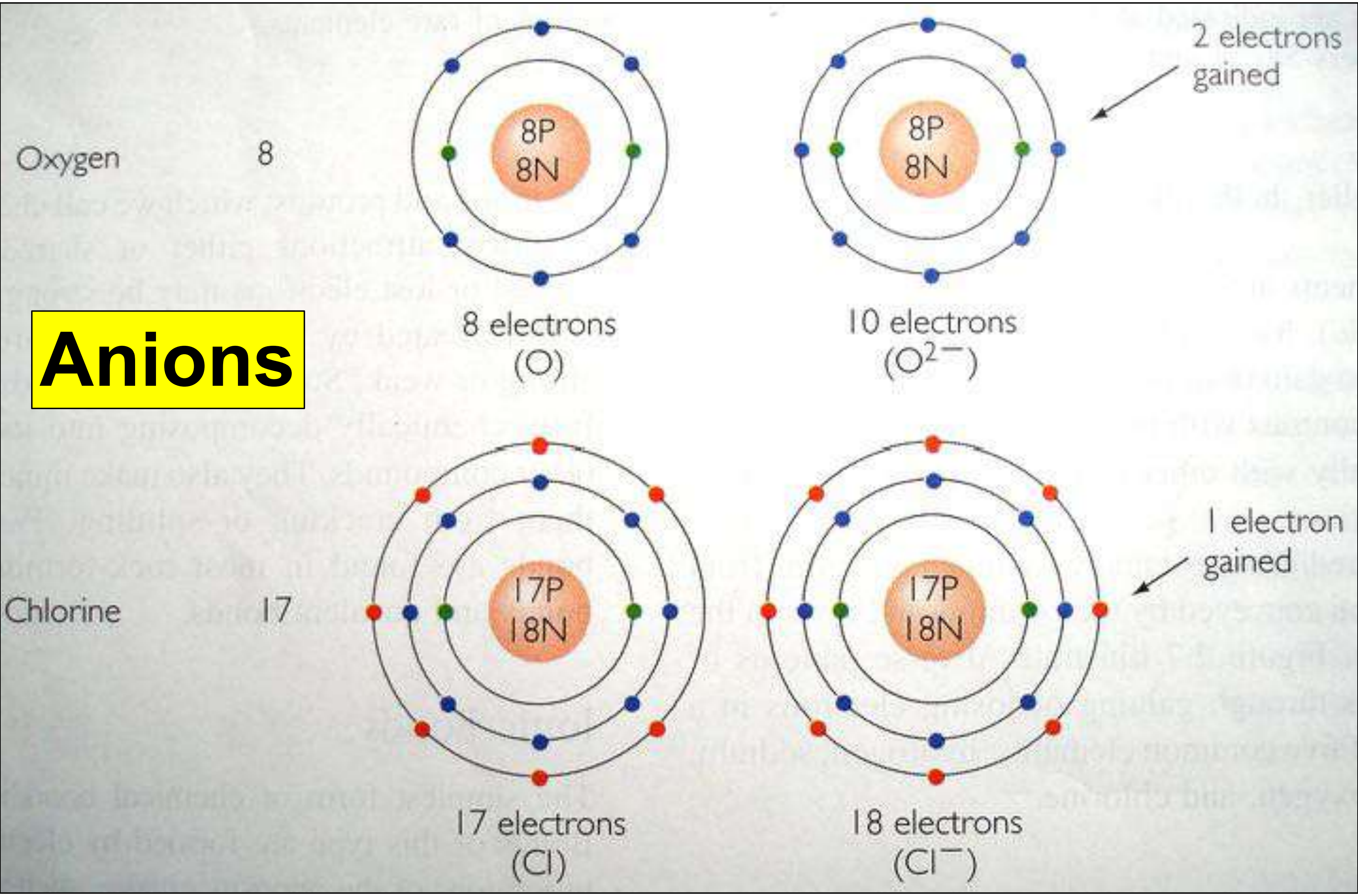


cations



(Press & Siever, 1994)

Anions



(Press & Siever, 1994)

Ionic bound

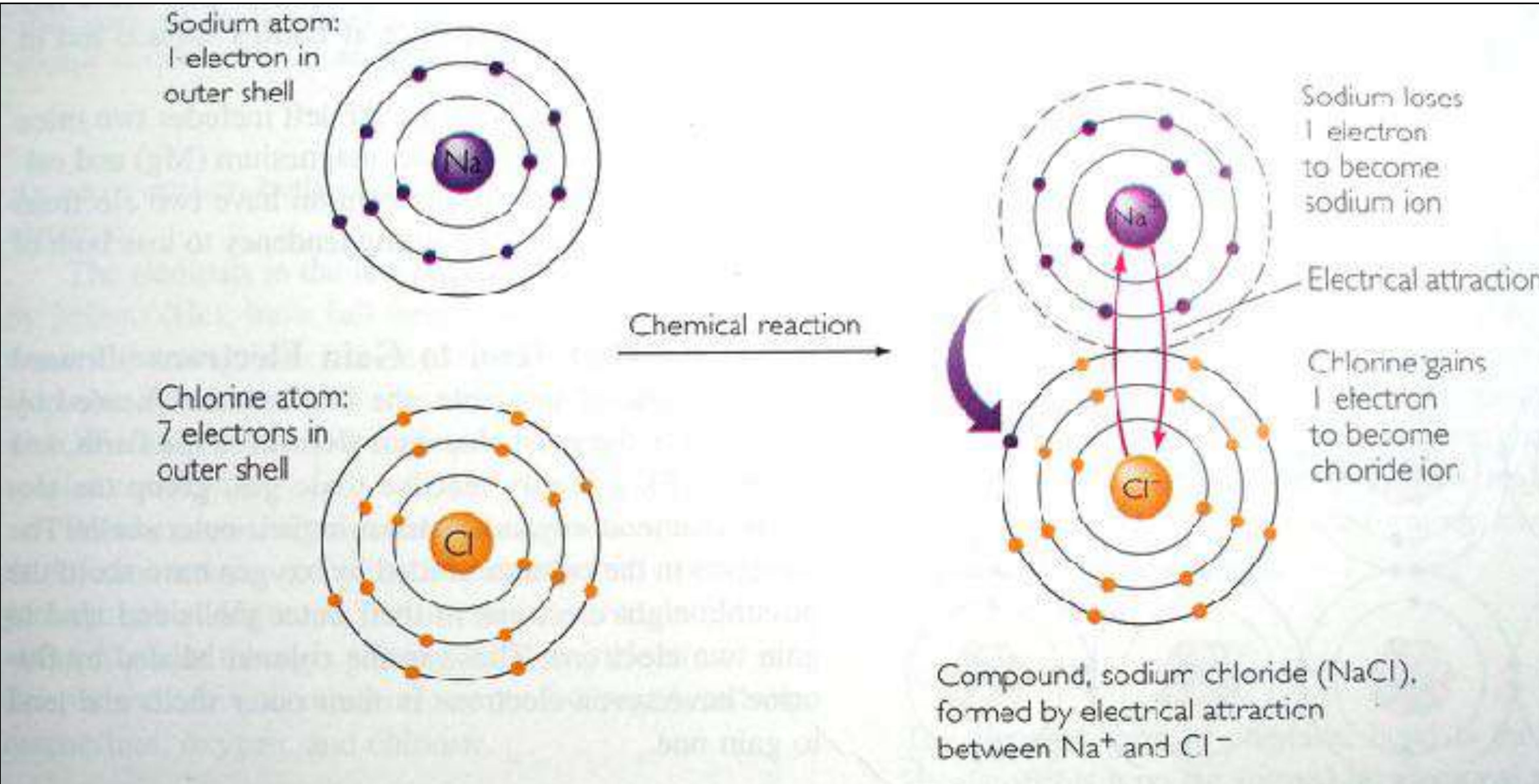
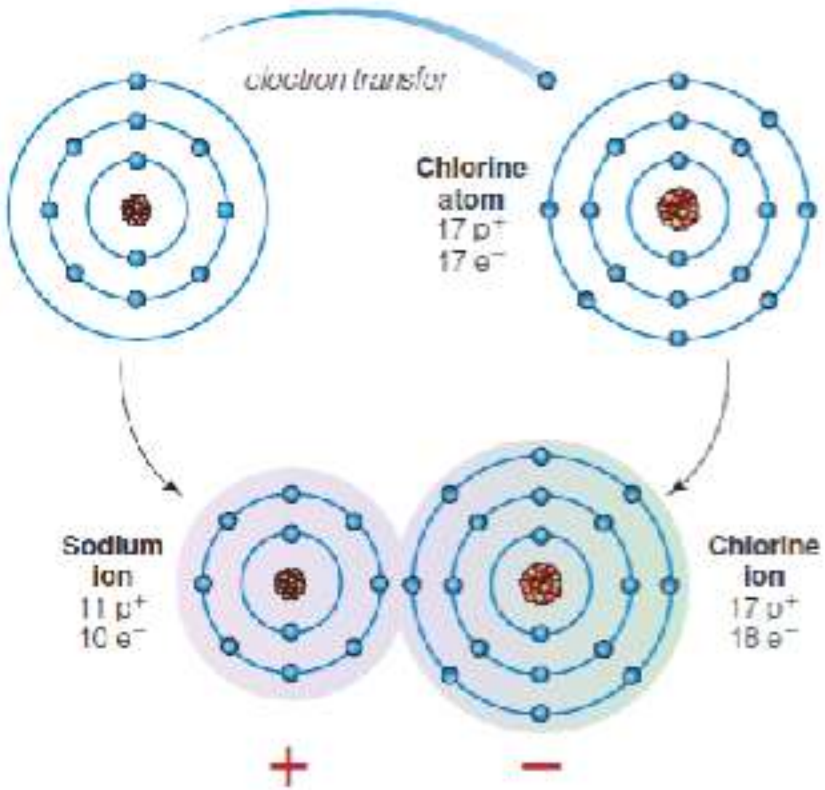


Figure 2.4 Formation of a chemical compound by reaction of chlorine and sodium atoms. When sodium (Na) and chlorine (Cl) react to form table salt (sodium chloride, NaCl), the sodium atom loses one electron from its outer shell and the chlorine atom acquires that electron. In this reaction, an orderly array of ions is formed.

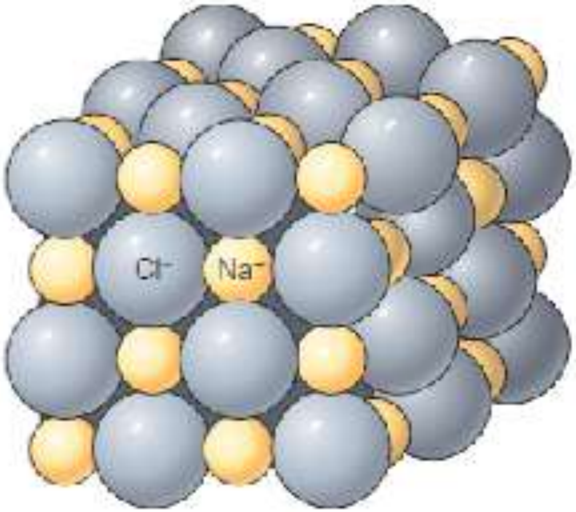
(Press & Siever, 1994)

IONIC BOND

Figure 3.5 Ionic Bond to Form the Mineral Halite (NaCl)



a Transfer of the electron in the outermost shell of sodium to the outermost shell of chlorine. After electron transfer, the sodium and chlorine atoms are positively and negatively charged ions, respectively.

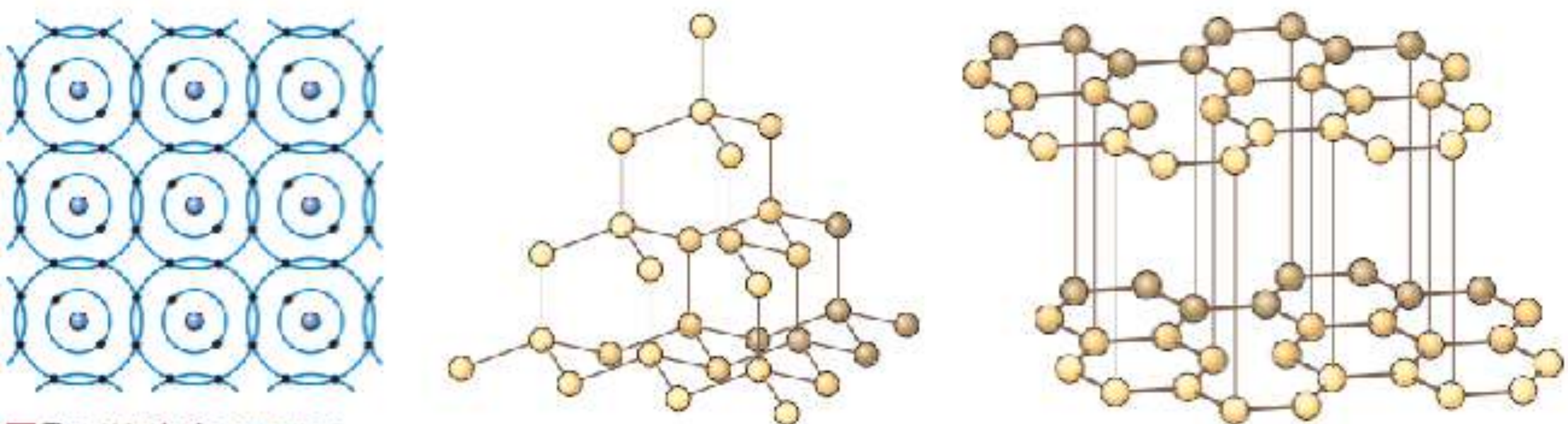


b This diagram shows the relative sizes of the sodium and chlorine atoms and their locations in a crystal of halite.

(Carlsons et al, 2011

COVALENT BOND

Figure 3.6 Covalent Bonds



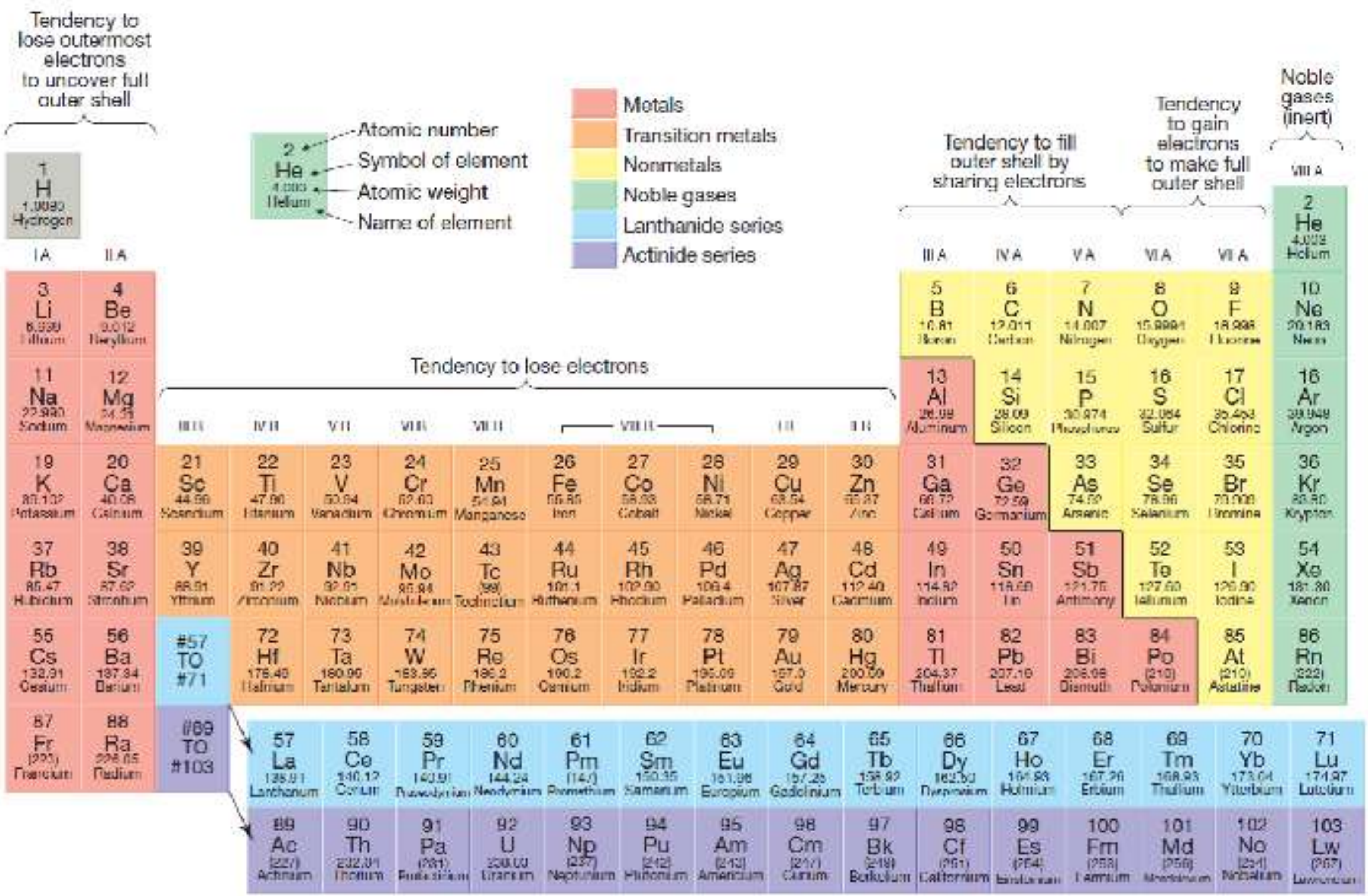
a The orbits in the outermost electron shell overlap, so electrons are shared in diamond.

b Covalent bonding of carbon atoms in diamond forms a three-dimensional framework.

c Covalent bonds in graphite form strong sheets, but the van der Waals bonds between sheets are weak.

(Carlsons et al, 2011

FIGURE 2.5 Periodic table of the elements.



(Lutgens et al, 2011)

Isotopes

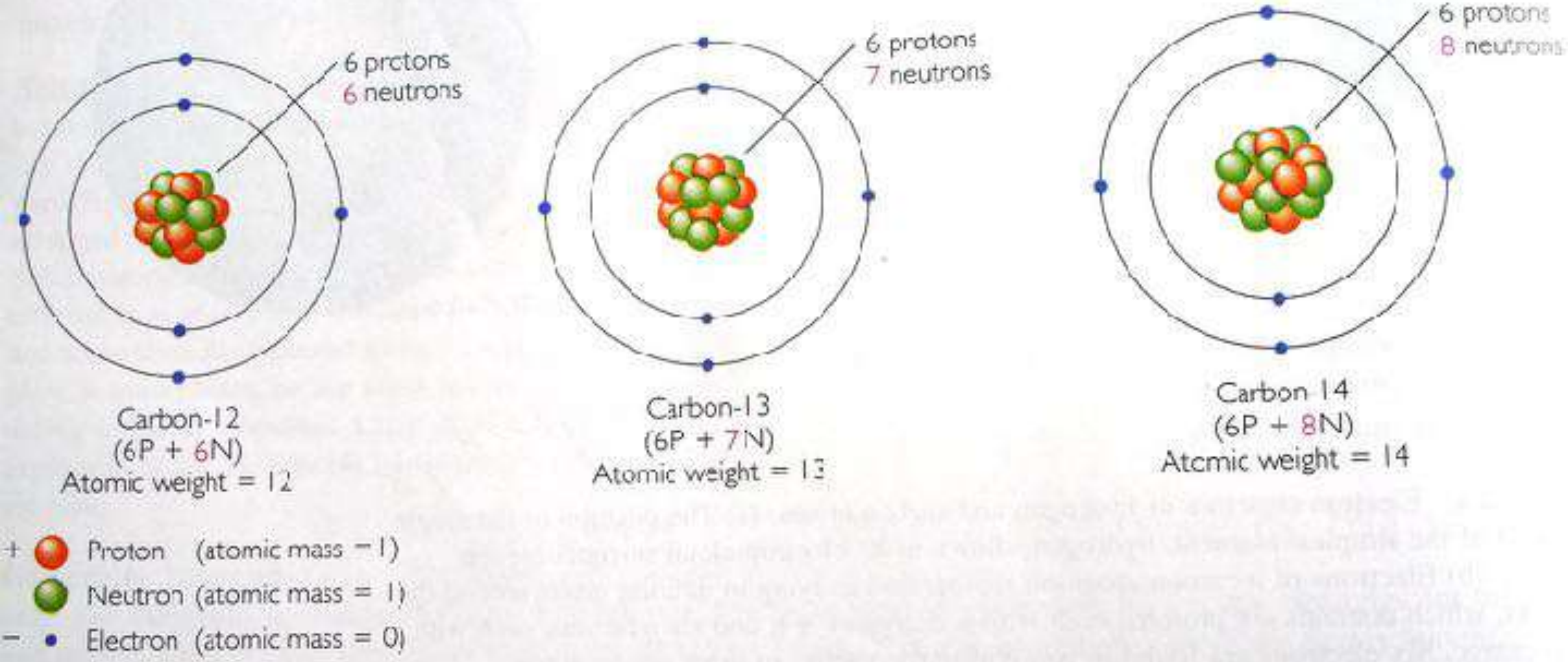


Figure 2.3 These three carbon isotopes all have the same number of protons and thus the same atomic number, 6. Their atomic masses differ, however, because they have different numbers of neutrons. The atomic mass of any element is the average of the weighted sum of the atomic masses of its various isotopes. One isotope of an element—for example, carbon-12—is far more abundant than the others because natural processes favor that particular isotope.

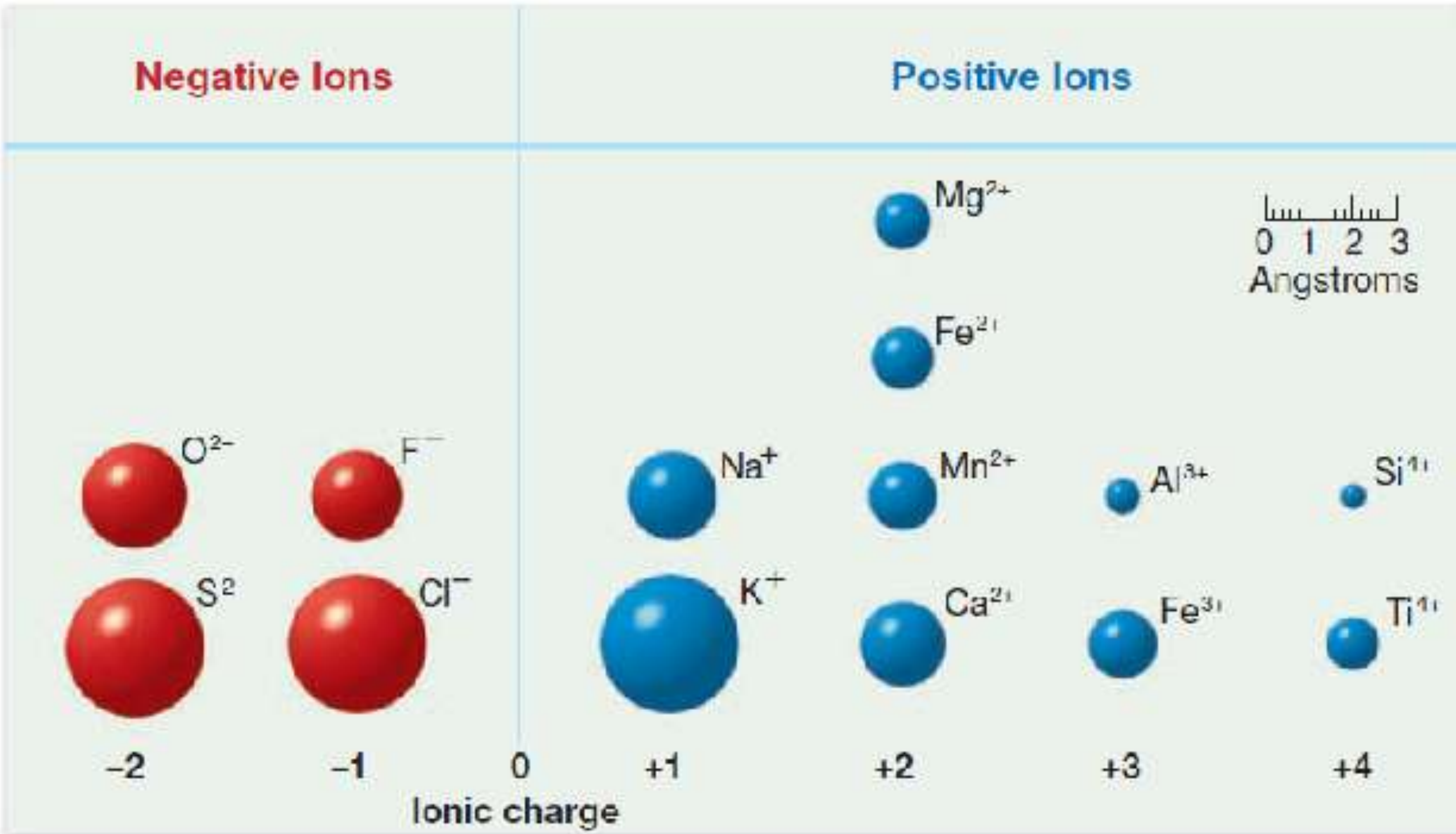


FIGURE 2.23 The relative sizes and charges of ions commonly found in minerals. Ionic radii are usually expressed in angstroms (1 angstrom equals 10^{-8} cm).

(Lutgens et, 2011)

Review

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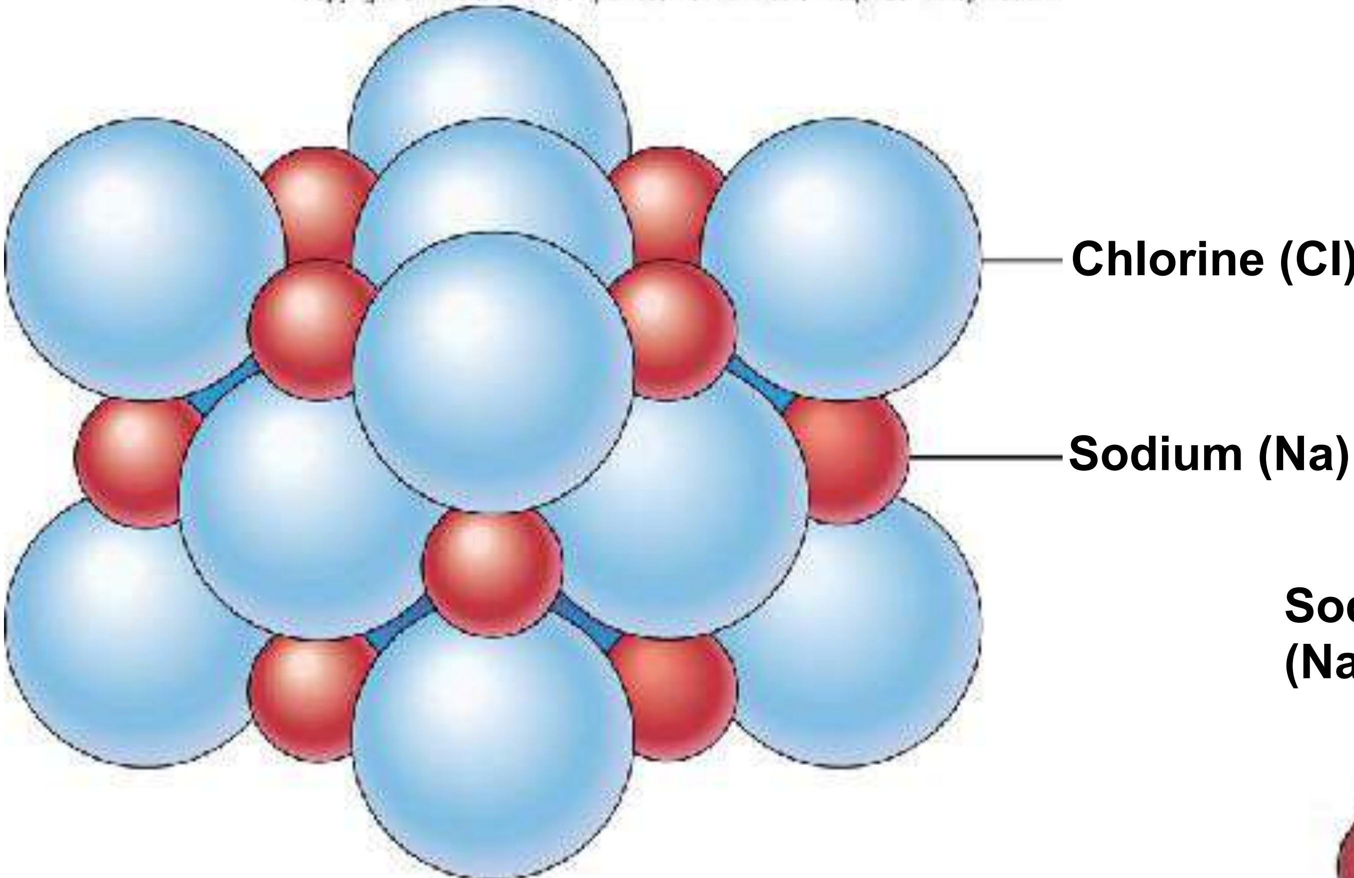
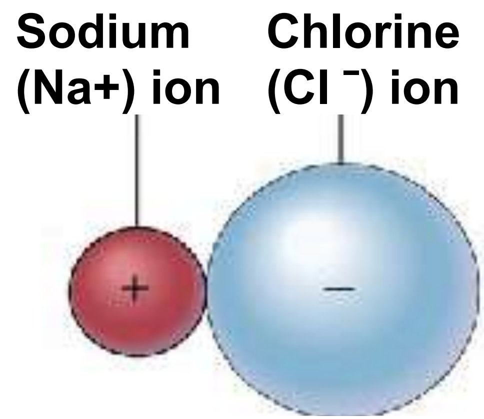




Ionic Bonding:
Electron Transfer

Model of crystalline structure of Halite (salt)

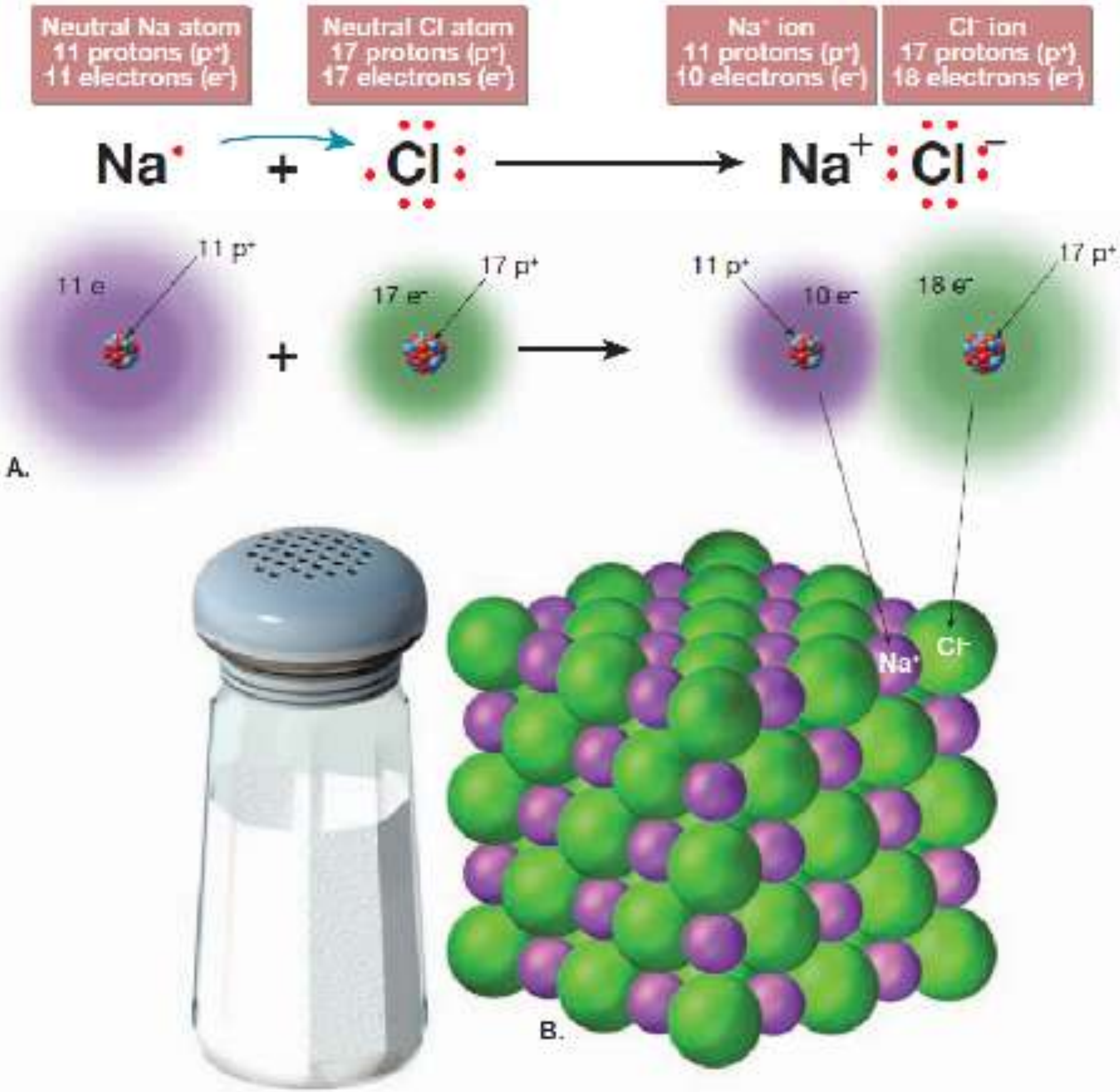
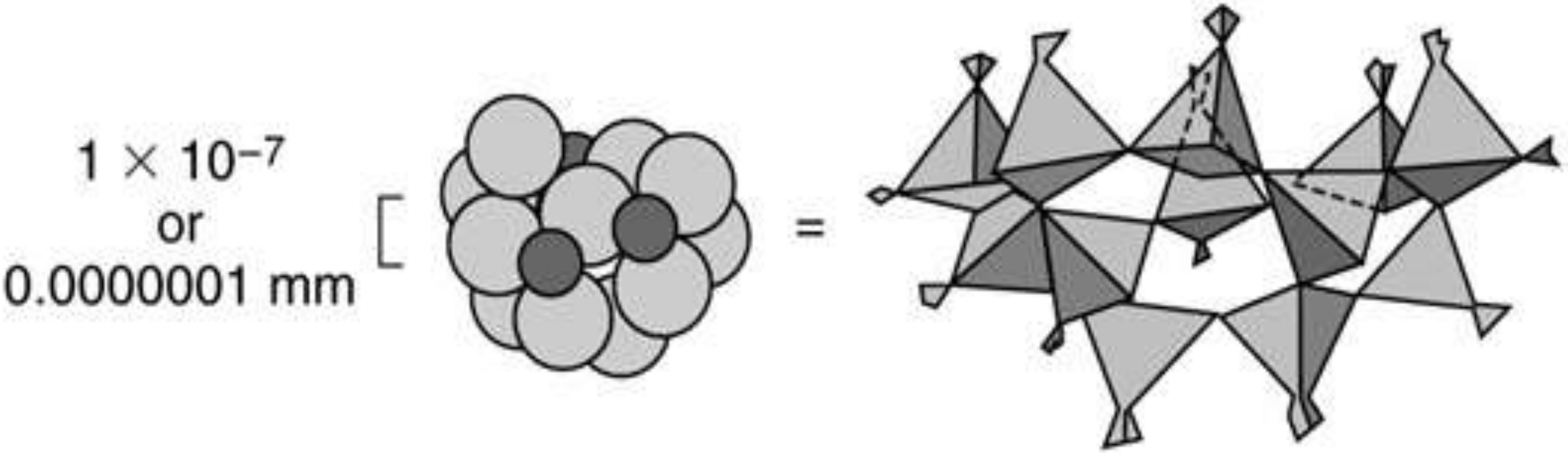


FIGURE 2.7 Chemical bonding of sodium chloride (table salt). **A.** Through the transfer of one electron in the outer shell of a sodium atom to a chlorine atom, sodium becomes a positive ion and chlorine a negative ion. **B.** Diagram illustrating the arrangement (packing) of sodium and chlorine ions in table salt.

(Lutgens et al, 2011)

Review

Mineral Structures and Atoms



Silicon and oxygen atoms in crystalline structure

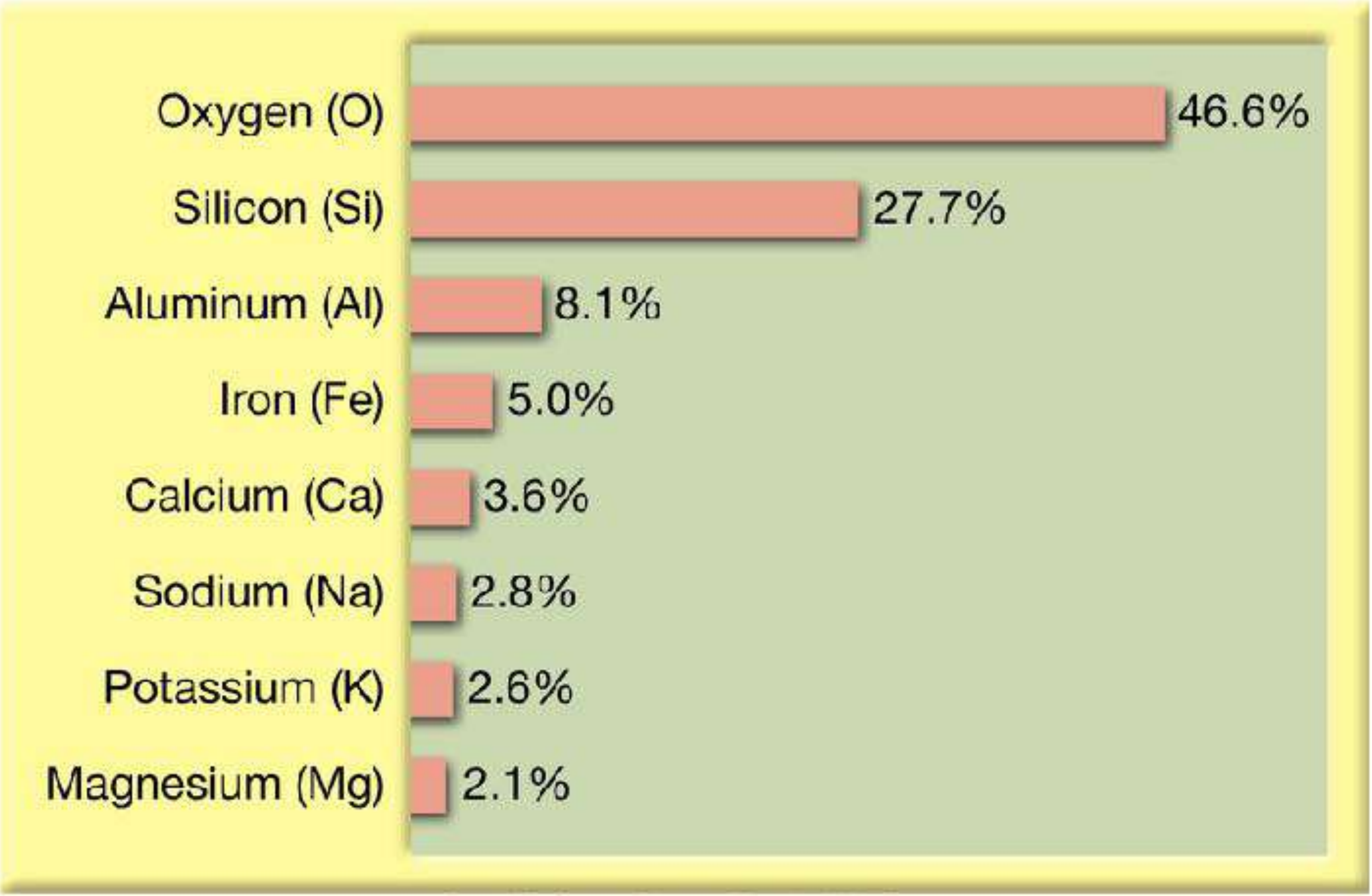
Diagrammatic representation of crystalline structure

Model of crystalline structure

Elemental Abundances in Continental Crust

Element	Simbol	% Berat	% Volume	% Atom
Oksigen	O	46,6	93,8	60,5
Silikon	Si	27,7	0,9	20,5
Aluminium	Al	8,1	0,8	6,2
Besi	Fe	5,0	0,5	1,9
Kalsium	Ca	3,6	1,0	1,9
Sodium	Na	2,8	1,2	2,5
Potasium	K	2,6	1,5	1,8
Magnesium	Mg	2,1	0,3	1,4
Other elements		1,5	-	3,3

Elemental Abundances in Continental Crust (% weight)



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Mineral Classes

- Silicate Mineral Group
- Non-silicate Mineral Group

Silicate Mineral Groups

- ***Silicate minerals (silicates) are composed of silica tetrahedra (SiO_4^{4-})***
- **For silica tetrahedra to be stable, they must either:**
  - be balanced by positive ions,
  - share oxygens with adjacent silica tetrahedra, or
  - substitute one or more Al^{3+} for Si^{4+}
- **Compositions of the silicates**
  - *Mafic composition*
    - Is rich in magnesium, iron, and/or calcium
  - *Intermediate composition*
    - Is compositionally between mafic and felsic
    - Is rich in feldspar and/or silica (quartz)
  - ***Felsic composition***
    - Is rich in feldspar and/or silica (quartz)
- ***All the common rock-forming minerals are silicate mineral***

Silicate Mineral Groups

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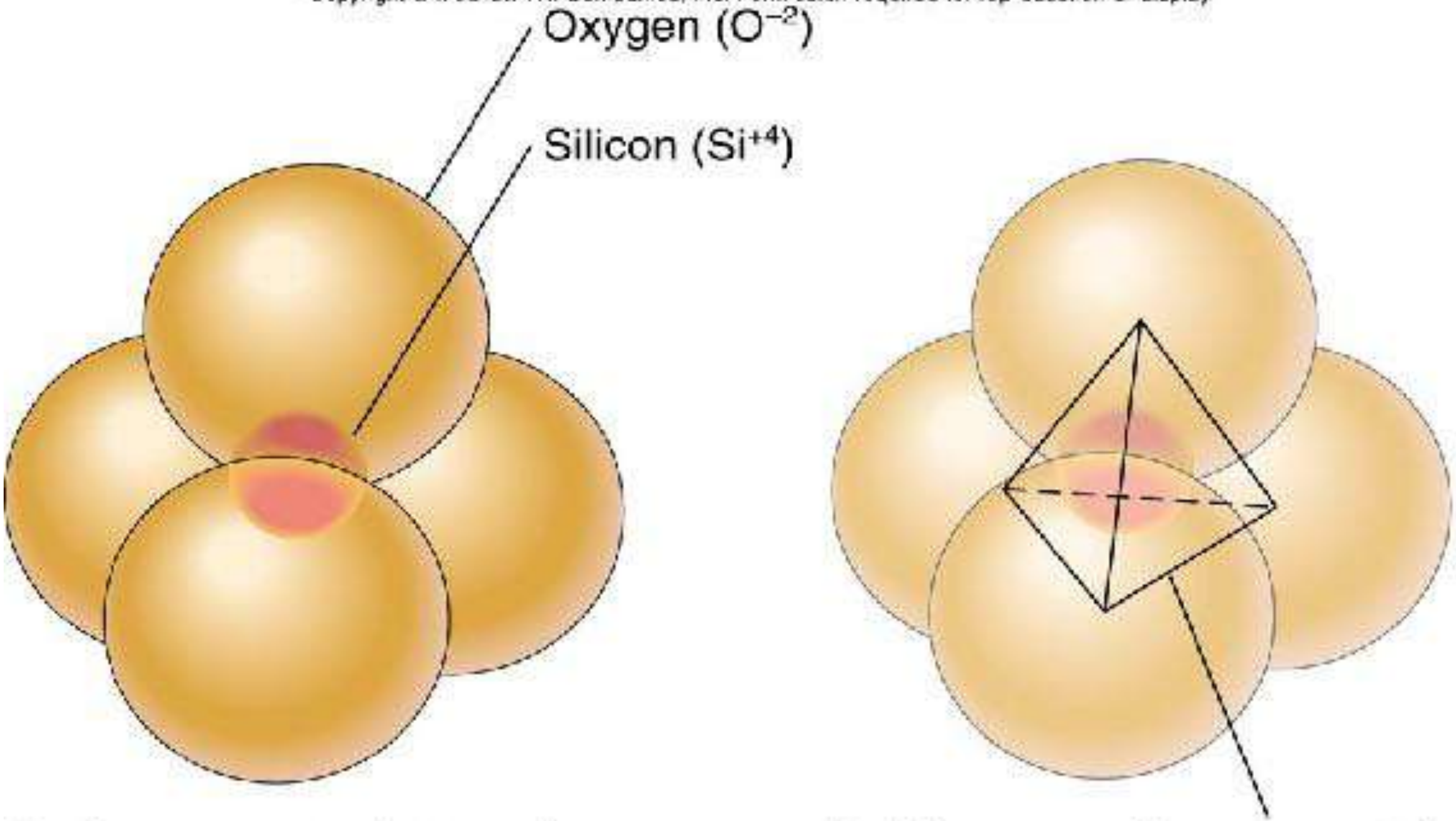
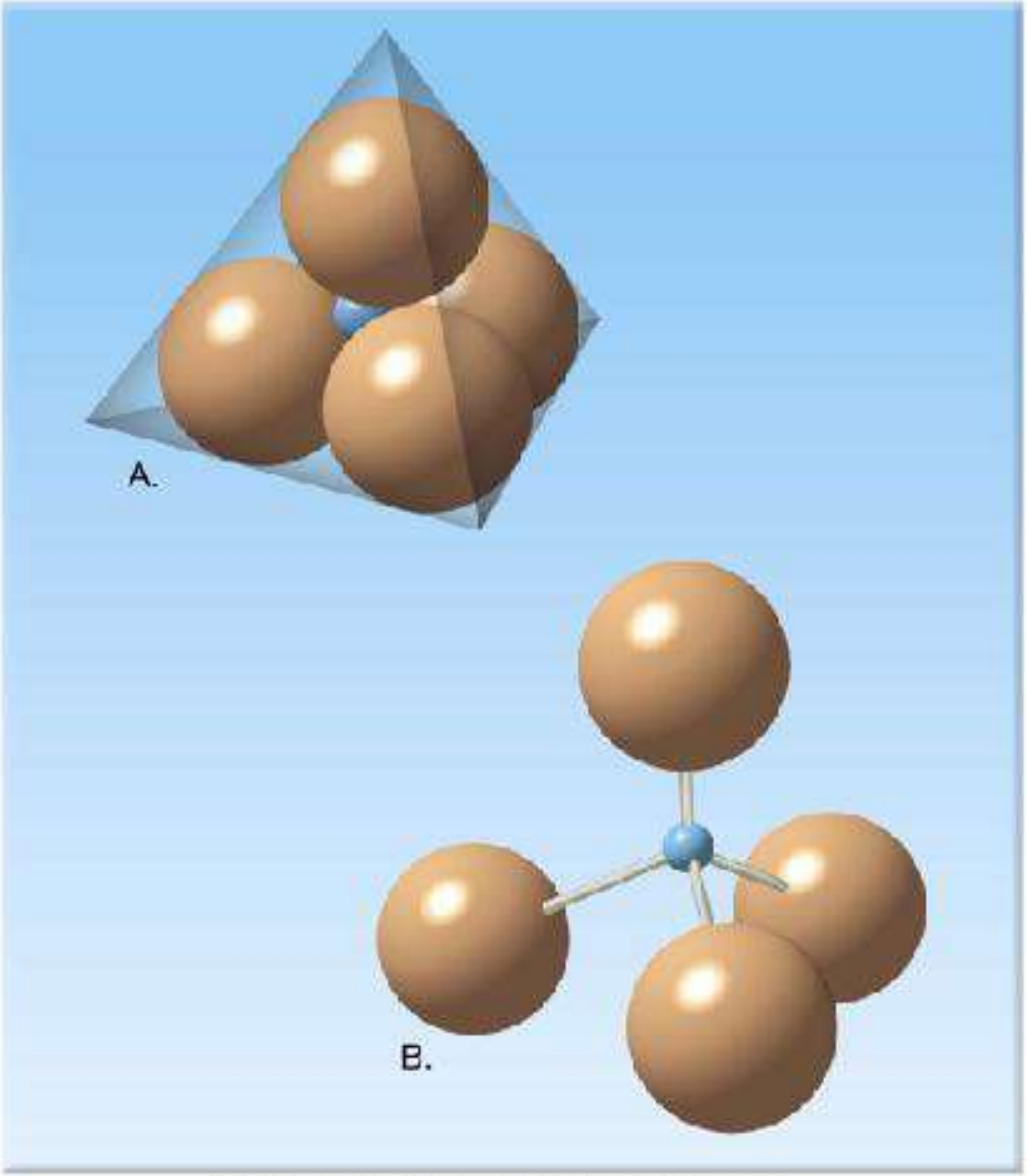


A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron

The Silica Tetrahedron
(composed of 4 oxygen atoms surrounding 1 silicon atom)

Silicate Mineral Groups



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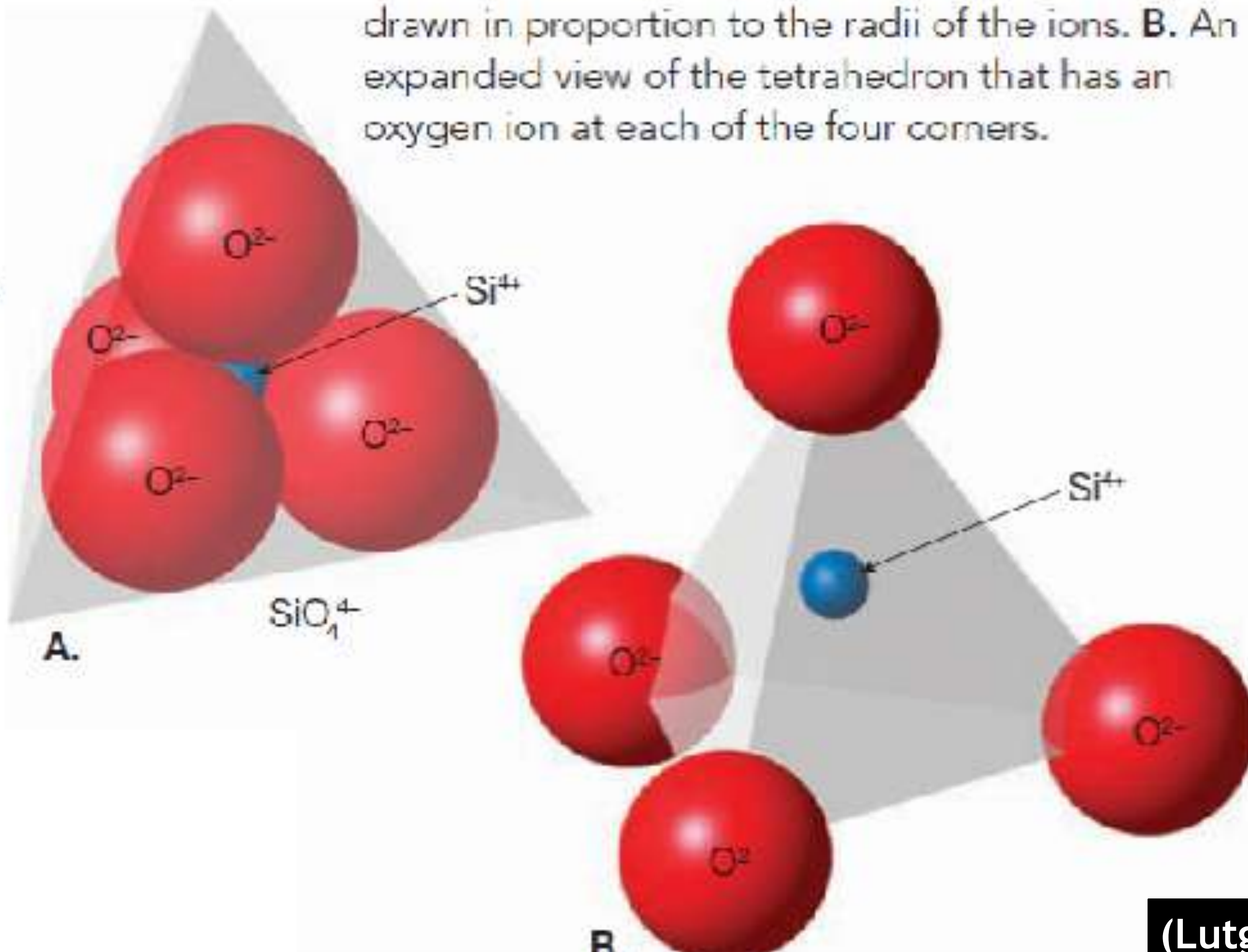
Two Illustrations of the Si–O_4 Tetrahedron

Si – O TETRAHEDRON

FIGURE 2.21 Two representations of the silicon–oxygen tetrahedron. **A.** The four large spheres represent oxygen ions, and the blue sphere represents a silicon ion. The spheres are drawn in proportion to the radii of the ions. **B.** An expanded view of the tetrahedron that has an oxygen ion at each of the four corners.



(Lutgens et al, 2011)

SILICATE STRUCTURES

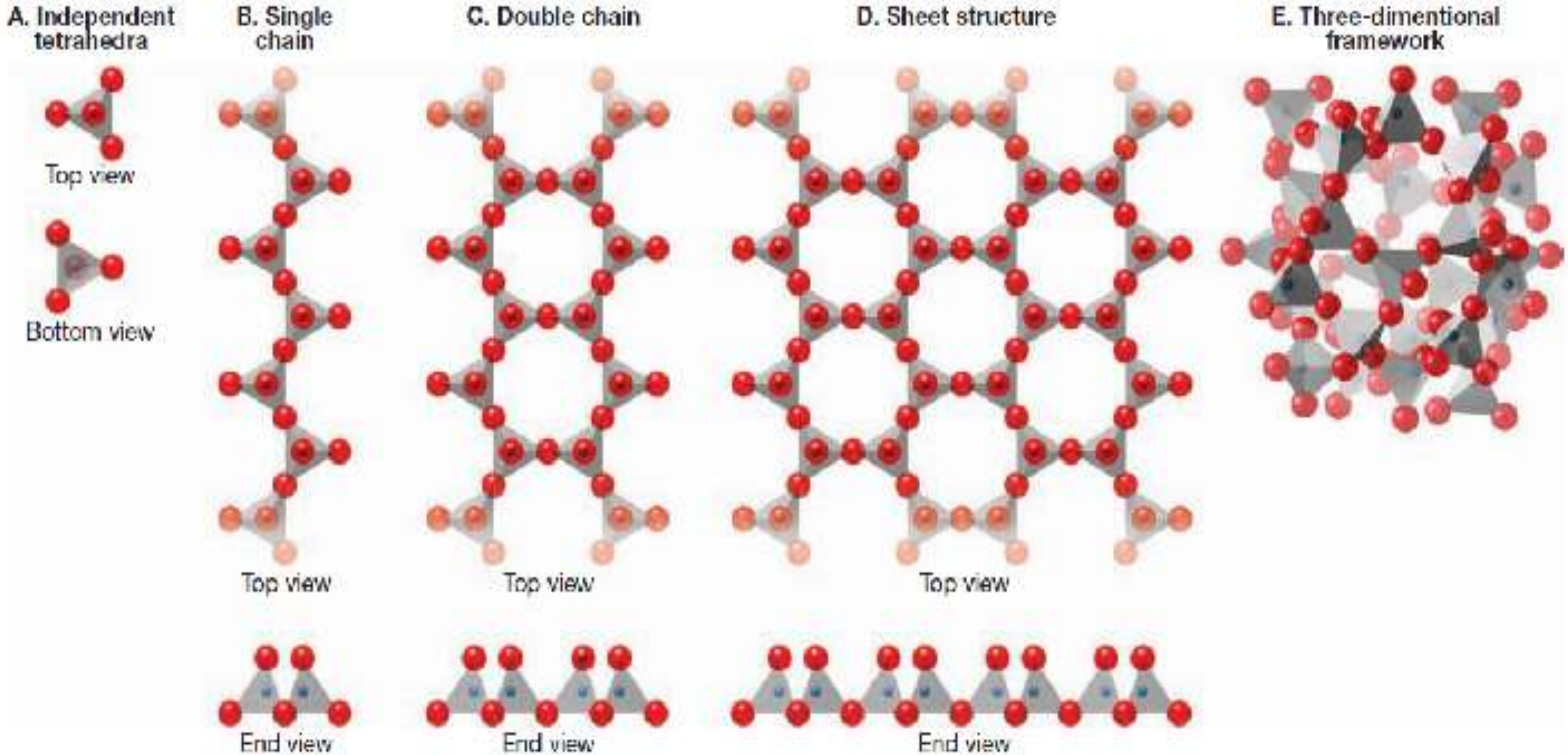
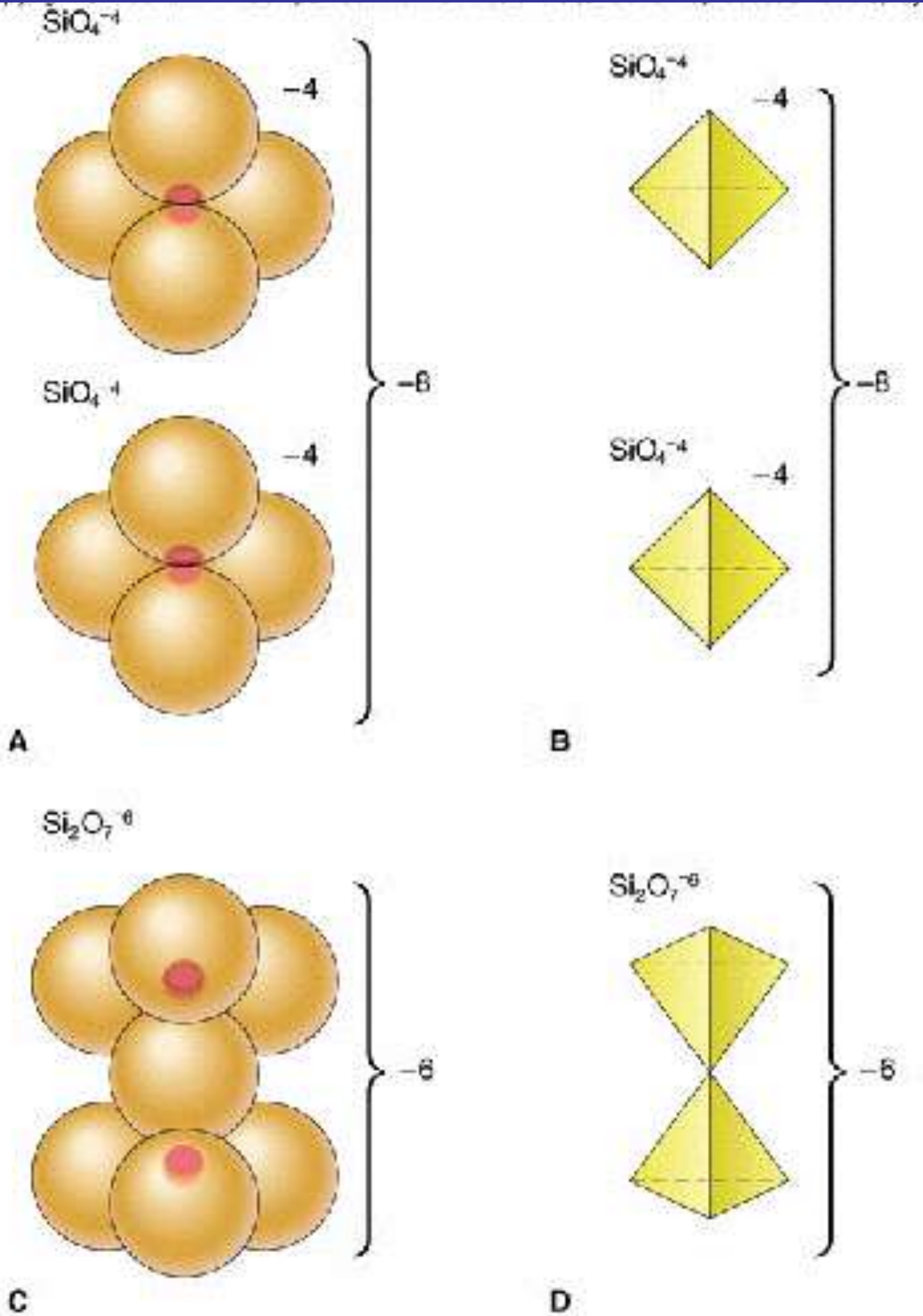


FIGURE 2.22 Five types of silicate structures. **A.** Independent tetrahedra. **B.** Single chains. **C.** Double chains. **D.** Sheet structures. **E.** Three-dimensional framework.

(Lutgens et al, 2011)

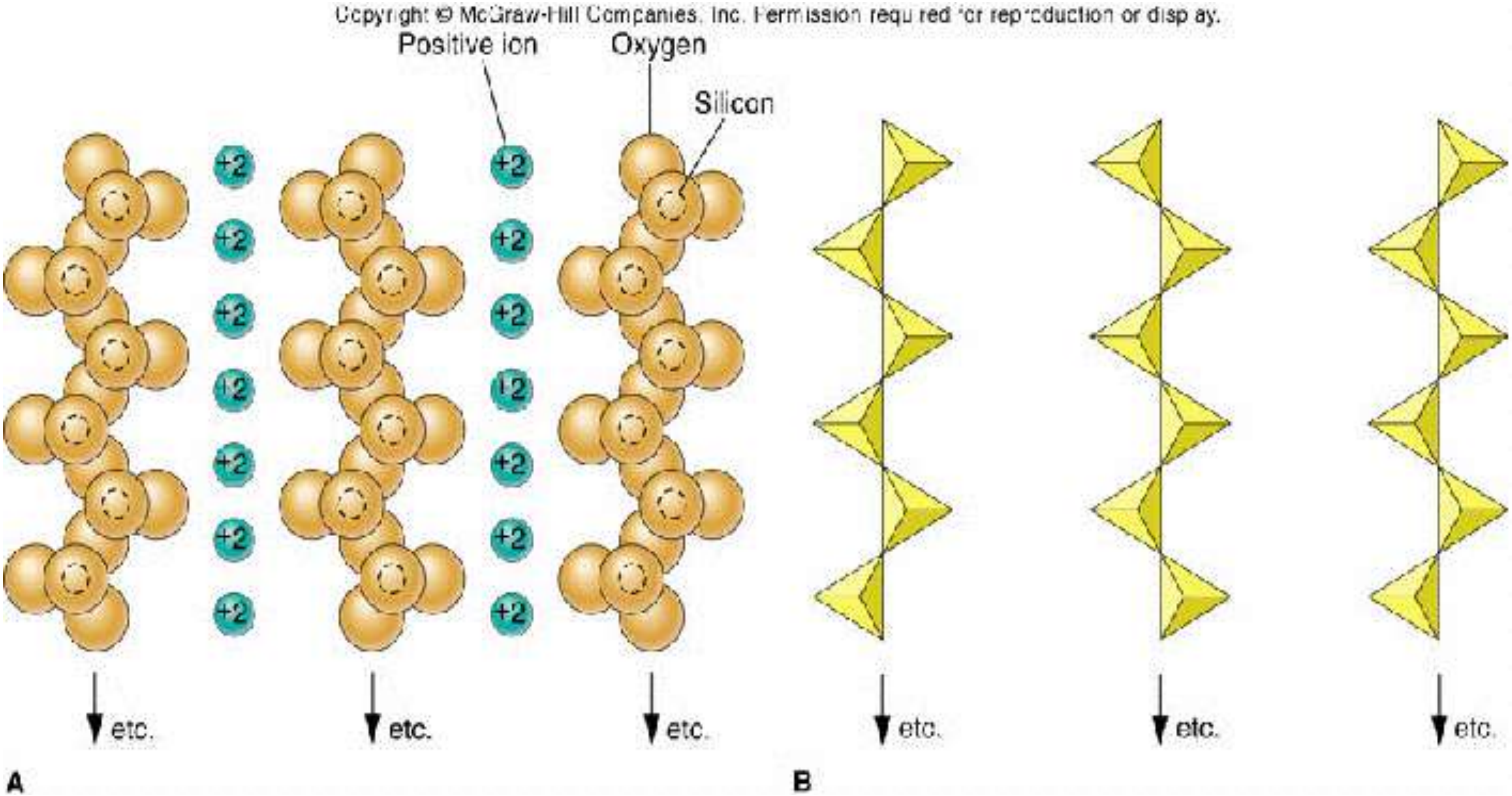
Silicate Mineral Groups



Single Island Silicates (ex.: olivine)

Single Chain Silicates (ex.: augite pyroxene)

Silicate Mineral Groups



Single Chain Silicates: The Pyroxenes (e.g., augite)

Silicate Mineral Groups

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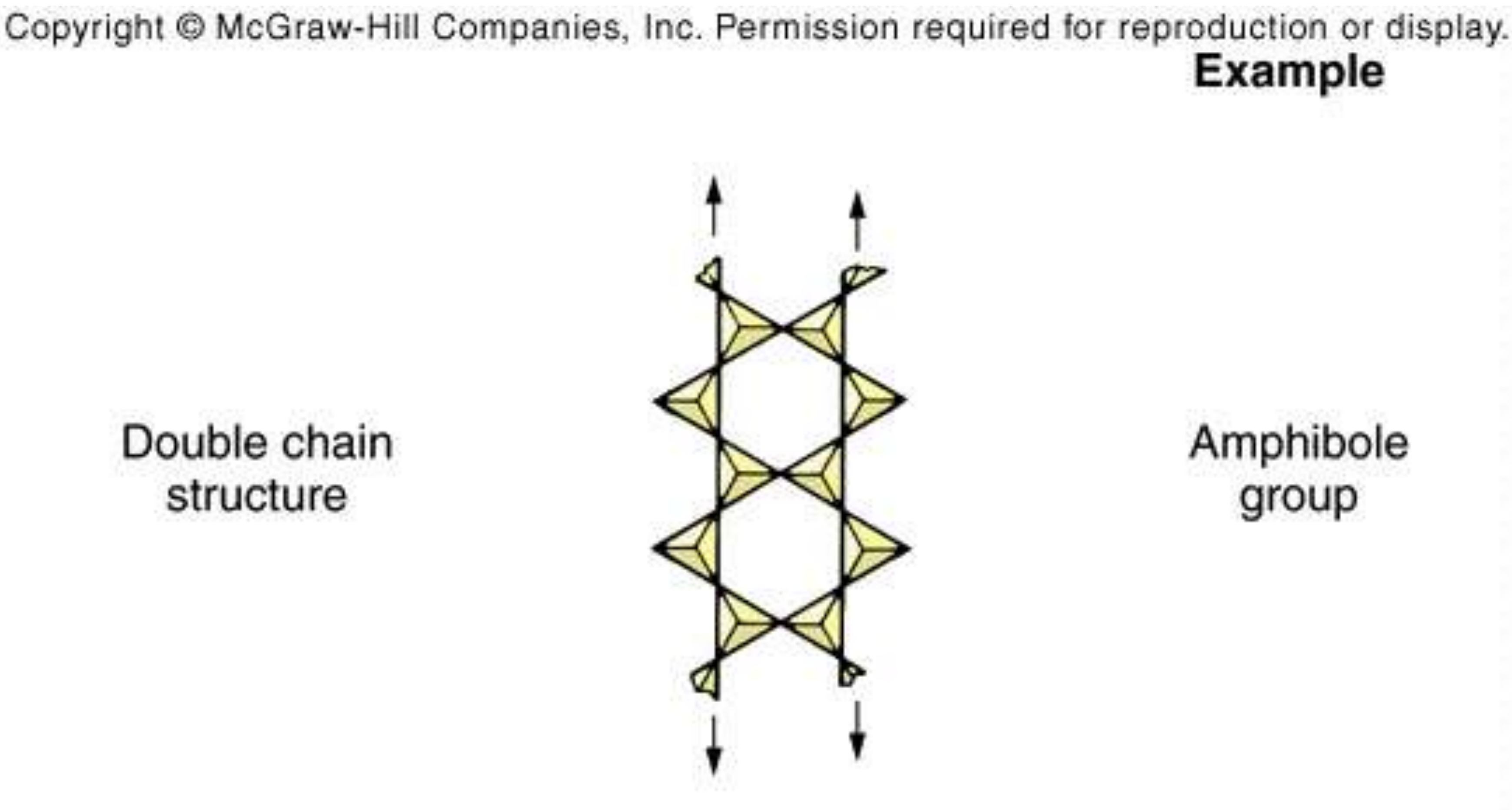
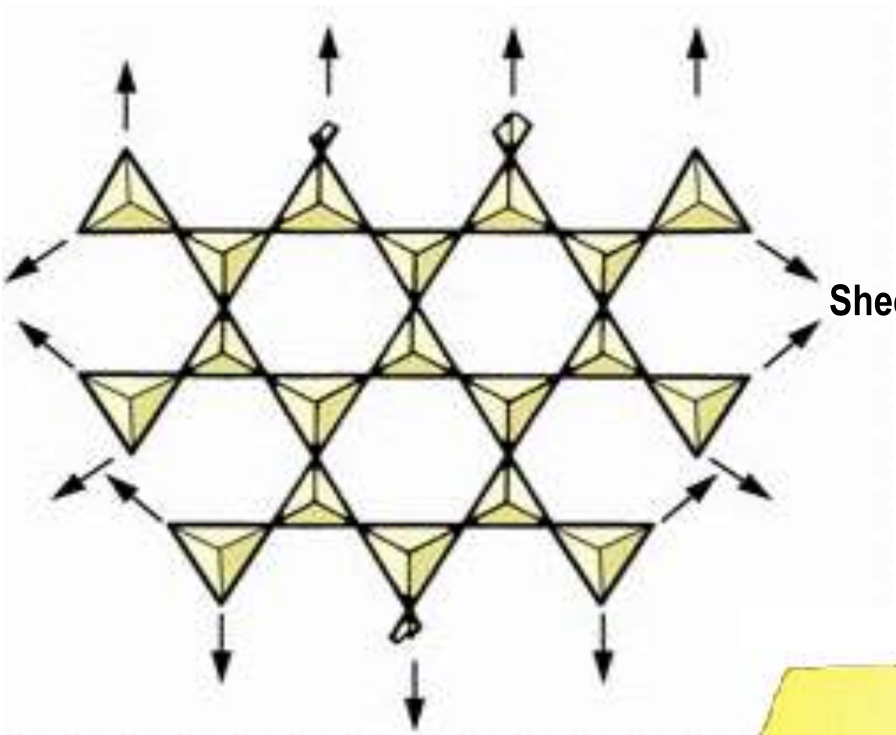


Double Chain Silicates: The Amphiboles (e.g., hornblende)

Silicate Mineral Groups

(e.g., biotite, muscovite, and the clays)

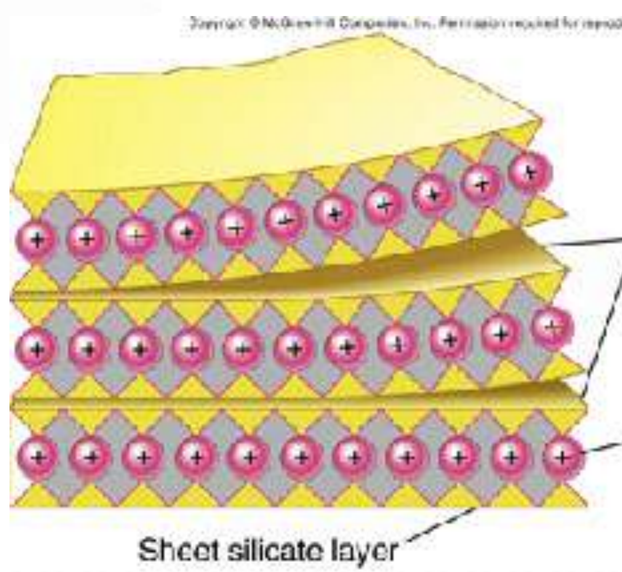


Sheet silicate structure

Example:

Clay groups

Mica groups



Because of weak bonds, mica splits asily between "sandwiches"

Positive ions, sandwiches between two sheets silicate layers

FIGURE 2.15 The thin sheets shown here were produced by splitting a mica (muscovite) crystal parallel to its perfect cleavage. *(Photo by Chip Clark)*

(Lutgens et al, 2011)

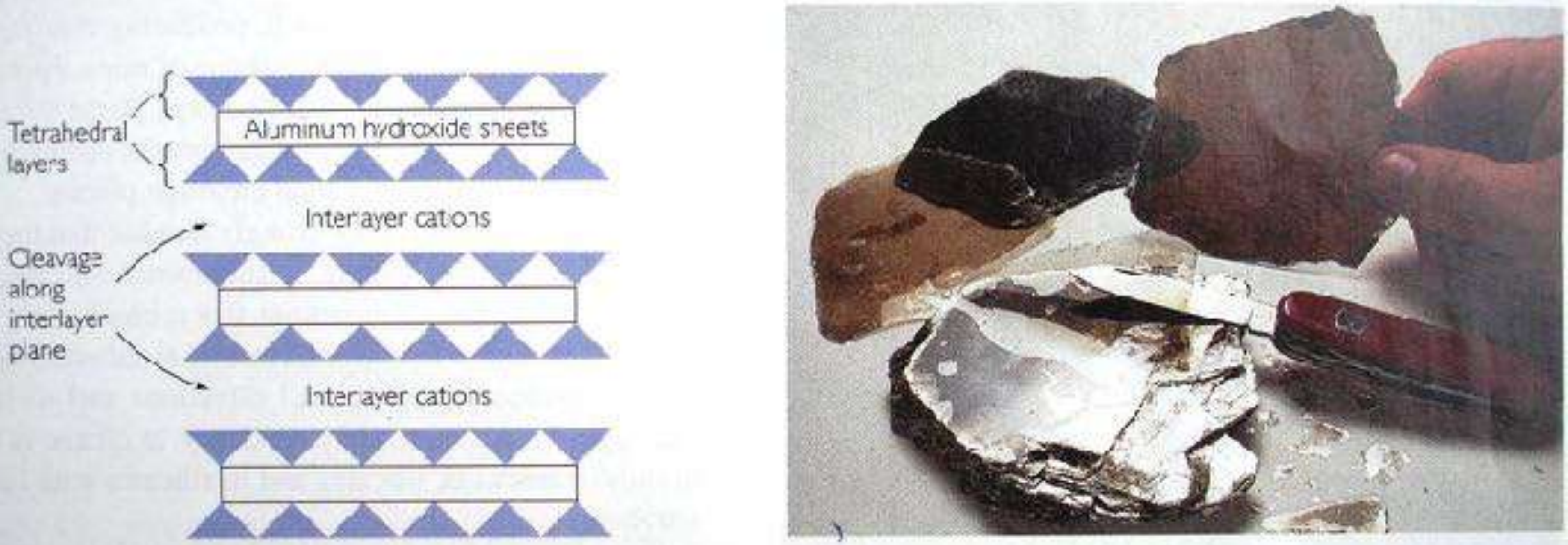


Figure 2.23 Cleavage of mica. The diagram shows the cleavage planes in the mineral structure, oriented perpendicularly to the plane of the page. Horizontal lines mark the interfaces of silica–oxygen tetrahedral sheets and sheets of aluminum hydroxide bonding the two tetrahedral layers into a "sandwich." Cleavage takes place between composite tetrahedral–aluminum hydroxide sandwiches. The photograph shows thin sheets separating along the cleavage planes. [*Chip Clark.*]

Silicate Mineral Groups

(potassium feldspar, sodium and calcium plagioclase feldspar, quartz)

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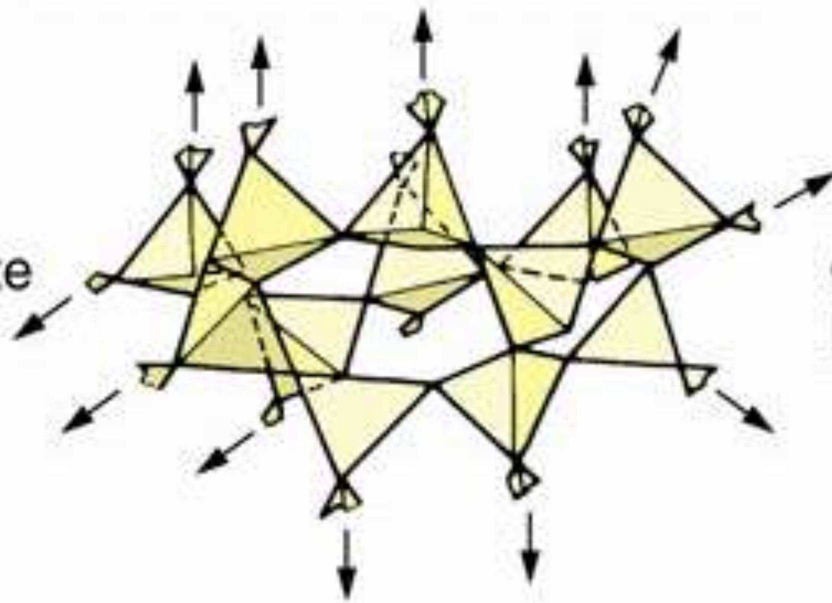
Example

Framework silicate structure



Quartz
Feldspar group

Silicate Mineral Groups

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.)	
Olivines	Mg, Fe silicate	Single-island silicate
Pyroxenes (augite most common)	Fe, Mg silicate (some with Al, Na, Ca)	Single-chain silicate
Amphiboles (hornblende most common)	Complex Fe, Mg, Al silicate hydroxide	Double-chain silicate
Micas		
Muscovite	K Al silicate hydroxide	Sheet silicate
Biotite	K Fe, Mg Al silicate hydroxide	Sheet silicate
Clays	Complex Al silicate hydroxides	Sheet silicate
Feldspars		
Plagioclase feldspar	Ca and Na Al silicate	Framework silicate
Potassium feldspar	K Al silicate	Framework silicate
Quartz	Silica	Framework silicate

The Common Rock-Forming Silicate Minerals

Non-silicate Mineral Groups

- **Native Elements**: consist of only one element.
  - Au (gold), Ag (silver), Cu (copper), S (sulfur), C (graphite, diamond)
- **Oxides**: contain O^{2-}
  - Fe_2O_3 (hematite), Fe_3O_4 (magnetite), Al_2O_3 (corundum)
- **Carbonates**: contain CO_3^{2-}
  - $CaCO_3$ (calcite), $CaMg(CO_3)_2$ (dolomite)
- **Sulfides**: contain S^{2-}
  - FeS_2 (pyrite), PbS (galena), $CuFeS_2$ (chalcopyrite)
- **Sulfates**: contain SO_4^{2-}
  - $CaSO_4.2H_2O$ (gypsum), $BaSO_4$ (barite)
- **Halides**: contain F^{1-}, Cl^{1-}, Br^{1-}, or I^{1-}
  - NaCl (halite), KCl (sylvite), CaF_2 (fluorite)

Table 2.1

Some Chemical Classes of Minerals

Class	Defining Anions	Example
Native elements	None: no charged ions	Copper metal (Cu)
Oxides and hydroxides	Oxygen ion (O^{2-})	Hematite (Fe_2O_3)
	Hydroxyl ion (OH^-)	Brucite ($Mg[OH]_2$)
Halides	Chloride (Cl^-), fluoride (F^-), bromide (Br^-), iodide (I^-)	Halite ($NaCl$)
Carbonates	Carbonate ion (CO_3^{2-})	Calcite ($CaCO_3$)
Sulfates	Sulfate ion (SO_4^{2-})	Anhydrite ($CaSO_4$)
Silicates	Silicate ion (SiO_4^{4-})	Olivine (Mg_2SiO_4)

Non-silicate Mineral Groups

Table 1.1 Common nonsilicate mineral groups

Mineral Group	Name	Chemical Formula	Economic Use
Oxides	Hematite	Fe_2O_3	Ore of iron, pigment
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water
Sulfides	Galena	PbS	Ore of lead
	Sphalerite	ZnS	Ore of zinc
	Pyrite	FeS_2	Sulfuric acid production
	Chalcopyrite	$CuFeS_2$	Ore of copper
	Cinnabar	HgS	Ore of mercury
Sulfates	Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud
Native elements	Gold	Au	Trade, jewelry
	Copper	Cu	Electrical conductor
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photograph
	Platinum	Pt	Catalyst
Halides	Halite	$NaCl$	Common salt
	Fluorite	CaF_2	Used in steelmaking
	Sylvite	KCl	Fertilizer
Carbonates	Calcite	$CaCO_3$	Portland cement, lime
	Dolomite	$CaMg(CO_3)_2$	Portland cement, lime

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Non-silicate Mineral Groups

FIGURE 2.21 Aerial view of Bingham Canyon copper mine near Salt Lake City, Utah. Although the amount of copper in the rock is less than 1 percent, the huge volume of material removed and processed each day (about 200,000 tons) yields enough metal to be profitable. (Photo by Michael Collier)

(Lutgens et al, 2011)

Geo-inSight The Precious Metals

The discovery of gold by James Marshall at Sutter's Mill near Coloma in 1848 sparked the California gold rush (1849–1853) during which $200 million in gold was recovered.

▲ 1. Specimen of gold from Grass Valley, California. Gold is too heavy and too soft for tools and weapons, so it has been prized for jewelry and as a symbol of wealth, but it is also used in glass making, electrical circuitry, gold plating, the chemical industry, and dentistry.

(Carlsons et al, 2011

How do minerals form?

- By crystallization from magma (molten rock material)
  - a saturation response
- By crystallization (precipitation) from aqueous fluids
  - a saturation response
- By chemical reaction with
  - magmatic fluids
  - hydrothermal fluids
  - water during weathering
- By solid state transformations (metamorphism)
  - changes crystal form
  - moves ions to new locations
  - promotes growth along the edges of mineral grains (crystals) at the expense of their neighboring mineral grains

How do minerals form?

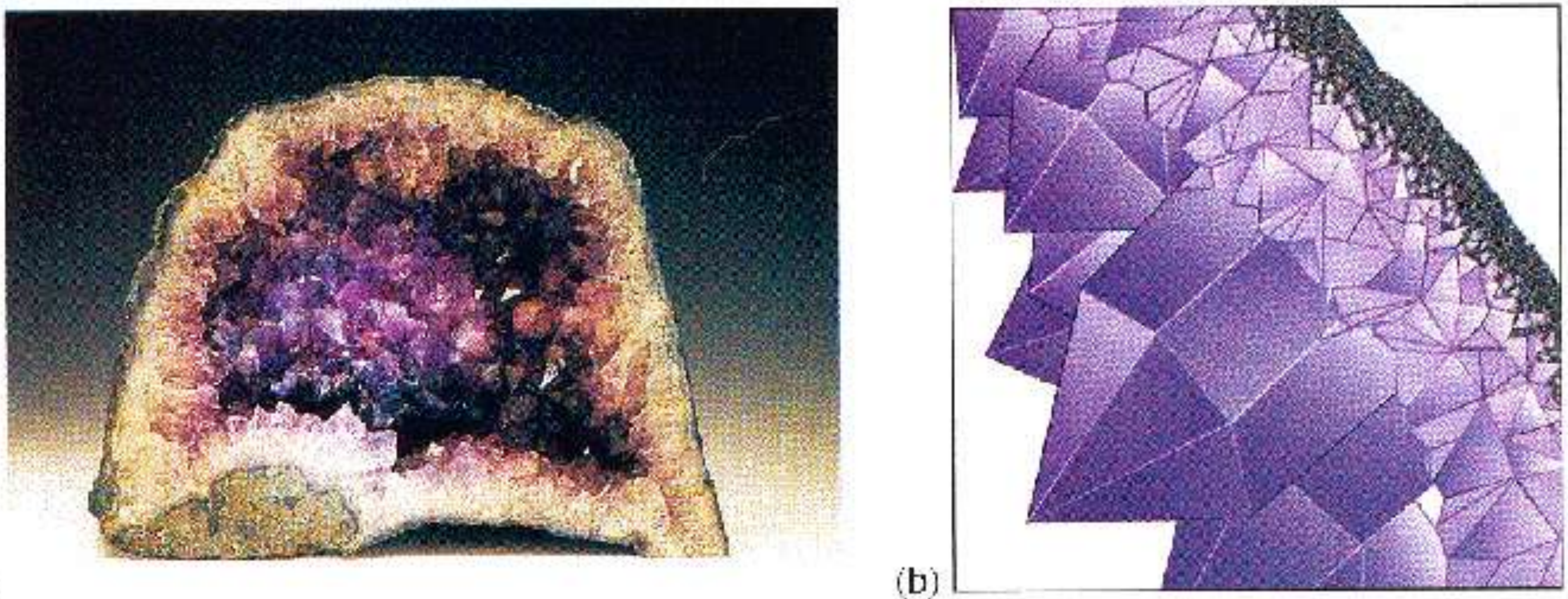

FIGURE 5.12 (a) A geode, in which euhedral crystals grow from the wall into the center. (b) An enlargement of a euhedral crystal, showing that the surfaces are crystal faces.

(a) (b)

(Marshak, Stephen, 2001, Earth. Portrait of a Planet, W.W. Norton & Company)

Crystallization of Minerals in Cavities: Geodes

How do minerals form?

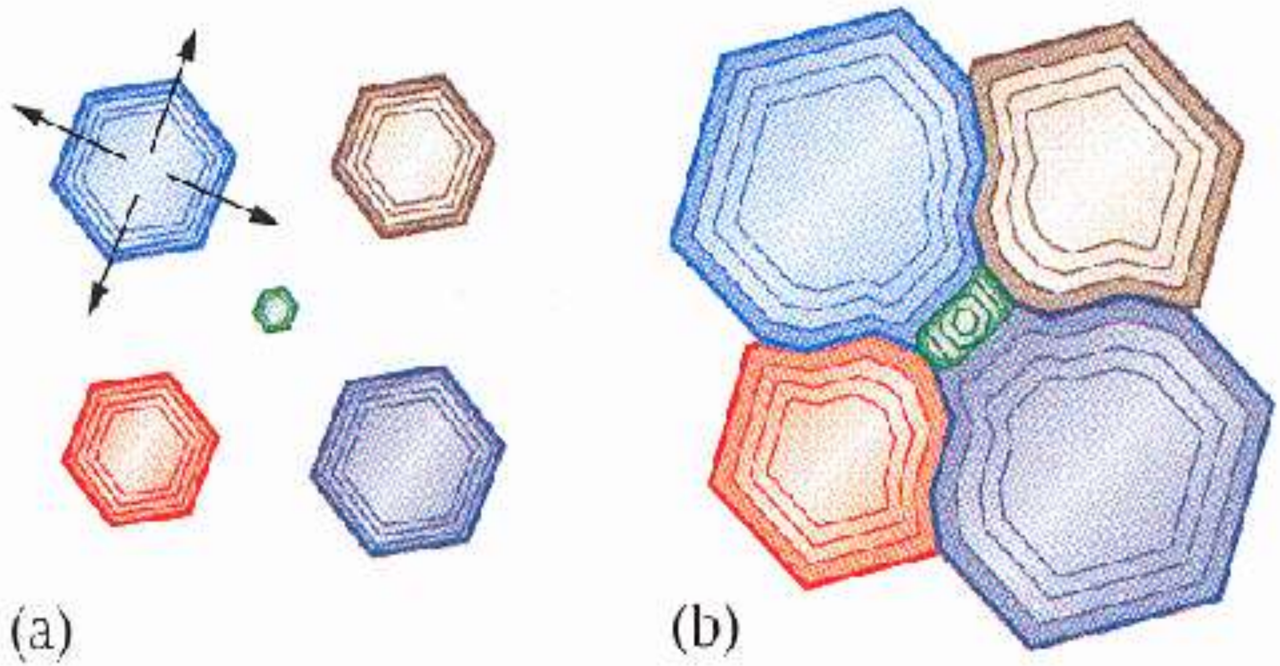

FIGURE 5.11 (a) Crystals grow outward from the central seed. (b) Crystals maintain their shape until they interfere with each other. When that happens, the crystal shapes can no longer be maintained.

(Marshak, Stephen, 2001, Earth, Portrait of a Planet, W.W. Norton & Company)

The Effect of Crowding on Crystal Growth

How do minerals form?

Polymorphs

- Polymorphs are minerals that have the same chemical composition but a different crystal form
- Graphite and diamond polymorphs of carbon
  - Graphite forms at low temperature and pressure
  - Diamond forms at high temperature and pressure
- Quartz, stishovite, and coesite are polymorphs of SiO_2
  - Quartz forms at low to medium temperature and pressure
  - stishovite and coesite form at high pressure, such as that associated with meteor impacts
- Andelusite, kyanite, and sillimanite are polymorphs of Al_2SiO_5
  - Andelusite is the low temperature low pressure polymorph
  - Kyanite is the low temperature high pressure polymorph
  - Sillimanite is the high temperature high pressure polymorph

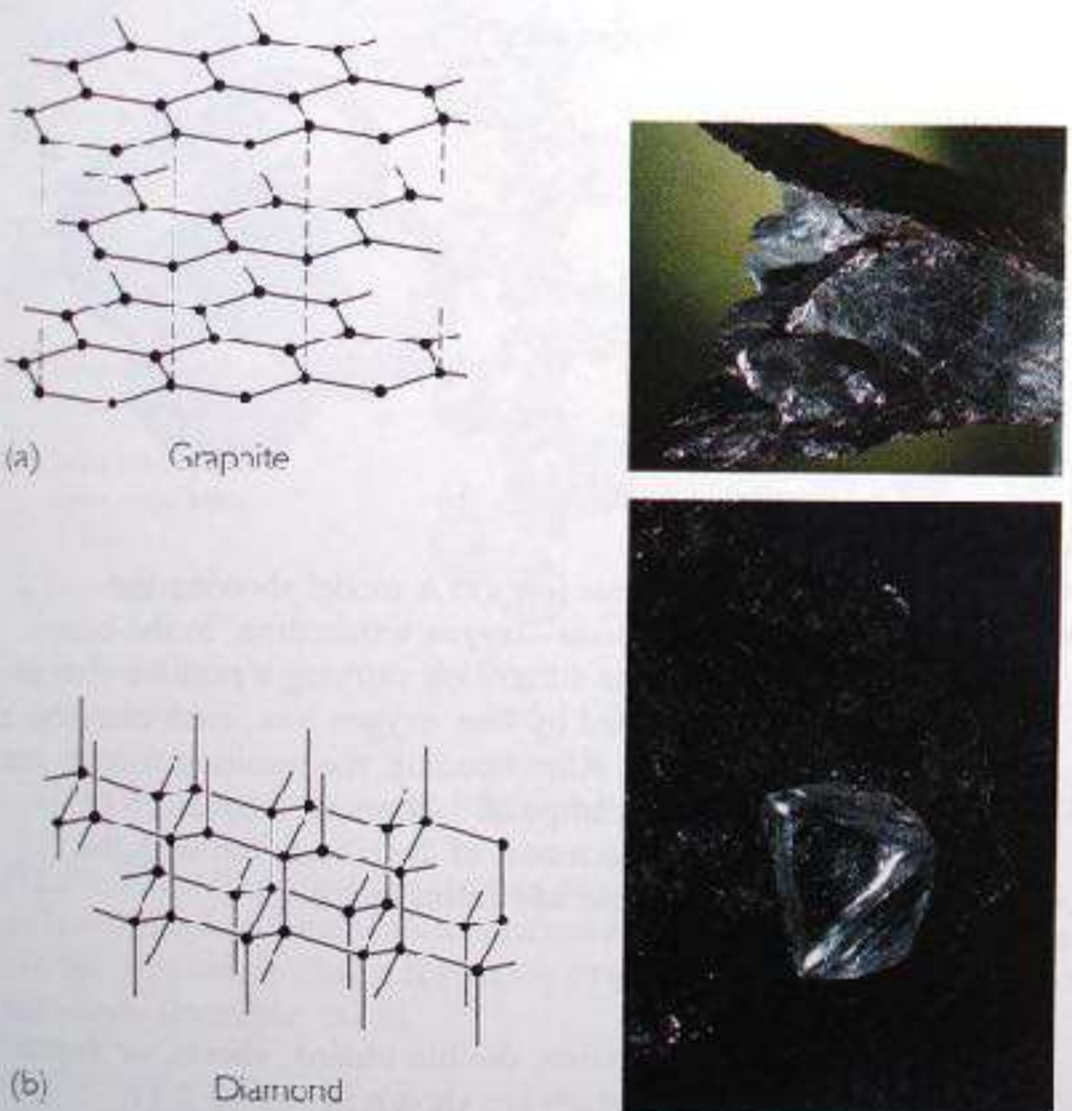

Figure 2.15 (a) In graphite, sheets of carbon atoms arranged in hexagons are stacked above one another with weak bonds (dashed lines) between the sheets. (b) In diamond, carbon atoms are arranged in a tetrahedral network. Graphite forms flat, platelike masses of crystals. [*Ken Lucas/Visuals Unlimited.*] Diamond, when well crystallized, typically forms octahedral (eight-faced) crystals. [*E. R. Degginger/Photo Researchers.*]

(Press & Siever, 1994)

How do minerals form?

Pseudomorphs

- Pseudomorphs are minerals that have the same crystal form but a different chemical composition
  - Limonite forms cubic pseudomorphs after pyrite
  - Quartz forms pseudomorphs after fluorite

Next ……………..

IDENTIFICATION OF MINERALS