Mineralogy

Course content

(Mineralogy)

(3- 4 lectures)

Minerals:

- **Classification of minerals;**
- **Mineral associations;**
- **Structure of silicate minerals;**
- **Physical properties of minerals**

1.1. The Science of Mineralogy

The science of mineralogy is the study of the physics and chemistry of natural, solid, crystalline materials.

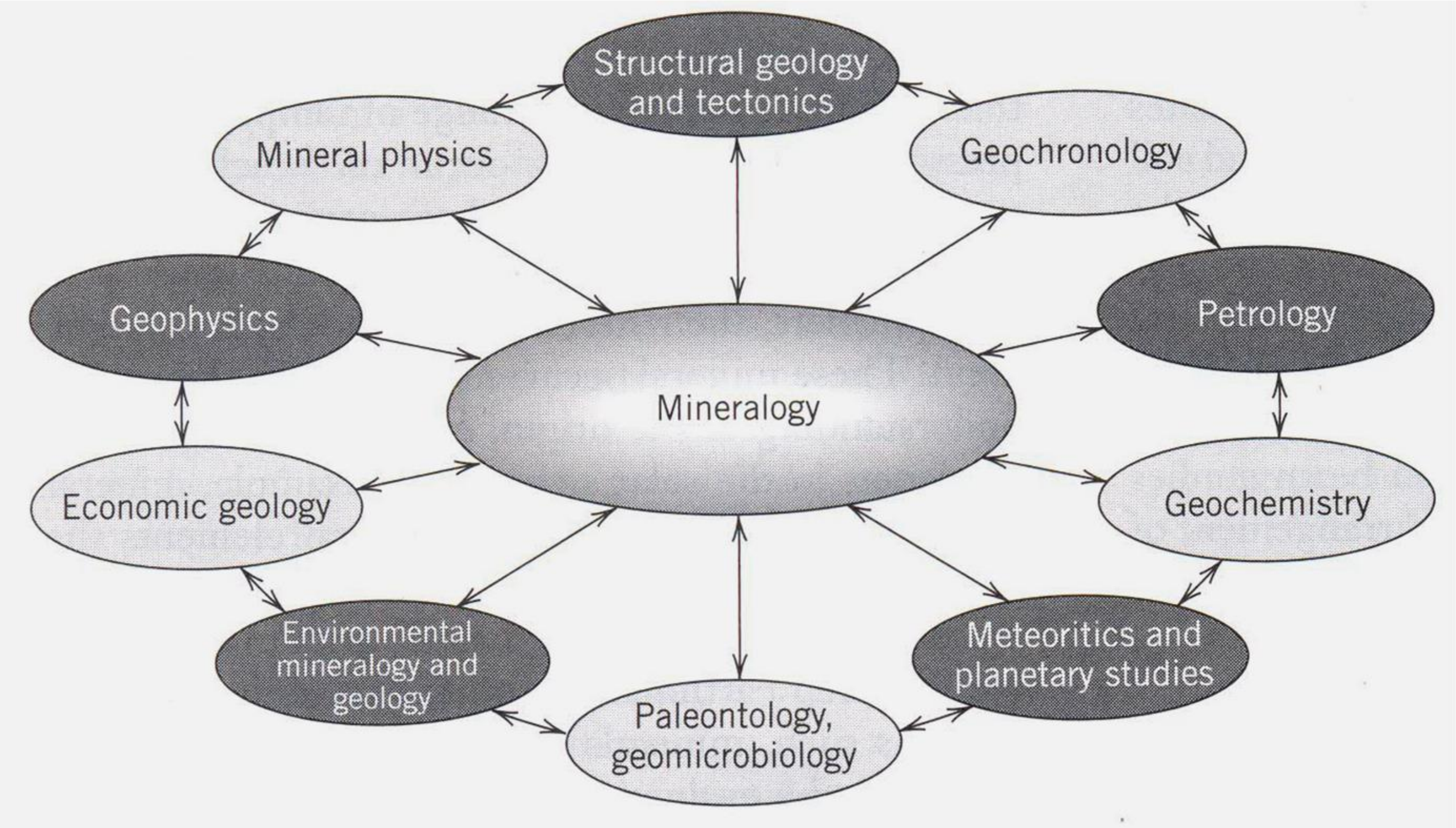


Fig. 1.1: The central role of mineral science in the earth sciences. The double arrows portray linkages of subdisciplines to one another and to mineral science; they indicate an especially close relationship between subdisciplines (see text for details)

Definition of a Mineral

A mineral is a naturally occurring, homogeneous solid with a definite, but generally not fixed, chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes.

A mineral is **any naturally occurring inorganic solid that possesses an orderly crystalline structure and can be represented by a chemical formula.**

Atoms => Ions (cations/anions) => Molecules => Crystals/Crystalline solid => Minerals

Definition of a mineral

Naturally occuring
Homogenous solid
Definite (but not fixed) chemical composition
Defined physical properties
Highly ordered atomic arrangement
Usually formed by inorganic processes

- **Ordered atoms distinguished crystals (solids) from liquids, gases and glasses**
- **Ordered…periodic repetition of atoms of atom or ion througout an infinite atomic array.**
- **An atom is surrounded by an identical arrangement of neighboring atoms, which are n quantity of unit cells**
- **Unit cells dimensions: 5-20 angstroms**

  (1A=10^{-8cm})

Thus, Earth materials that are classified as minerals exhibit the following characteristics:

1. Naturally occurring. Minerals form by natural, geologic processes. Synthetic materials, meaning those produced in a laboratory or by human intervention, are not considered minerals.

2. Solid substance. Only crystalline substances that are solid at temperatures encountered at Earth's surface are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral.

Whereas liquid water and water vapor do not. The exception is mercury, which is found in its liquid form in nature.

Murcury named after the Roman messenger of the gods, Mercurius.

Mercury is officially classed as a mineral species for historical reasons, and also because it is distinctive in its chemical and physical properties.

However, because it occurs as a liquid, it does not satisfy the normal criteria to be a valid mineral. It crystallizes at -40 degrees celsius, at which point is forms rhombohedral crystals.

It is usually found as small isolated drops associated with cinnabar, but it can also be found as large liquid masses in rock cavities.

Mercury is often found, along with cinnabar and other Hg minerals, as a precipitate from hot springs and in volcanic regions.

Because of its rarity, it is not often used as an ore of mercury.

Glasses (obsidian), liquids, and gases however, are not crystalline, and the elements in them may occur in any ratios, so they are not minerals.

So in order for a natural compound to be a mineral, it must have a unique composition and structure.

3. Orderly crystalline structure. Minerals are crystalline substances, which means their atoms are arranged in an orderly, repetitive manner (Fig. 2.2).

This orderly packing of atoms is reflected in the regularly shaped objects called crystals.

Some naturally occurring solids, such as volcanic glass (obsidian), lack a repetitive atomic structure and are not considered minerals.

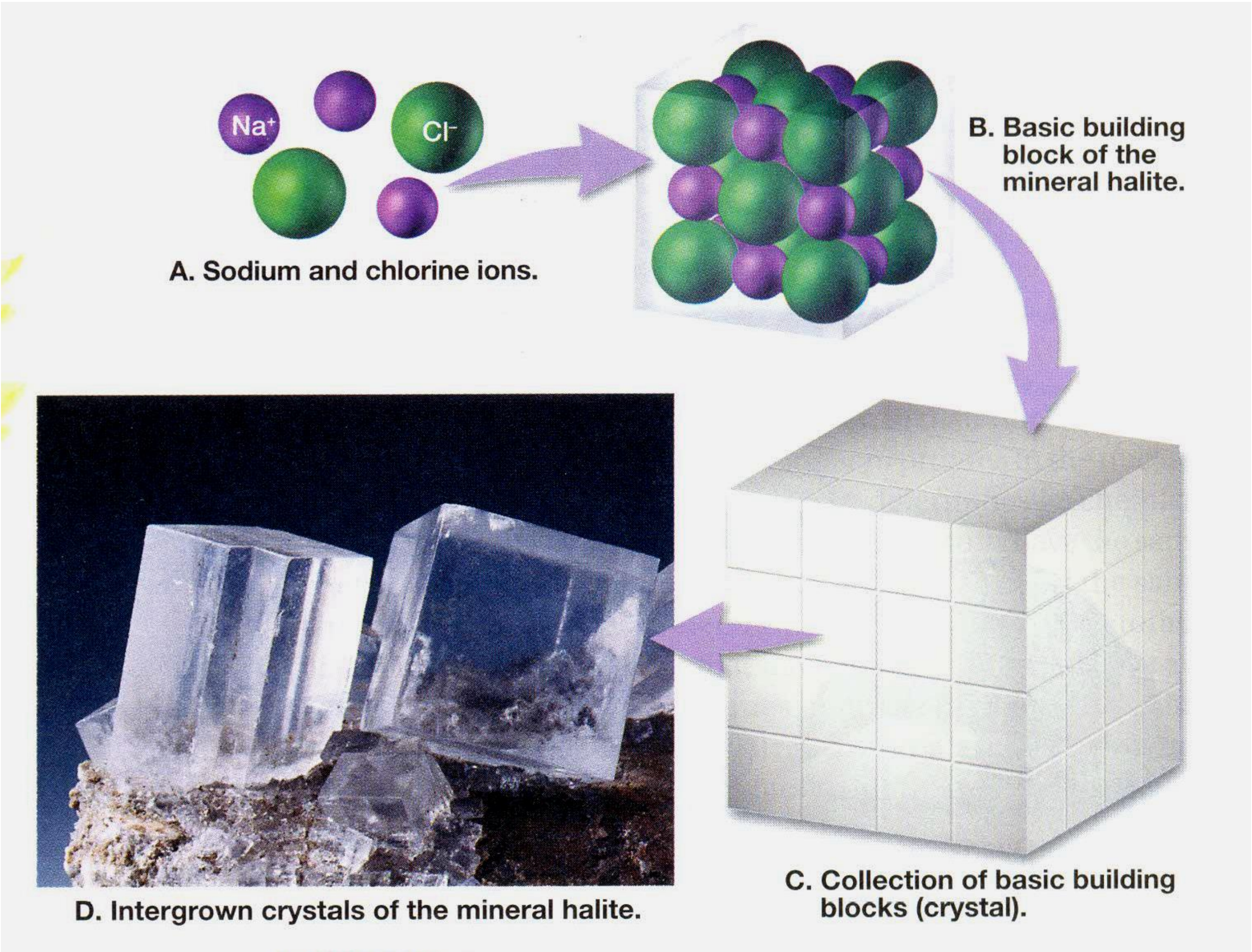
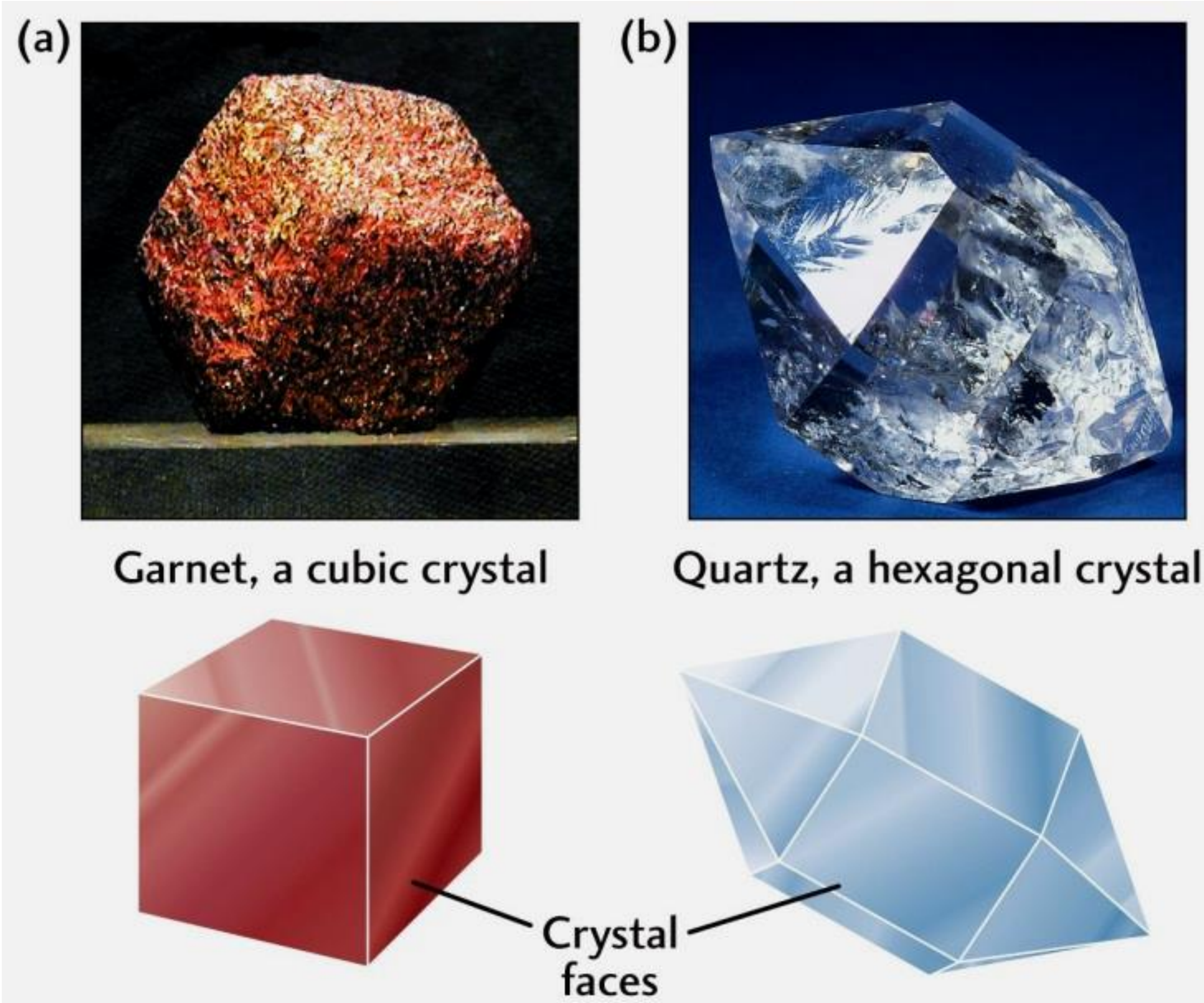
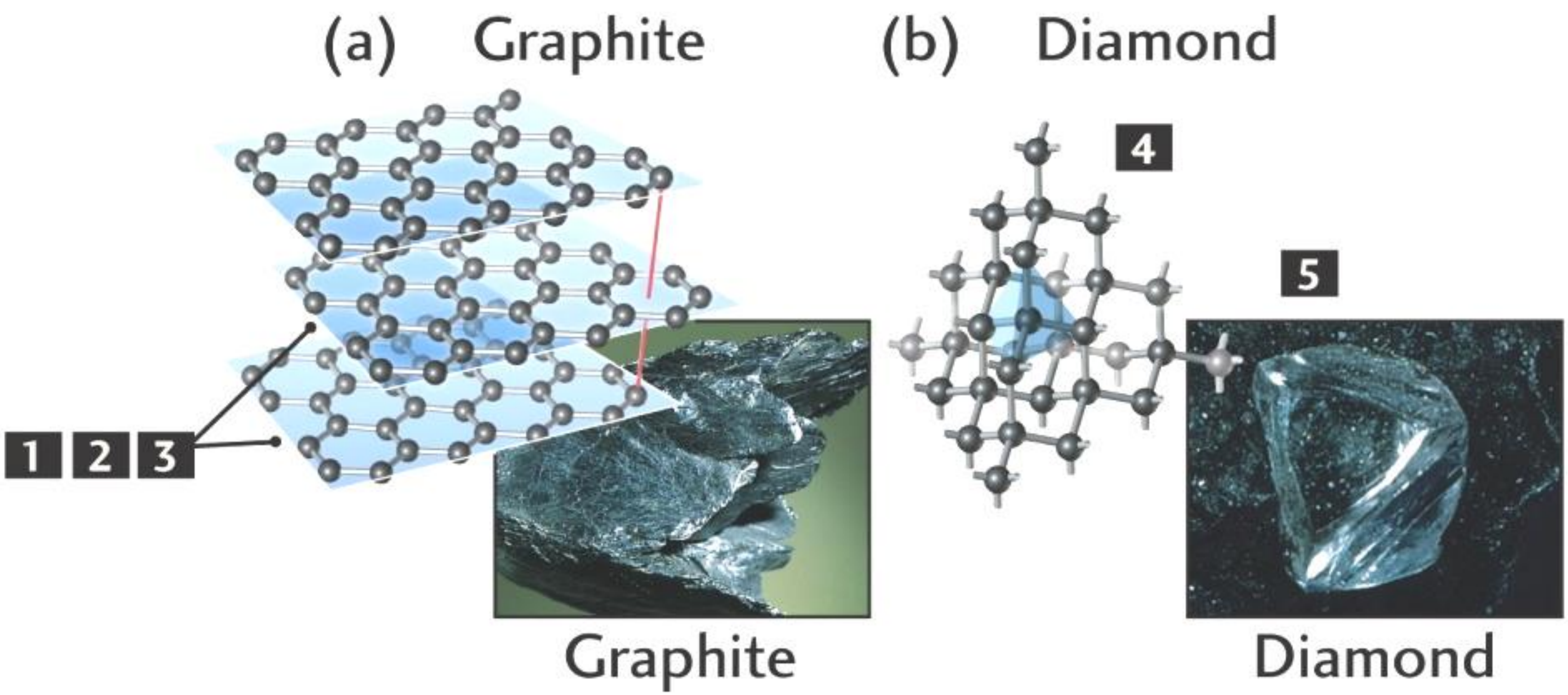


FIGURE 2.2 This diagram illustrates the orderly arrangement of sodium and chloride ions in the mineral halite. The arrangement of atoms into basic building blocks having a cubic shape results in regularly shaped cubic crystals. (Photo by Dennis Tasa)


(a)
(b)
Garnet, a cubic crystal
Quartz, a hexagonal crystal
Crystal
faces

CARBON POLYMORPH MINERALS



4. Generally inorganic. Inorganic crystalline solids, such as ordinary table salt (halite), that are found naturally in the ground are considered minerals.

Organic compounds, on the other hand, are generally not. Sugar, a crystalline solid like salt but which comes from sugarcane or sugar beets, is a common example of such an organic compound, and is not a mineral.

Many marine animals secrete inorganic compounds, such as calcium carbonate (calcite), in the form of shells and coral reefs.

If these materials are buried and become part of the rock record, they are considered minerals by geologists.

5. Can be represented by a chemical formula.

Most minerals are chemical compounds having compositions that can be expressed by a chemical formula.

For example, the common mineral quartz has the formula $Si0_2$, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms in a ratio of one-to-two.

This proportion of silicon to oxygen is true for any sample of pure quartz, regardless of its origin.

However, the compositions of some minerals vary *within specific, well-defined limits.*

This occurs because certain elements can substitute for others of similar size without changing the mineral's internal structure.

An example is the mineral olivine, in which either the element magnesium (Mg) or iron (Fe) may occupy the same site in the crystal structure.

Therefore, olivine's formula, $(Mg, Fe)_2Si0_4$, expresses variability in the relative amounts of magnesium and iron.

However, the ratio of magnesium plus iron (Mg + Fe) to silicon (Si) and oxygen (O) remains fixed at 2:1:4.

The fifth part of our definition of a mineral leads us to a brief discussion of stoichiometry, the ratios in which different elements (atoms) occur in minerals.

Because minerals are crystals, dissimilar elements must occur in fixed ratios to one another.

Complete free substitution of very similar elements (e.g., Mg+2 and Fe+2 which are very similar in charge (valence) and radius) is very common and usually results in a crystalline solution (solid solution).

For example, the minerals forsterite (Mg2SiO4) and fayalite (Fe2SiO4) are members of the olivine group and have the same crystal structure, that is, the same geometric arrangement of atoms.

Mg and Fe substitute freely for each other in this structure, and all compositions between the two extremes, forsterite and fayalite, may occur.

However, Mg or Fe do not substitute for Si or O, so that the three components, Mg/Fe, Si and O always maintain the same 2 to 1 to 4 ratio because the ratio is fixed by the crystalline structure.

These two minerals are called end-members of the olivine series and represent extremes or "pure" compositions.

Because these two minerals have the same structure, they are called isomorphs and the series, an isomorphous series.

Rocks: **In contrast to minerals, rocks are more loosely defined. Simply a rock is any solid that consists of an aggregate of minerals, pieces of preexisting rocks, or a mass of mineral-like matter such as natural glass.**

Some rocks are composed almost entirely of one mineral. A common example is the sedimentary rock *limestone,* which consists of impure masses of the mineral calcite.

However, most rocks, like the common rock granite shown in Figure 2.3, occur as aggregates of several different minerals.

The term *aggregate* implies that the minerals are joined in such a way that their individual properties are retained.

Note that the mineral constituents of granite can be easily identified (Fig. 2.3).

FIGURE 2.3 Most rocks are aggregates of two or more minerals. Shown here is a hand sample of the igneous rock granite and three of its major constituent minerals. (Photos by E. J. Tarbuck)

Some rocks are composed of nonmineral matter. These include the volcanic rocks *obsidian* and *pumice*, which are non-crystalline glassy substances, and *coal*, which consists of solid organic debris.

Thus most rocks are simply aggregates of minerals.

Atomic structure of minerals

Many mineral properties are closely related to the underlying chemical properties of constituent atoms and molecules.

Let us start, therefore, by reviewing some fundamental chemistry.

The basic building unit of a crystal is the atom.

An atom is the smallest subdivision of matter that retains the characteristics of the element.

It consists of a very small, massive nucleus composed of protons and neutrons (Table 3.1) surrounded by a much larger region thinly populated by electrons.

Each proton carries a unit positive charge; the neutron, as the name implies, is electrically neutral; and each electron carries a unit negative charge (Table 3.1).

Table 3.1 Some Atomic Particles*

Particle	Symbol	Atomic Mass Units	Relative Change
Electron	*e*	0.0005486	−1
Proton	*p*	1.007276	+1
Neutron	*n*	1.008665	0

*Consideration of other particles discovered in studies of high-energy physics is unnecessary in this context.

The fundamental difference between atoms of the different elements lies in the electrical charge of the nucleus.

This positive charge is the same as the number of protons.

This number, equal to the number of electrons in an uncharged atom, is called the atomic number (= Z).

The sum of the number of protons and neutrons determines the characteristic mass, or mass number of an element and is based on atomic mass units (amu).

The amu is defined as exactly 1/12 of the mass of an atom of carbon-12 (^{12}C).

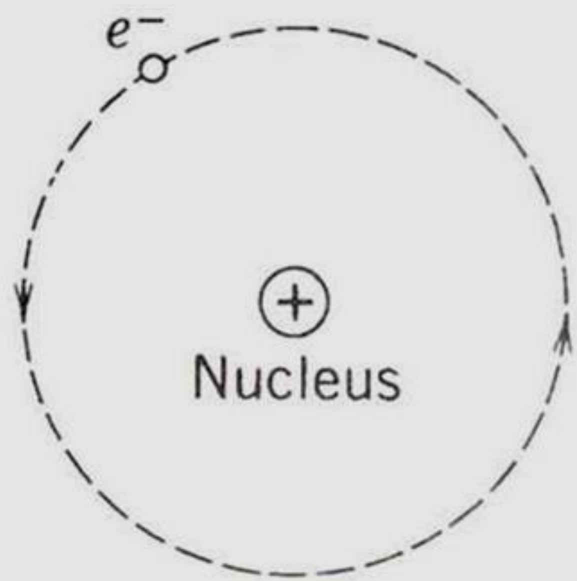
Traditionally, this is termed atomic weight (AW), but the measurement is most properly termed a mass rather than weight.

The mass of the atom is concentrated in the nucleus because the mass of an electron is only 1/1837 or nearly 1/2000 that of the proton.

The simplest atom is that of hydrogen, which consists of one proton and one electron (Fig. 3.1); Atomic number Z = 1 and its atomic mass = 1.00794.

Atoms of the other elements have from 2 protons (helium, He, Z = 2) to 116 protons (Ununhexium i.e. Uuh, Z = 116) (Table 3.2).

FIG. 3.1 Schematic representation of the hydrogen atom as based on the model of Niels Bohr. A single electron (e^-) moves in an orbit around the nucleus (composed of only a proton), as in a planetary system.



For example, oxygen (Z = 8) has three isotopes, the most common of which has a nucleus with eight protons and eight neutrons; this is known as ^{16}O.

Rarer and heavier isotopes of oxygen carry eight protons and nine or ten neutrons; these are ^{17}O and ^{18}O, respectively.

Similarly, hydrogen, H, can exist in several isotopic forms.

The element H (Z =1) consists of one proton and one electron;

the H isotope with one neutron in the nucleus is ^{2}H, known as deuterium (D), and

the isotope with two neutrons in the nucleus is ^{3}H, tritium (T).

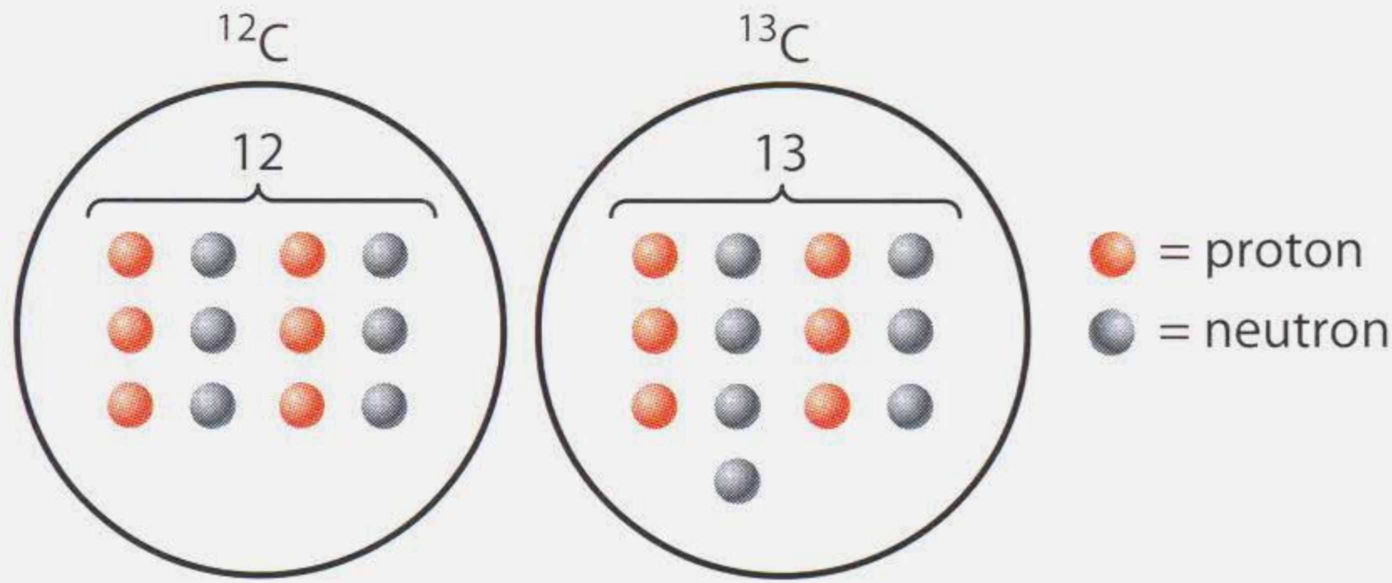


Figure 4.16 Schematic illustration of the content of the nucleus of two different isotopes of carbon, namely ^{12}C and ^{13}C.

Atoms: Building Blocks of Minerals

When minerals are carefully examined, even under optical microscopes, the innumerable tiny particles of their internal structures are not discernable.

Nevertheless, all matter, including minerals, is composed of minute building blocks called atoms—the smallest particles that cannot be chemically split.

Atoms in turn contain even smaller particles—protons and neutrons located in a central nucleus that is surrounded by electrons (Fig. 2.4).

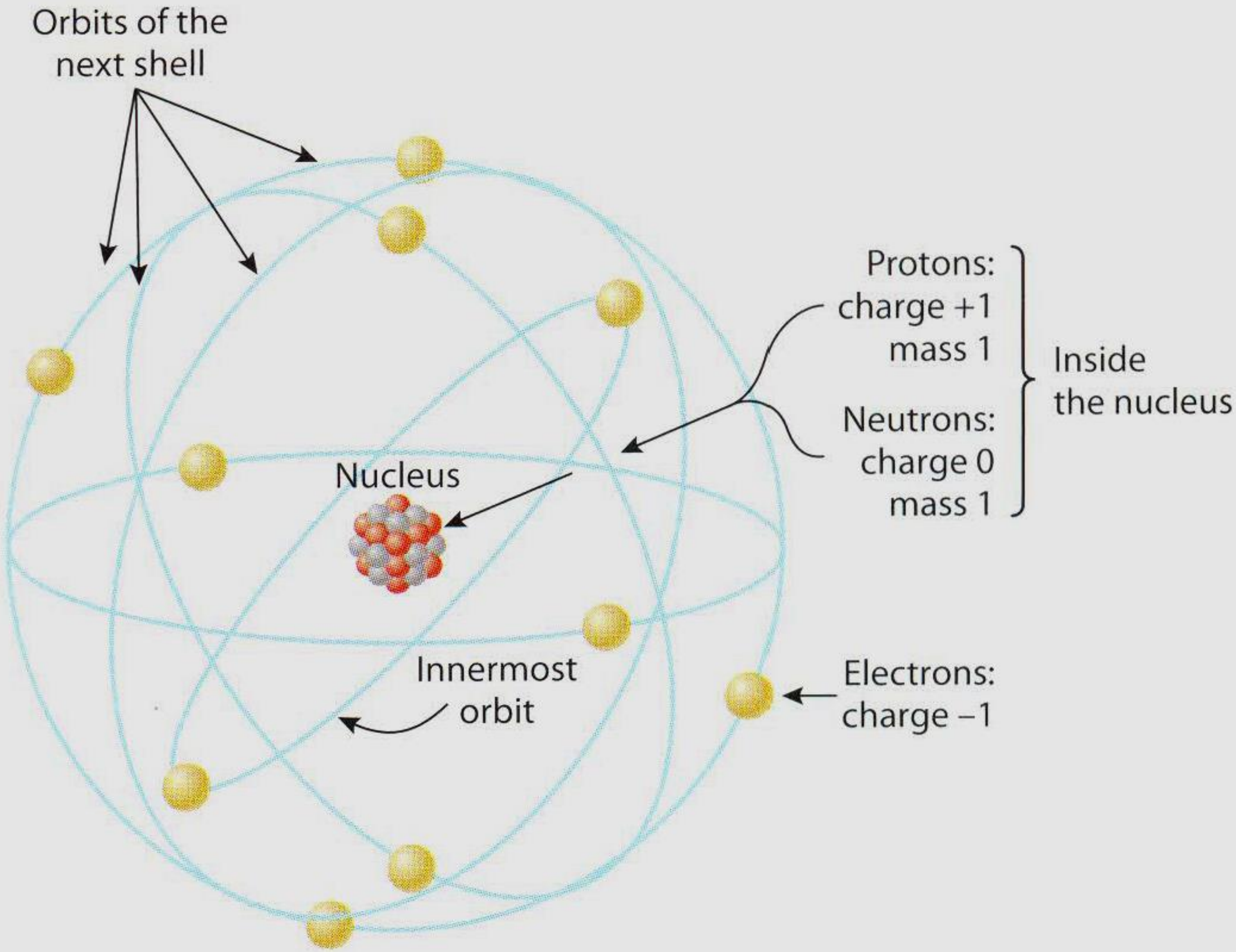


Figure 4.14 The Bohr model of the atom. Neutrons and protons in the nucleus and electrons circling outside.

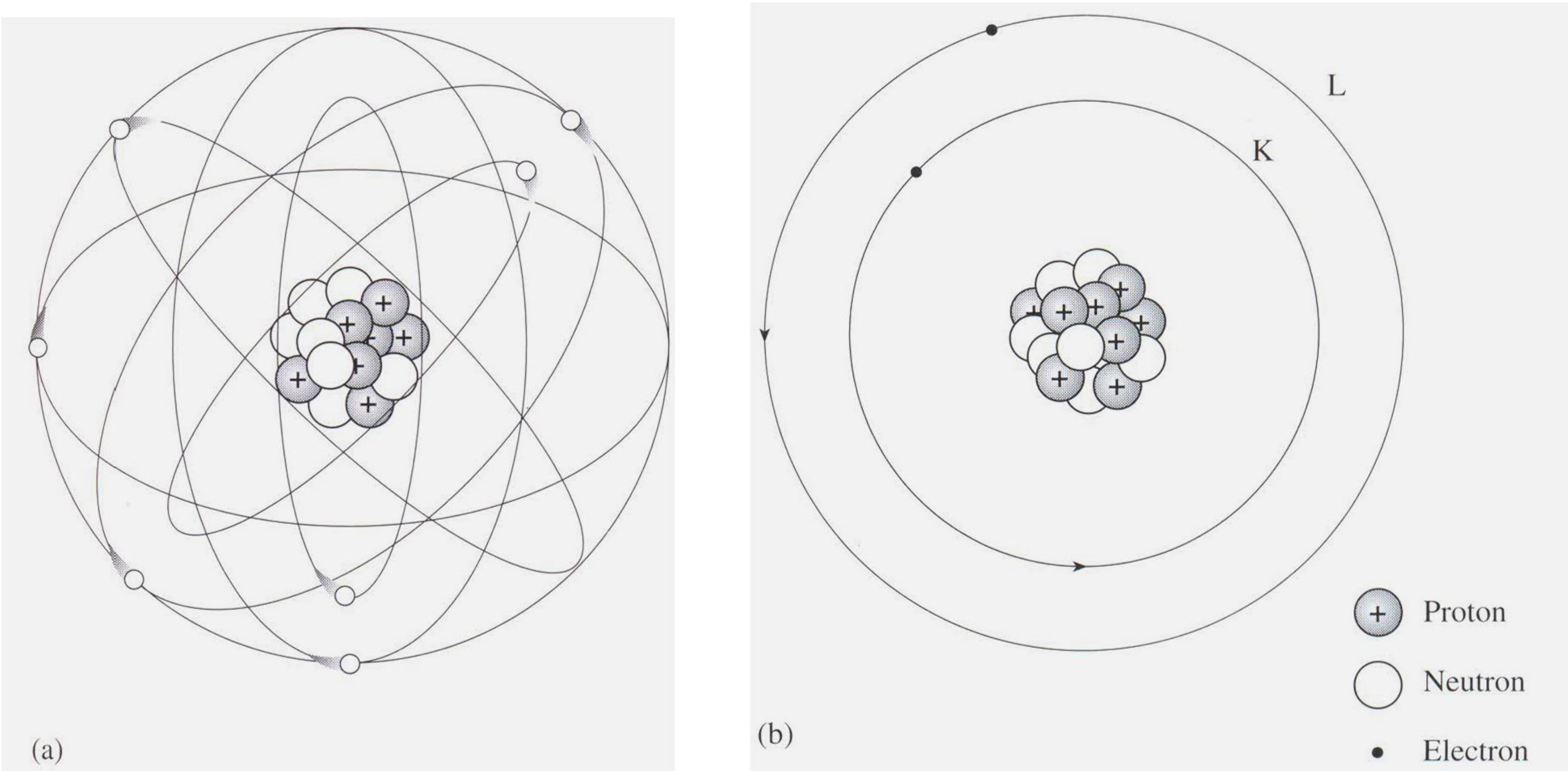
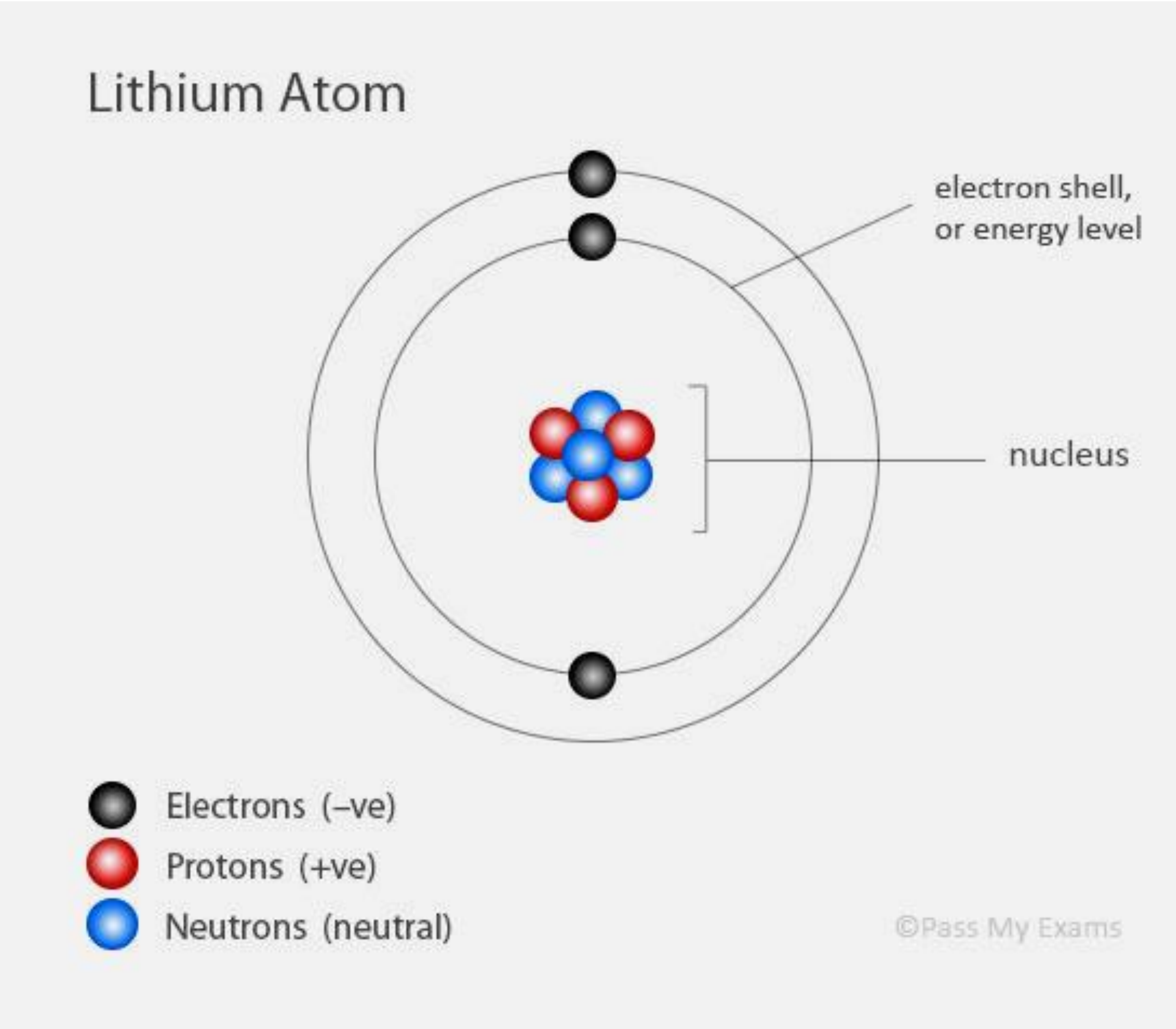
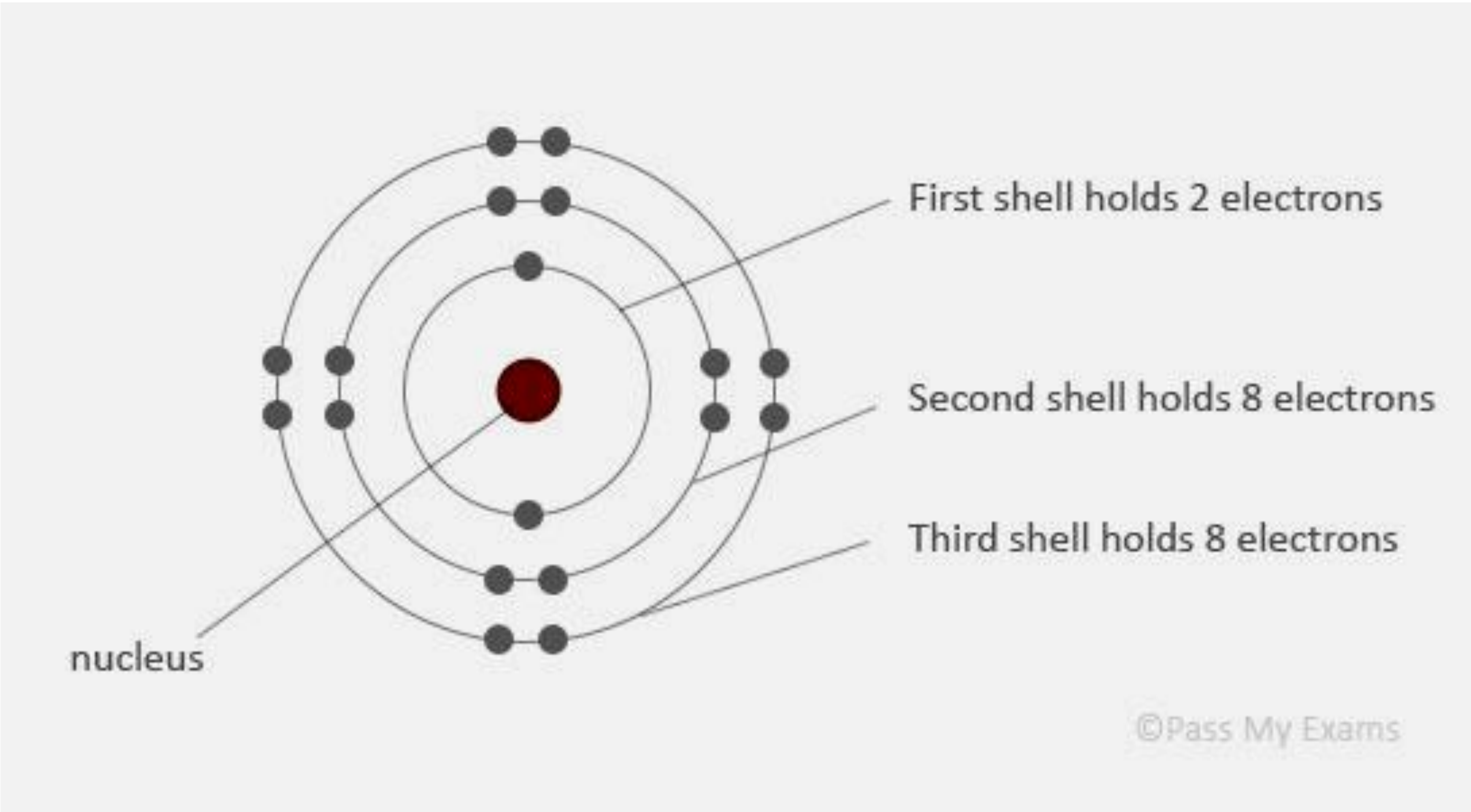


Fig. 2.1 Generalized models of atomic structure. (a) Within an atom a small nucleus consisting of protons and neutrons is surrounded by an electron "cloud". (The size of the nucleus relative to the electron cloud is greatly exaggerated.) (b) A more detailed view of the Bohr model of the atom reveals that electrons are arranged in shells (K, L, M, etc.).


Lithium Atom
electron shell,
or energy level
nucleus
Electrons (–ve)
Protons (+ve)
Neutrons (neutral)
©Pass My Exams


First shell holds 2 electrons
Second shell holds 8 electrons
Third shell holds 8 electrons
nucleus
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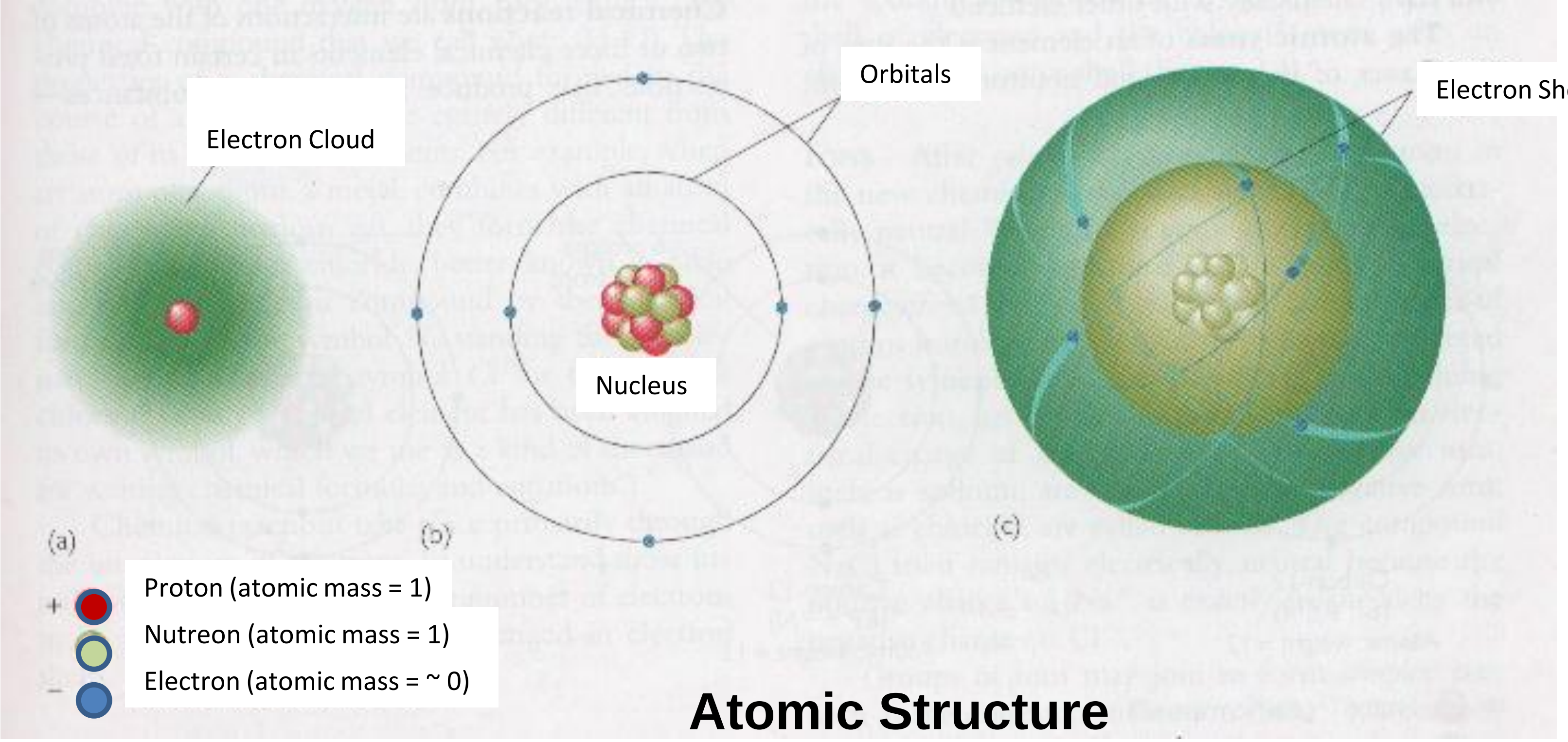
An atom is composed of a nucleus and a cloud of electrons around

Nucleus = protons (positively charged particles)+ neutrons (neutrally charged particles); electrons are negativelly charged

Atoms of the same element have a constant number of protons but can have a varying number of neutrons; elements have different isotopes



Atomic Structure

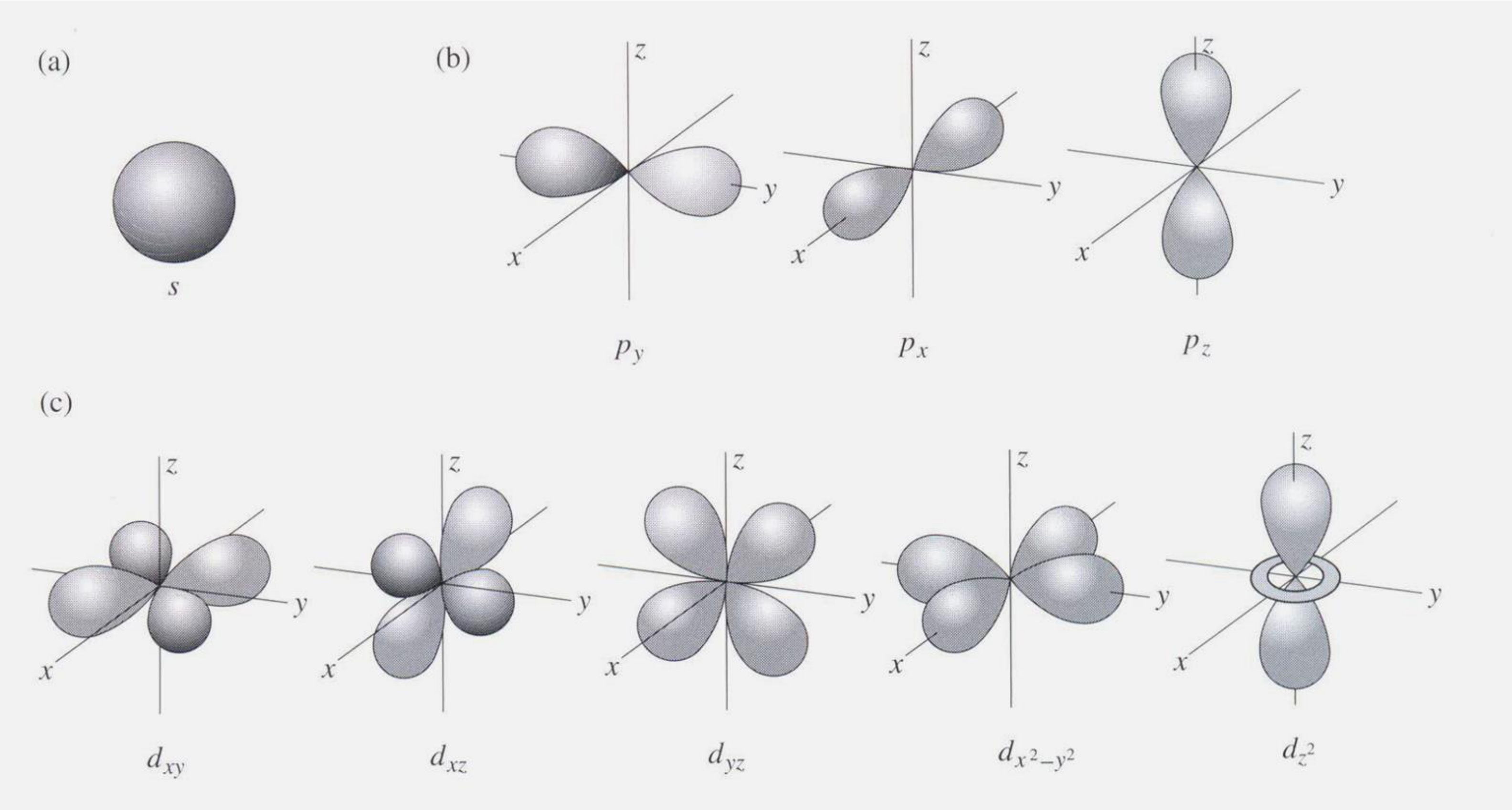


Fig. 2.3 Within a shell, electrons are arranged in orbitals. (a) The *s*-orbitals have a spherical geometry, (b) *p*-orbitals are directional along the principal axes, and (c) *d*-orbitals display more complicated distributions.

Studies of the arrangements of electrons show that they move about the nucleus in regions called *principal shells*, each with an associated energy level.

In addition, each shell can hold a specific number of electrons, with the outermost shell containing valence electrons that interact with other atoms to form chemical bonds.

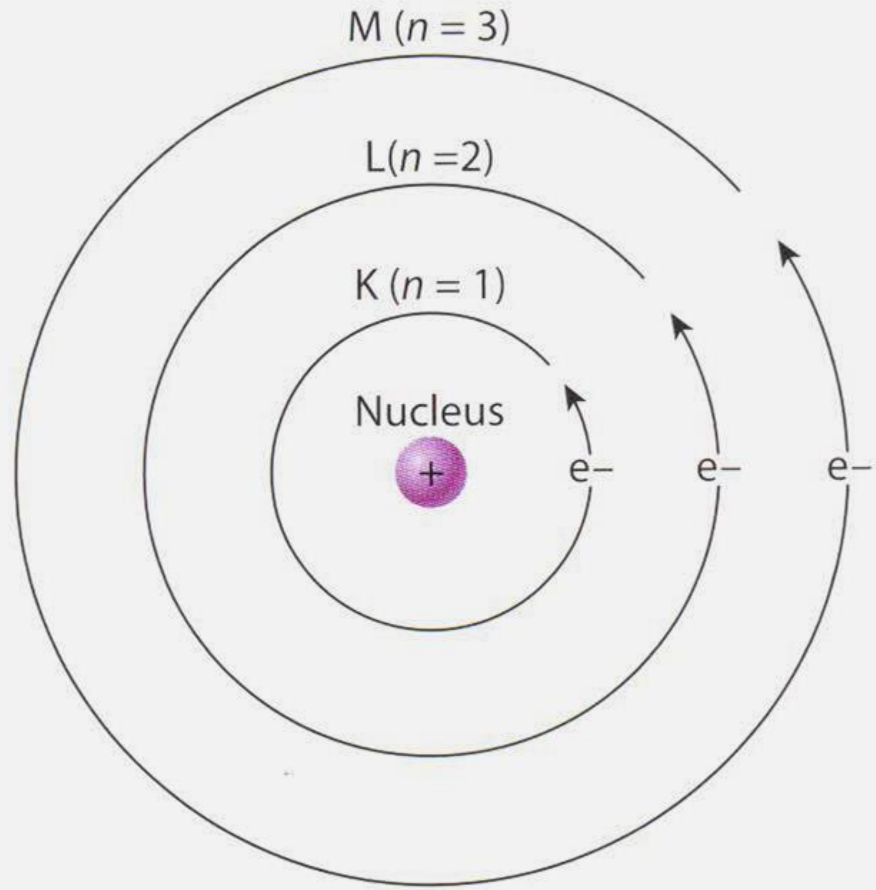


Figure 4.15 In the Bohr model, the electrons are able to travel along certain specific orbits of fixed energy. The orbits are identified as K, L, M, N, … shells with specific quantum numbers, $n = 1, 2, 3, 4 \ldots \infty$.

Most of the atoms in the universe (except hydrogen and helium) were created inside massive stars by nuclear fusion and released into interstellar space during hot, fiery supernova explosions.

As this ejected material cooled, the newly formed nuclei attracted electrons to complete their atomic structure.

At the temperatures found at Earth's surface, all free atoms (not bonded to other atoms) have a full complement of electrons- one for each proton in the nucleus.

Electrons

Negatively charged electrons, distributed over a much larger volume, surround the nucleus.

In the absence of an electric field, an isolated atom has a spherical shape with a diameter of 1-2 A^{0}(1 angstrom = 10^{-10} meter or 0.1 nanometers (nm)) (Fig. 2.1a).

Electrons are responsible mainly for the chemical behavior of atoms and for bonding, which combines atoms to form larger molecules and crystals.

The smallest atom, hydrogen, has a radius of only 0.46 A^0, whereas the largest, cesium, has a radius of 2.72 A^0.

Depending on the number of protons, atoms form different *elements* with distinct chemical properties.

At present 109 elements are known and new ones are being discovered.

The atomic number of an element is the number of protons found in an atom of that element.

It is also equal to the number of electrons when the atom is in a neutral state.

Elements are represented in the *Periodic Table* (Fig. 2.2) by placement into rows and columns that arrange atoms with specific electronic configurations.

Tendency to lose outermost electrons to uncover full outer shell

Key: 2 He 4.003 Helium — Atomic number, Symbol of element, Atomic weight, Name of element

- Metals
- Transition metals
- Nonmetals
- Noble gases
- Lanthanide series
- Actinide series

Tendency to lose electrons (III B – II B)

Tendency to fill outer shell by sharing electrons (III A – V A)

Tendency to gain electrons to make full outer shell (VI A – VII A)

Noble gases (inert) (VIII A)

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 Hydrogen																	2 He 4.003 Helium
3 Li 6.939 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.011 Carbon	7 N 14.007 Nitrogen	8 O 15.9994 Oxygen	9 F 18.998 Fluorine	10 Ne 20.183 Neon
11 Na 22.990 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminum	14 Si 28.09 Silicon	15 P 30.974 Phosphorus	16 S 32.064 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
19 K 39.102 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.90 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.71 Nickel	29 Cu 63.54 Copper	30 Zn 65.37 Zinc	31 Ga 69.72 Gallium	32 Ge 72.59 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.909 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc (99) Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.90 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.87 Silver	48 Cd 112.40 Cadmium	49 In 114.82 Indium	50 Sn 118.69 Tin	51 Sb 121.75 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.30 Xenon
55 Cs 132.91 Cesium	56 Ba 137.34 Barium	#57 TO #71	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.85 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.09 Platinum	79 Au 197.0 Gold	80 Hg 200.59 Mercury	81 Tl 204.37 Thallium	82 Pb 207.19 Lead	83 Bi 208.98 Bismuth	84 Po (210) Polonium	85 At (210) Astatine	86 Rn (222) Radon
87 Fr (223) Francium	88 Ra 226.05 Radium	#89 TO #103															

57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (147) Promethium	62 Sm 150.35 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.92 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thullium	70 Yb 173.04 Ytterbium	71 Lu 174.97 Lutetium
89 Ac (227) Actinium	90 Th 232.04 Thorium	91 Pa (231) Protactinium	92 U 238.03 Uranium	93 Np (237) Neptunium	94 Pu (242) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (249) Berkelium	98 Cf (251) Californium	99 Es (254) Einsteinium	100 Fm (253) Fermium	101 Md (256) Mendelevium	102 No (254) Nobelium	103 Lw (257) Lawrencium

The periodic table is the ordered result of basic chemical properties that depend on the nature of the outer electrons, the valence electrons.

These are the electrons available for chemical bonding so that atoms can combine to form crystalline solids.

Thus, *"electrons are the glue that holds minerals together."*

The periodic table groups elements together that have a similar chemical character. And, as a result of this similarity (caused by their similarity in outer electron configurations), these elements generally have similar chemical behavior.

When these elements are incorporated into minerals, they can be found in similar crystallographic sites within mineral structures and similar mineral behavior results.

Of the 109 known elements, 92 occur naturally on the earth, while the others have been produced only in the laboratory (dark shading in Fig. 2.2). Figure 2.4 illustrates the abundance of the major elements in the earth's crust and in the earth as a whole.

The crustal abundances are clearly best defined by direct observations. Whole earth abundances are based on estimates inferred from meteoritic evidence and from physical properties of the earth's interior.

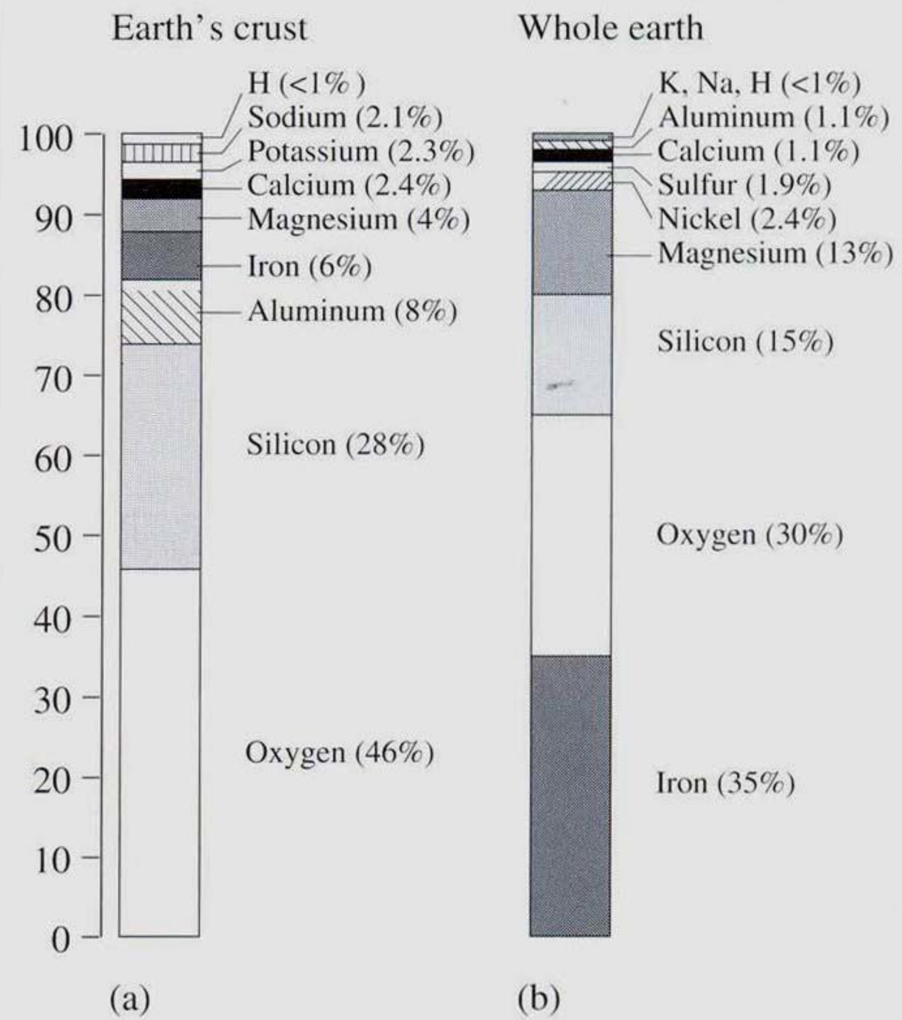


Fig. 2.4 Abundance of elements by weight percentage (weight%) (a) in the earth's crust, (b) in the whole earth.

As we can see, oxygen, silicon, and aluminum are by far the most common elements in the earth's crust and the major components of common rocks.

The most common minerals are therefore compounds of oxygen, silicon, and aluminum and, to a lesser extent, of magnesium, iron, titanium, calcium, potassium, sodium and phosphorus.

Examples are quartz (Si02), feldspar (CaAl2Si208), and olivine (Mg2Si04).

If we look at the whole earth, magnesium is a major component of the lower mantle and iron dominates in the core, and the abundances of these elements are significantly higher than in the crust.

If we were to look at the elemental abundances of the whole solar system, hydrogen, helium, and carbon dominate.

These light elements have largely been lost during the condensation of the inner planets, but ice (H_20) and methane (CH_4) are still the main components in the outer planets.

Properties of Protons, Neutrons, and Electrons

Protons and neutrons are very dense particles with almost identical masses.

By contrast, electrons have a negligible mass, about l/2000th that of a proton.

For comparison, if a proton or a neutron had the mass of a baseball, an electron would have the mass of a single grain of rice.

Both protons and electrons share a fundamental property called electrical charge. Protons have an electrical charge of +1, and electrons have a charge of -1.

Neutrons, as the name suggests, have no charge.

The charge of protons and electrons are equal in magnitude but opposite in polarity, so when these two particles are paired, the charges cancel each other.

Since matter typically contains equal numbers of positively charged protons and negatively charged electrons, most substances are electrically neutral.

In illustrations, electrons are sometimes shown orbiting the nucleus in a manner that resembles the planets of our solar system orbiting the Sun (Fig. 2.4A). However, electrons do not actually behave this way. A more realistic depiction shows electrons as a cloud of negative charges surrounding a nucleus (Fig. 2.4B).

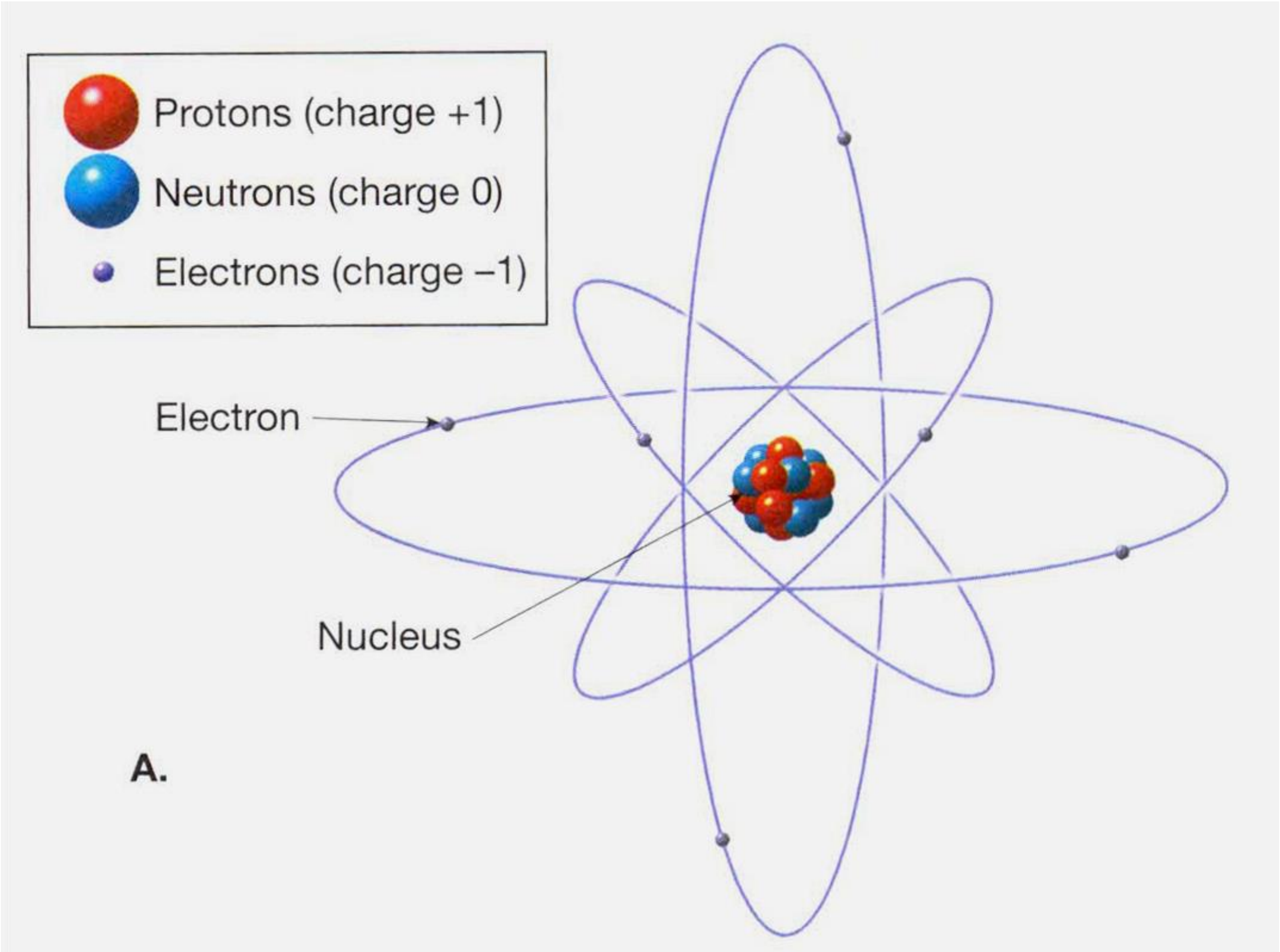


FIGURE 2.4 Two models of the atom. **A.** A very simplified view of the atom. The central nucleus consists of protons and neutrons encircled by high-speed electrons. B. This model of the atom shows electron clouds (shells) surrounding a central nucleus. The nucleus contains virtually all of the mass 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.)

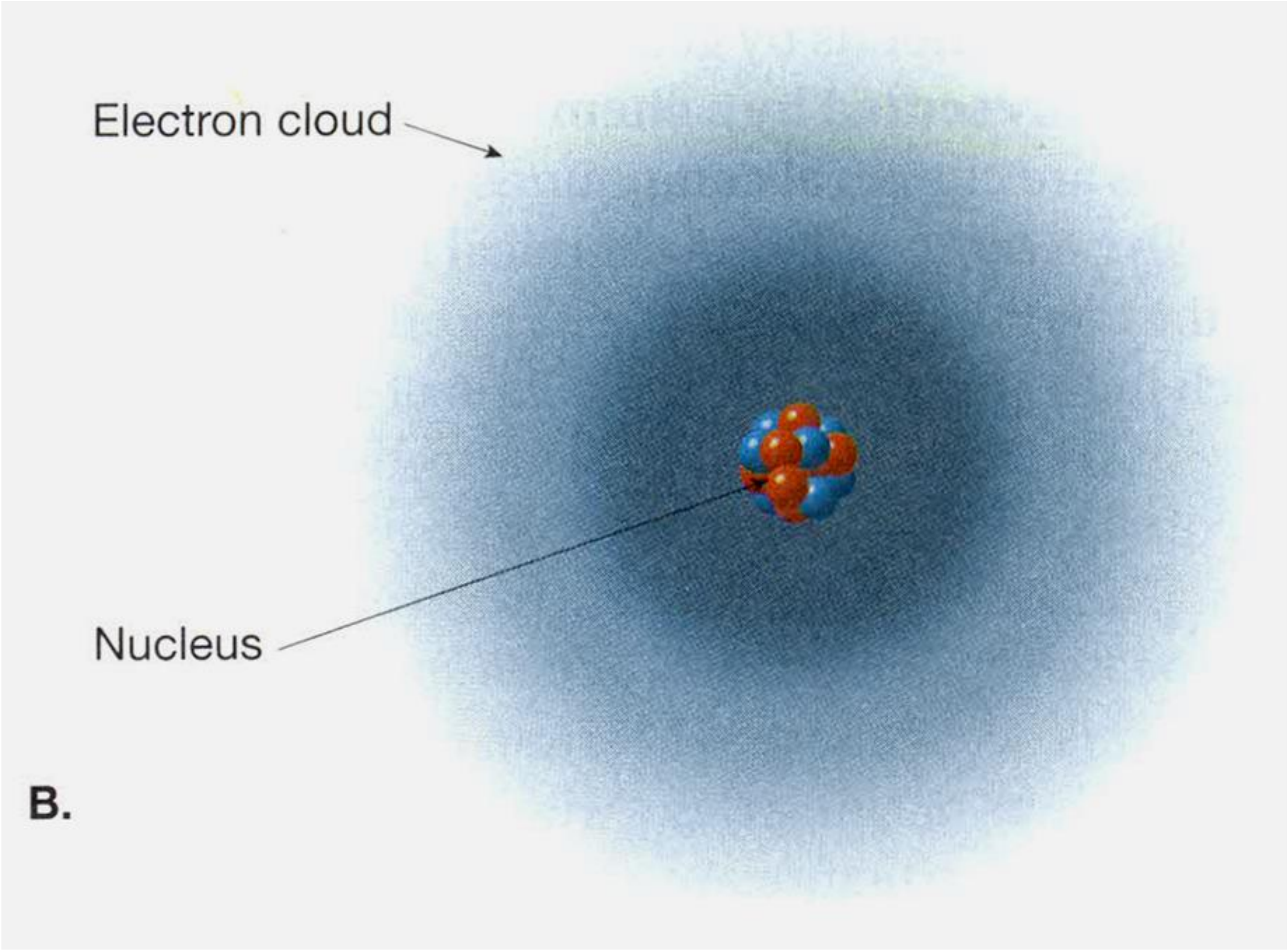
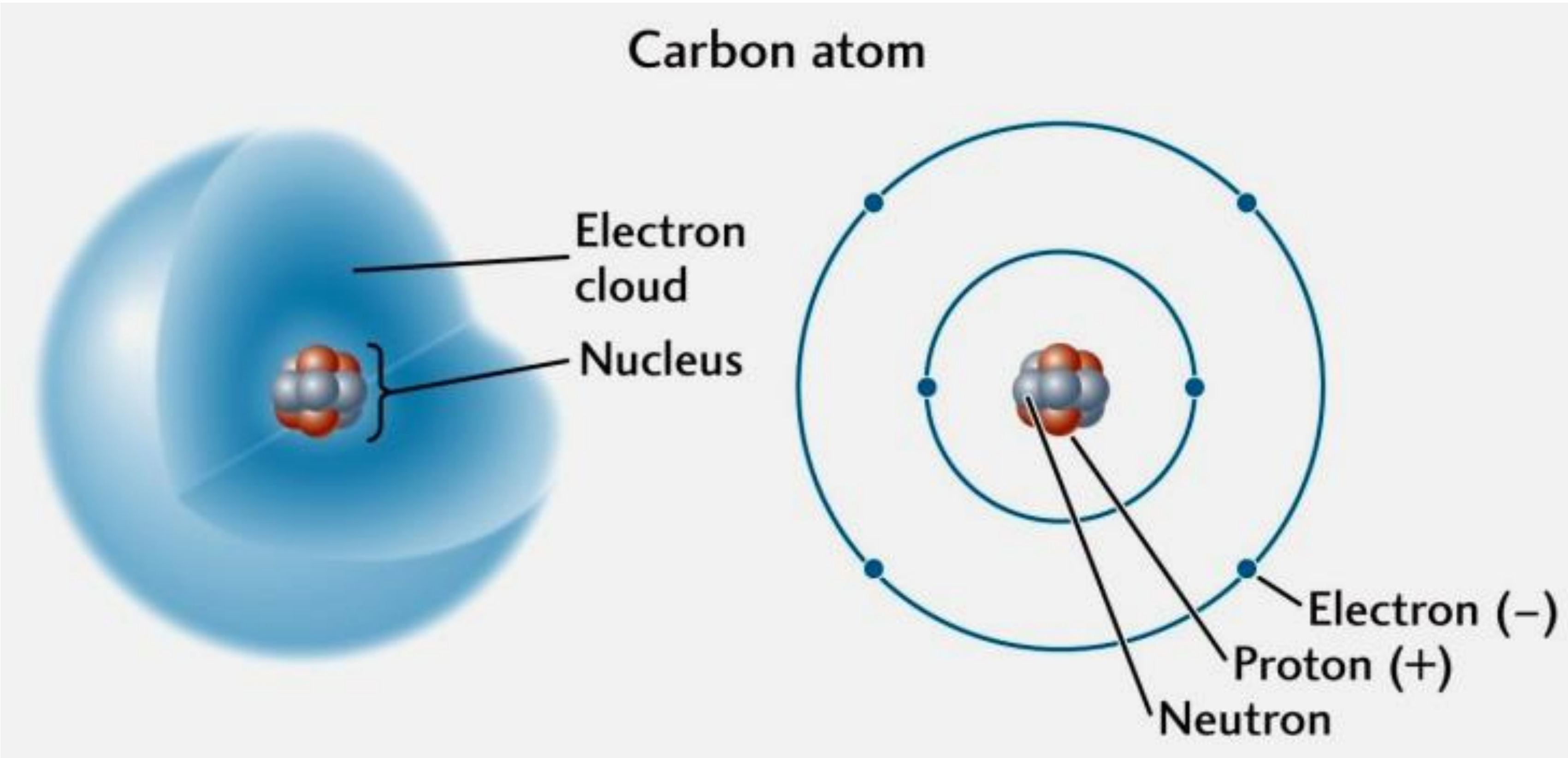
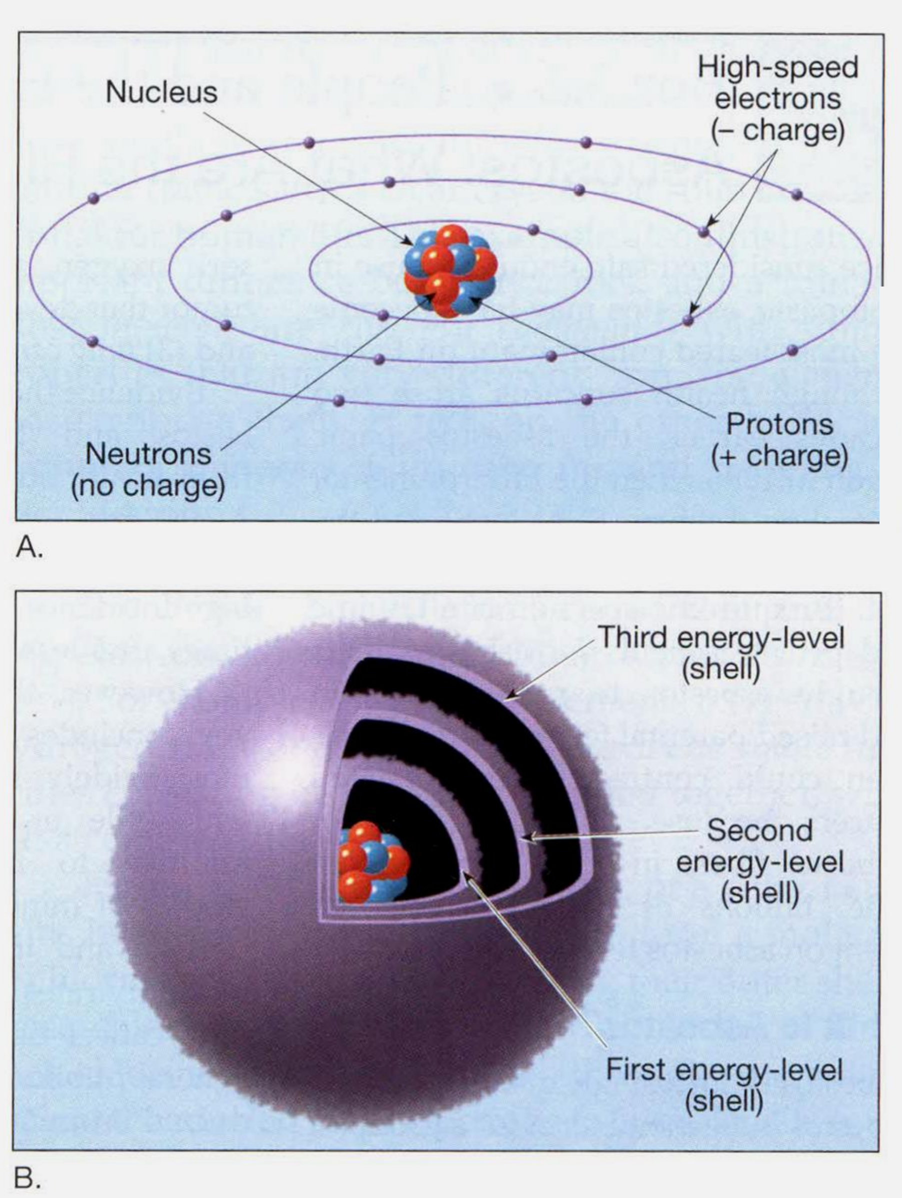


FIGURE 2.4 B

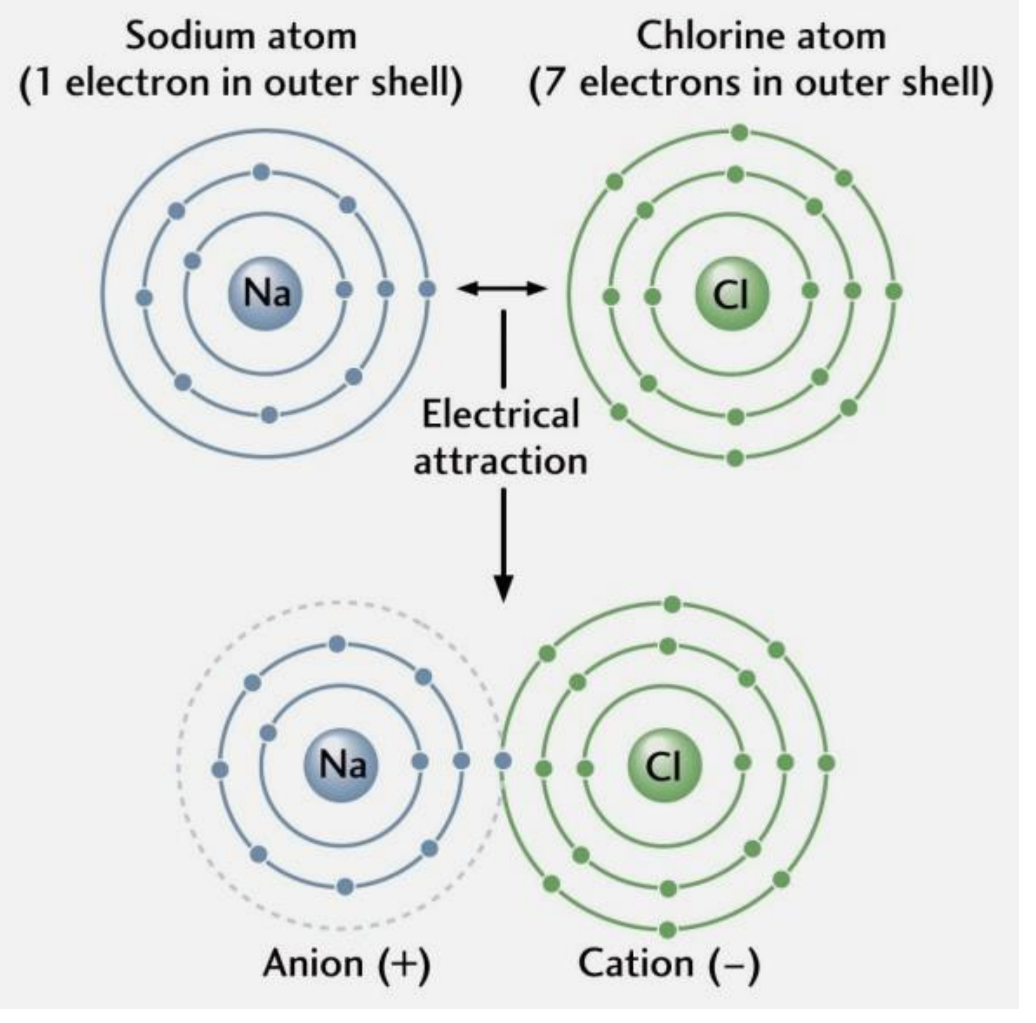


Carbon atom
Electron cloud
Nucleus
Electron (–)
Proton (+)
Neutron



▲ **FIGURE 3.4** Two models of the atom. A. A very simplified view of the atom, which consists of a central nucleus, consisting of protons and neutrons, encircled by high-speed electrons. B. Another model of the atoms showing spherically shaped electron clouds (energy level shells). Note that these models are not drawn to scale. Electrons are minuscule in size compared to protons and neutrons, and the relative space between the nucleus and electron shells is much greater than illustrated.

Atoms => Ions (cations/anions) => Molecules => Crystals/Crystalline solid => Minerals



Studies of the arrangements of electrons show that they move about the nucleus in regions called principal shells, each with an associated energy level.

In addition, each shell can hold a specific number of electrons, with the outermost shell containing valence electrons that interact with other atoms to form chemical bonds.

Elements: Defined by Their Number of Protons

The simplest atoms have only one proton in their nuclei, whereas others have more than 100. The number of protons in the nucleus of an atom, called the atomic number, determines its chemical nature.

All atoms with the same number of protons have the same chemical and physical properties.

Together, a group of the same kind of atoms is called an element. There are about 90 naturally occurring elements and 23 that have been synthesized.

We are probably familiar with the names of many elements including carbon, nitrogen, and oxygen.

All carbon atoms have six protons, all nitrogen atoms have seven protons, and all oxygen atoms have eight protons.

Atoms of the naturally occurring elements are the basic building blocks of Earth's minerals. A few minerals, such as native copper, diamonds, and gold, are made entirely of atoms of only one element (Fig. 2.6).

However, most elements tend to join with atoms of other elements to form chemical compounds. Most minerals are chemical compounds composed of atoms of two or more elements.

FIGURE 2.6 Gold mixed with quartz. Gold, silver, copper, and diamonds are naturally occurring minerals composed entirely of atoms of a single element.

Ions

Ions, unlike electrically neutral atoms with an equal number of protons and electrons, are charged particles.

They have an excess or deficiency of electrons when compared to the numbers of protons.

There are several ways to turn an atom into an ion, such as heat, light, or exchange of electrons with another atom.

The charge on the ion is known as its valence or oxidation state.

Electrons in the outermost shell are the valence electrons. When one or more electrons are lost from the electron configuration of an atom, a cation is formed (net positive charge, +), and when electrons are added, an anion results (with a net negative charge, —). This can be expressed as:

$$X_{atom} - e^{-} \rightarrow X^{+}{}_{cation}$$

and

$$X_{atom} + e^{-} \rightarrow X^{-}{}_{anion}$$

Bonding

Bonding

In the solid state, atoms are closely surrounded by neighboring atoms. The forces that bind atoms together are electrical in nature.

Their type and intensity are largely responsible for the physical and chemical properties of crystals.

These electrical forces between atoms are referred to as bonds.

Depending on the electronic structure of an atom and its nearest neighbor, the types of bonding forces can vary In general,

in the solid state at low temperature, where thermal vibration is only moderate,

four types of bonding are distinguished, which we will discuss briefly.

Types of Bonding

(1) Ionic bonding
(2) Covalent bonding
(3) Metallic bonding
(4) The van der Waals bond

(1) Ionic bonding relies on electrostatic attraction between atoms of different charge, where electrons have been removed (+ charge) or added (- charge).

As we will discuss below, such charged atoms are called ions.

(2) covalent bonding: Here single electrons are shared between two atoms in a common orbital.

In reality all bonding forces are active in a crystal, but in different minerals some forces can dominate.

For example, in halite (NaCl) bonding is largely ionic, whereas in diamond (C) it is covalent.

Bonding can be mixed, and different types of bonding may exist between different atoms in a mineral structure.

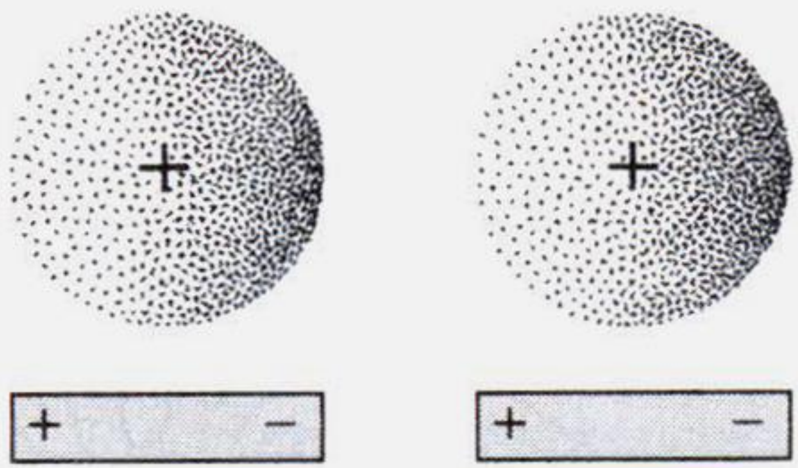
For example, the important Si-0 bond involves covalent and ionic forces. In the case of sulfur, some S-S bonds are largely covalent, whereas others are of the van der Waals type.

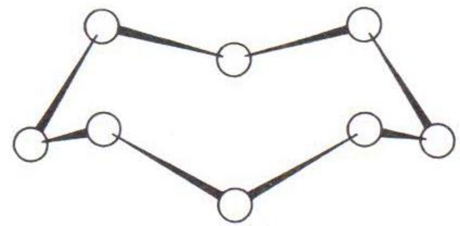
(3) ***Metallic bonding*:** **Here some outer electrons have been removed from the atoms and move freely within the structure.**

The attractive force between the positively charged atoms and the negatively charged *electron cloud* holds such structures together.

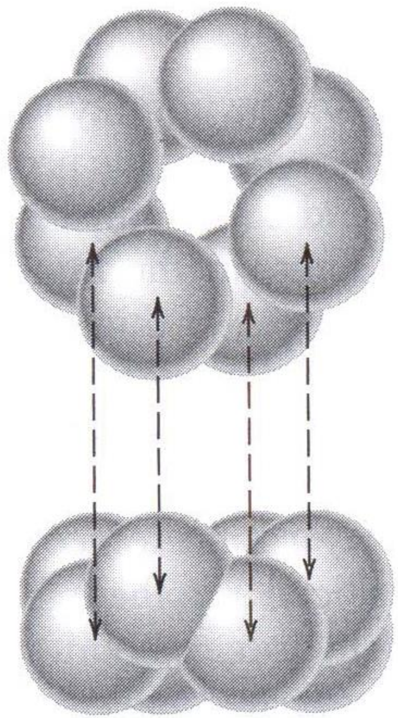
(4) The van der Waals (or residual) bond is a weak overall attraction between neutral atoms; it arises because the electron distribution in atoms is not uniform.

FIG. 3.23 Polarization of one atom by another because of an increase in the concentration of electrons on one side of the atom. This causes a dipole effect. The weak dipole attraction is that of the van der Waals bond.





(a)



(b)

FIG. 3.25 (a) S_8 rings occur in the crystal structure of sulfur. These rings are linked to each other by van der Waals bonds. (b) The S_8 rings in plan view and in cross section.

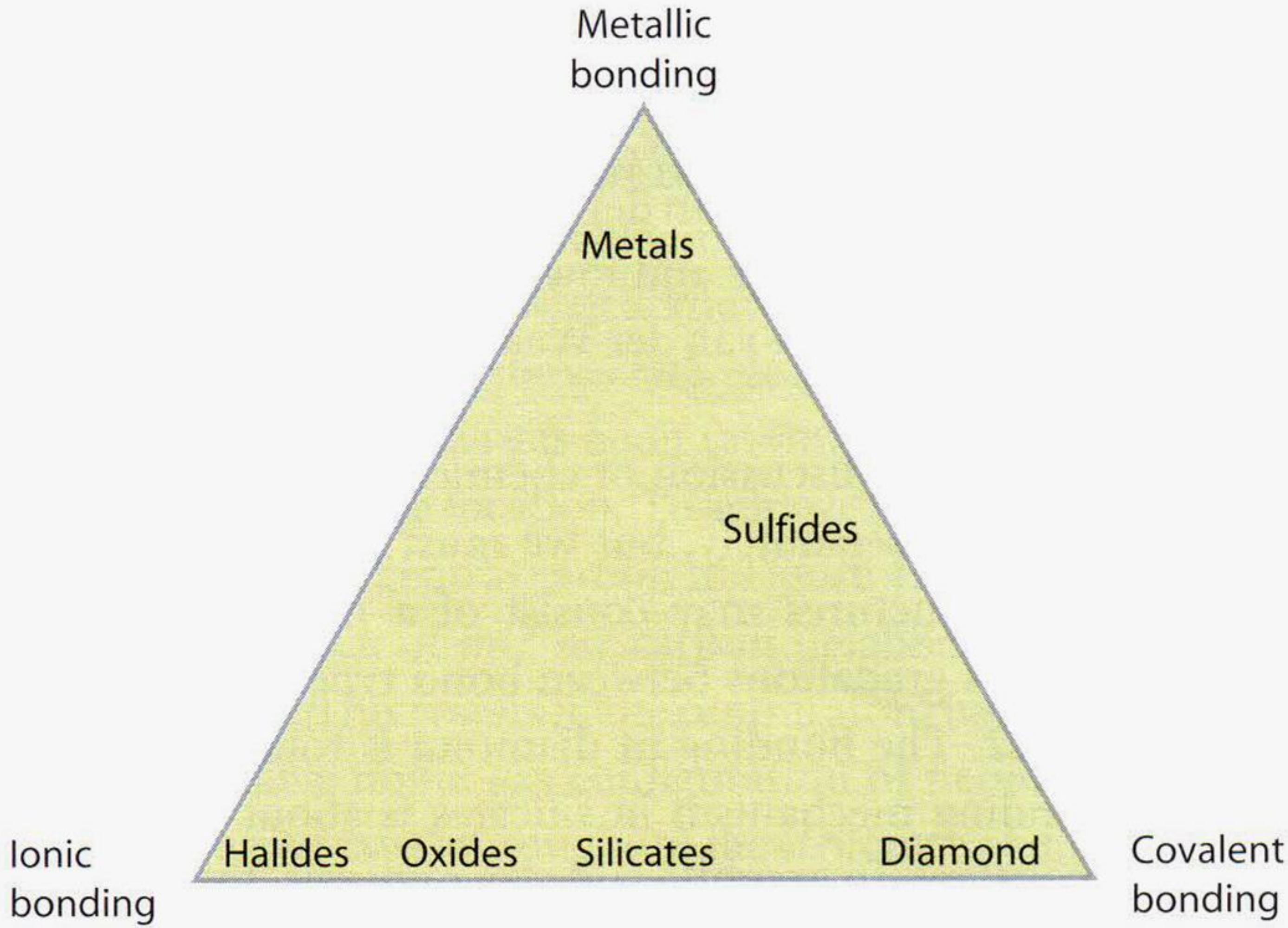


Figure 4.22 Depiction of the gradational and/or mixed nature of bond types in many mineral structures. The corners represent pure bonding of one type.

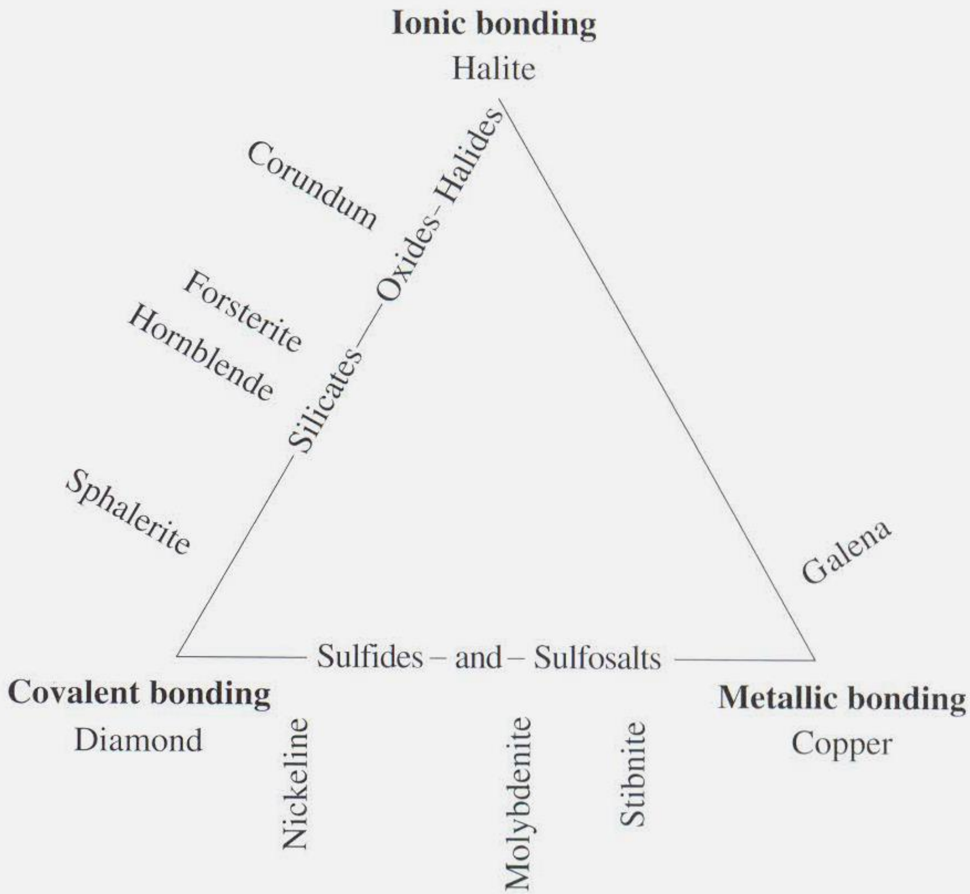


Fig. 2.5 Triangular representation of ionic, covalent, and metallic bonding with some mineral representatives.

Why Atoms Bond

Except for a group of elements known as the noble gases, atoms bond to one another under the conditions (temperatures and pressures) that occur on Earth.

Some atoms bond to form ionic compounds, some form molecules, and still others form metallic substances.

Why does this happen? Experiments show that electrical forces hold atoms together and bond them to each other.

These electrical attractions lower the total energy of the bonded atoms, which, in turn, generally makes them more stable.

Consequently, atoms that are bonded in compounds tend to be more stable than atoms that are free (not bonded).

As was noted earlier, valence (outer shell) electrons are generally involved in chemical bonding.

Figure 2.7 shows a shorthand way of representing the number of valence electrons.

Notice that the elements in Group I have one valence electron, those in Group II have two valence electrons, and so on, up to eight valence electrons in Group VIII.

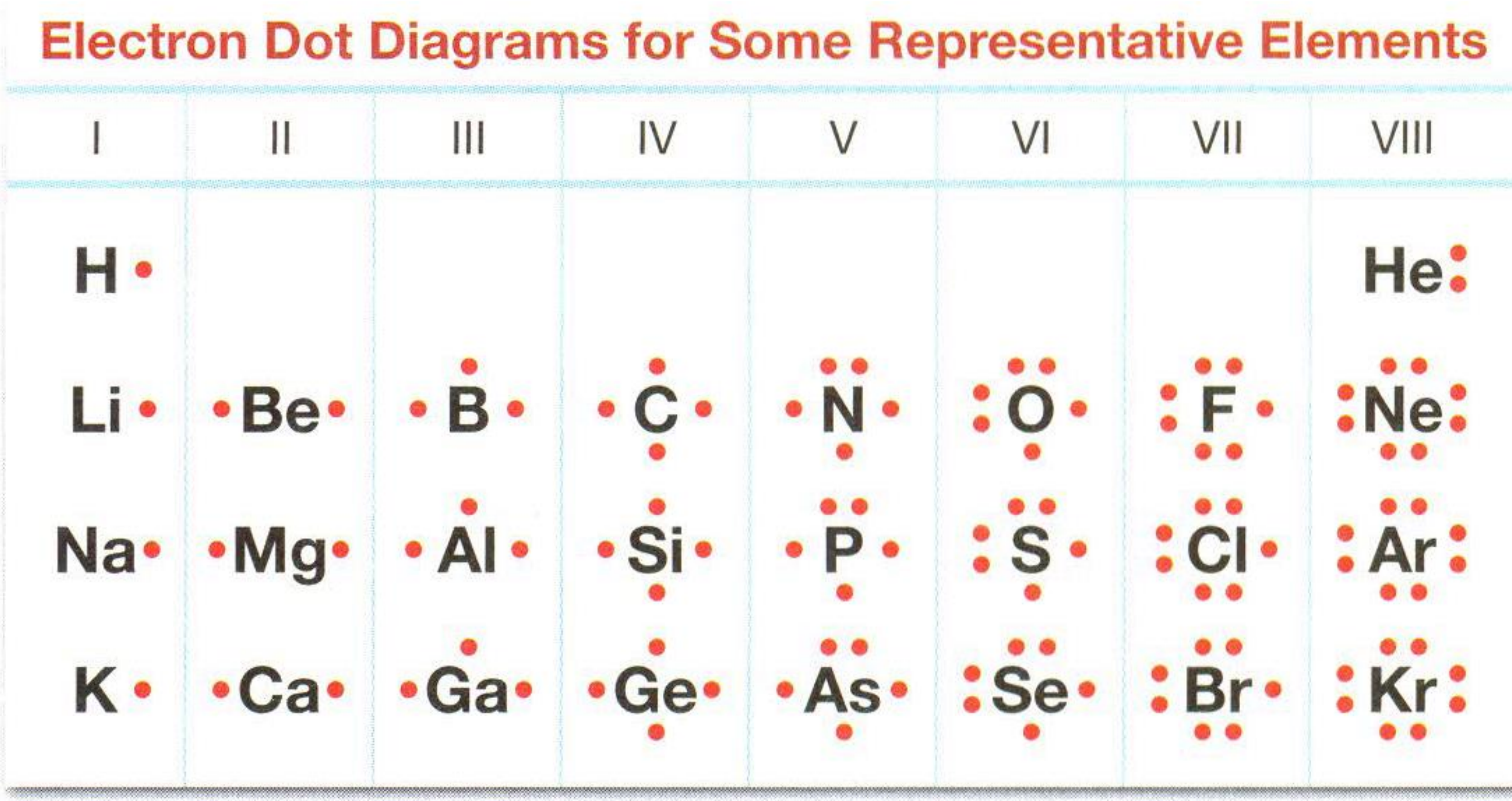


FIGURE 2.7 Dot diagrams for some representative elements. Each dot represents a valence electron found in the outermost principal shell.

Octet Rule

The noble gases (except helium) have very stable electron arrangements with eight valence electrons and, therefore, tend to lack chemical reactivity.

Many other atoms gain, lose, or share electrons during chemical reactions to end up with electron arrangements of the noble gases. This observation led to a chemical guideline known as the octet rule.

octet rule: ***Atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons.***

Although there are exceptions to the octet rule, it is a useful rule of thumb for understanding chemical bonding.

When an atom's outer shell does not contain eight electrons, it is likely to chemically bond to other atoms to fill its shell.

A chemical bond **is the transfer or sharing of electrons that allows each atom to attain a full valence shell of electrons.**

Some atoms do this by transferring all of their valence electrons to other atoms so that an inner shell becomes the full valence shell.

When the valence electrons are transferred between the elements to form ions, the bond is an ***ionic bond.***

When the electrons are shared between the atoms, the bond is a *covalent bond.*

When the valence electrons are shared among all the atoms in a substance, the bonding is *metallic*.

In any case, the bonding atoms get stable electron configurations, which usually consist of eight electrons in their outmost shells.

Ionic Bonds: Electrons Transferred

Perhaps the easiest type of bond to visualize is the ionic bond, in which one atom gives up one or more of its valence electrons to another atom to form ions—positively and negatively charged atoms.

The atom that loses electrons becomes a positive ion, and the atom that gains electrons becomes a negative ion.

Oppositely charged ions are strongly attracted to one another and join to form *ionic compounds*.

Consider the ionic bonding that occurs between sodium (Na) and chlorine (Cl) to produce sodium chloride, the mineral halite—common table salt.

Notice in Figure 2.8A that sodium gives up its single valence electron to chlorine.

As a result, sodium now has a stable configuration with eight electrons in its outermost shell.

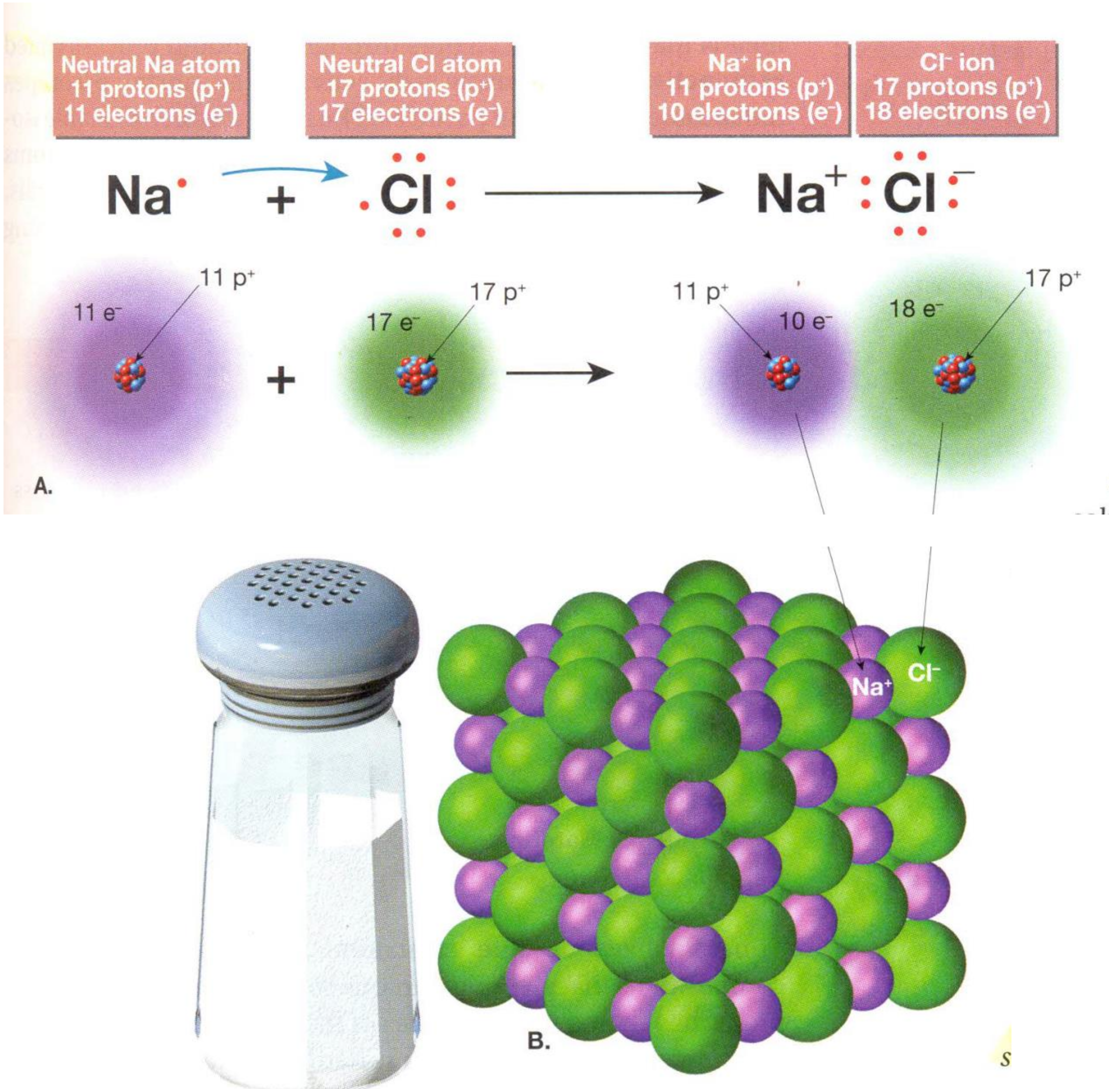
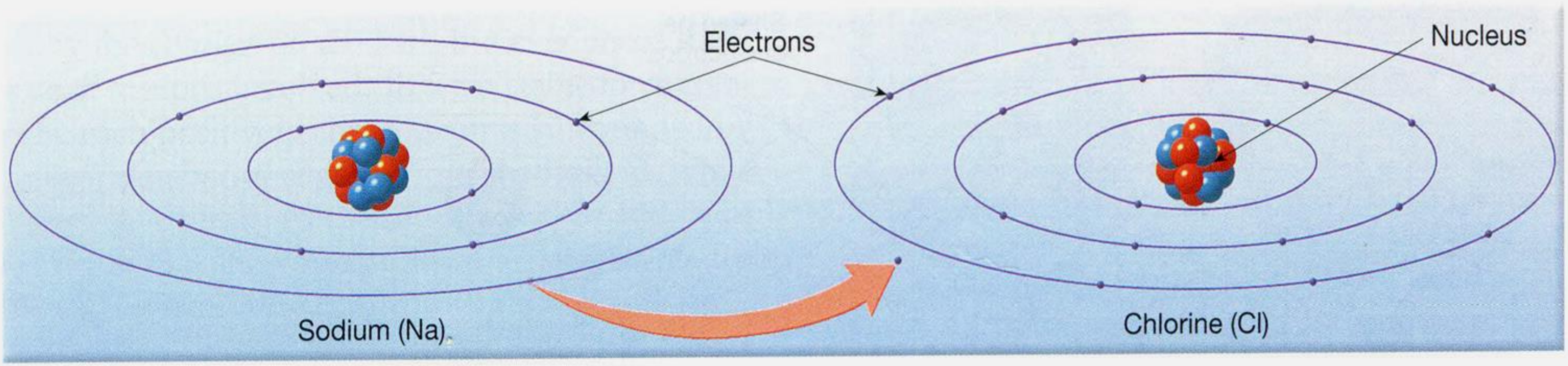
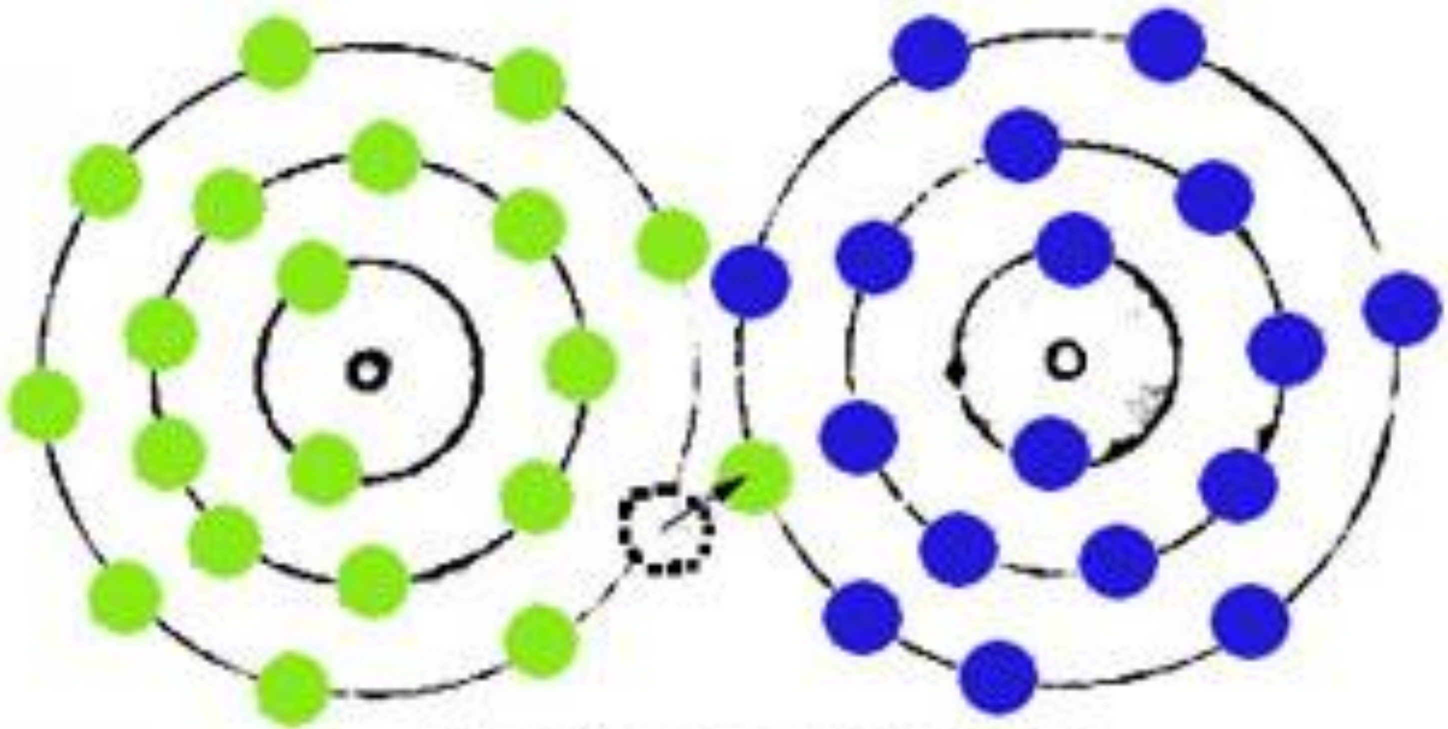


FIGURE 2.8 Chemical bonding of sodium chloride (table salt). **A.** Through the transfer of one electron in the outer shell of a sodium atom to a chlorine atom, sodium becomes a positive ion and chlorine a negative ion. **B.** Diagram illustrating the arrangement (packing) of sodium and chlorine ions in table salt.



▲ **FIGURE 3.5** Chemical bonding of sodium and chlorine through the transfer of the lone outer electron from a sodium atom to a chlorine atom. The result is a positive sodium ion (Na^+) and a negative chloride ion (Cl^-). Bonding to produce sodium chloride (NaCl) is due to electrostatic attraction between the positive and negative ions. In this process note that both the sodium and chlorine atoms have achieved the stable noble-gas configuration (eight electrons in their outer shell).



Electron exchange

Ionic bond

By acquiring the electron that sodium loses, chlorine (which has seven valence electrons) gains the eighth electron needed to complete its outermost shell.

Thus, through the transfer of a single electron, both the sodium and chlorine atoms have acquired a stable electron configuration.

After electron transfer takes place, the atoms are no longer electrically neutral. By giving up one electron, a neutral sodium atom becomes positively charged (with 11 protons and 10 electrons).

Similarly, by acquiring one electron, a neutral chlorine atom becomes negatively charged (with 17 protons and 18 electrons).

We know that ions with like charges repel, and those with unlike charges attract.

Thus, an ionic bond is the attraction of oppositely charged ions to one another, producing an electrically neutral compound.

Figure 2.8B illustrates the arrangement of sodium and chlorine ions in ordinary table salt.

Notice that salt consists of alternating sodium and chlorine ions, positioned in such a manner that each positive ion is attracted to and surrounded on all sides by negative ions, and vice versa.

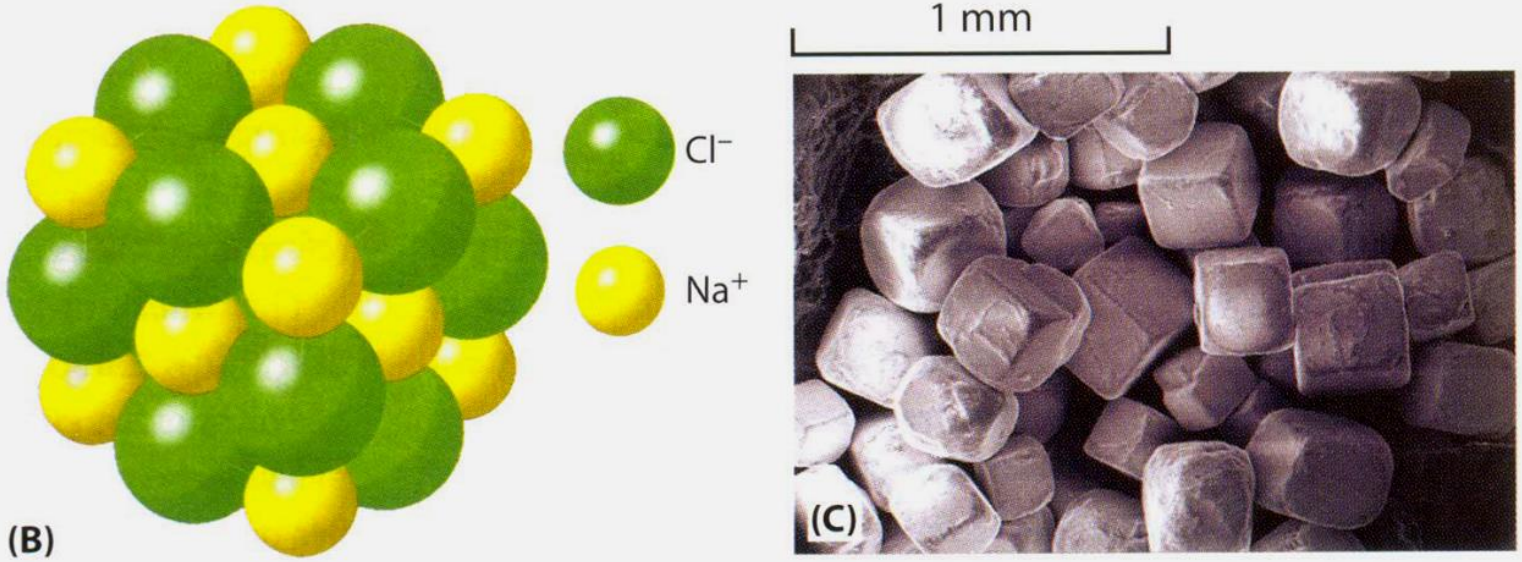


Figure 2.1 (**A**) A standard container of table salt, NaCl, with some salt in a Petri dish. (**B**) A perspective view of the internal atomic structure of NaCl with an overall cubic outline. (**C**) Salt grains from the Petri dish in (A) photographed by scanning electron microscopy. This shows perfect cubic cleavage fragments with somewhat beveled corners and edges as a result of abrasion. The abrasion is due to the juggling of salt grains in the large container during transport. (Photograph courtesy of Adrian Brearley, University of New Mexico.)

This arrangement maximizes the attraction between ions with opposite charges while minimizing the repulsion between ions with identical charges.

Thus, ionic compounds consist of an orderly arrangement of oppositely charged ions assembled in a definite ratio that provides overall electrical neutrality.

The properties of a chemical compound are dramatically different from the properties of the various elements comprising it.

For example, sodium is a soft silvery metal that is extremely reactive and poisonous. If We were to consume even a small amount of elemental sodium, you would need immediate medical attention.

Chlorine, a green poisonous gas, is so toxic that it was used as a chemical weapon during World War I.

Together, however, these elements produce sodium chloride, a harmless flavor enhancer that we call table salt.

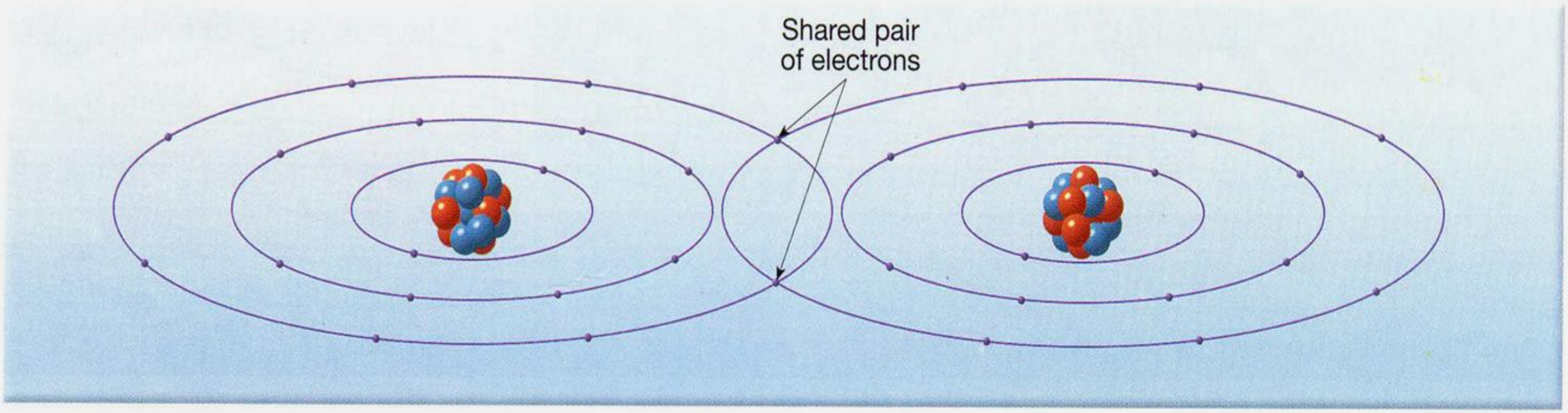
Thus, when elements combine to form compounds their properties change significantly.

Covalent Bonds: Electrons Shared

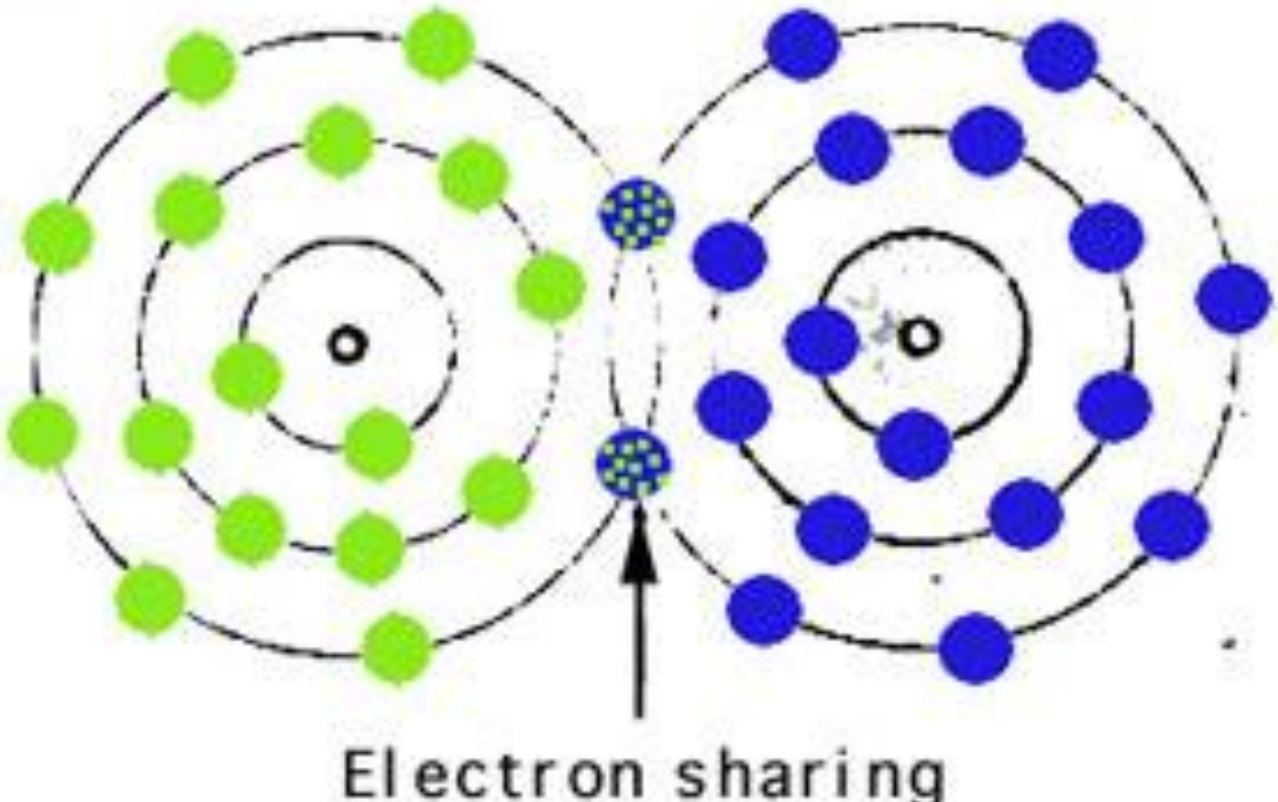
Sometimes the forces that hold atoms together cannot be understood on the basis of the attraction of oppositely charged ions.

One example is the hydrogen molecule (H_2), in which the two hydrogen atoms are held together tightly and no ions are present.

The strong attractive force that holds two hydrogen atoms together results from a covalent bond, *a chemical bond formed by the sharing of a pair of electrons between atoms.*



▲ **FIGURE 3.7** Illustration of the sharing of a pair of electrons between two chlorine atoms to form a chlorine molecule. Notice that by sharing a pair of electrons, both chlorine atoms have eight electrons in their valence shell.



Covalent bond

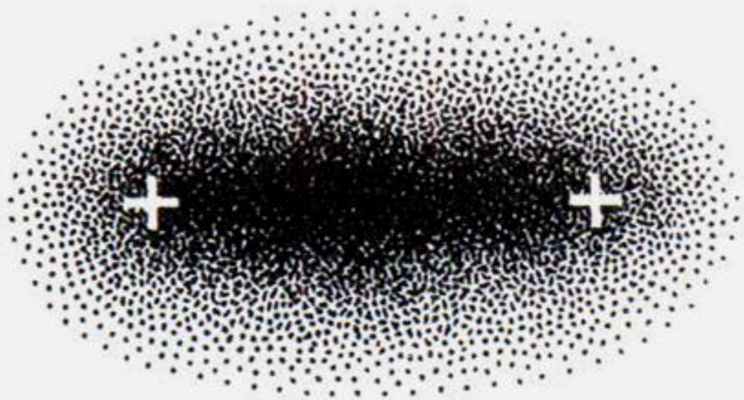
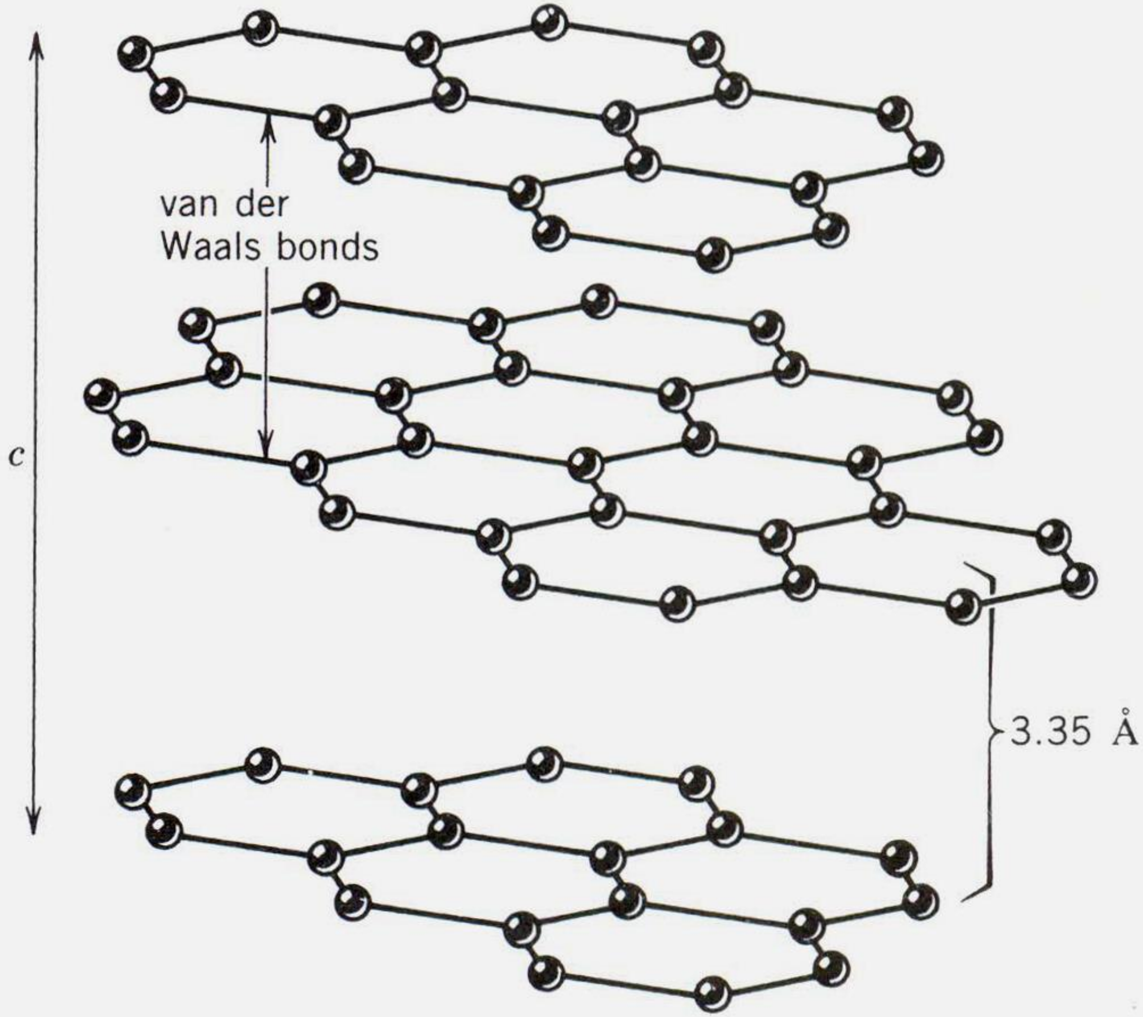


FIG. 3.17 Schematic representation of the electron distribution between two covalently bonded atoms.

FIG. 3.24 Perspective sketch of the graphite structure with covalent bonding between carbon atoms within layers and residual (van der Waals) bonding between layers. Note the large separation (3.35 Å) between layers, which leads to cleavage.



Imagine two hydrogen atoms (each with one proton and one electron) approaching one another so that their electron clouds overlap (Fig. 2.9).

Once they meet, the electron configuration will change so that both electrons will primarily occupy the space between the atoms. Now the two electrons are shared by both hydrogen atoms and attracted simultaneously by the positive charge of the proton in the nucleus of each atom.

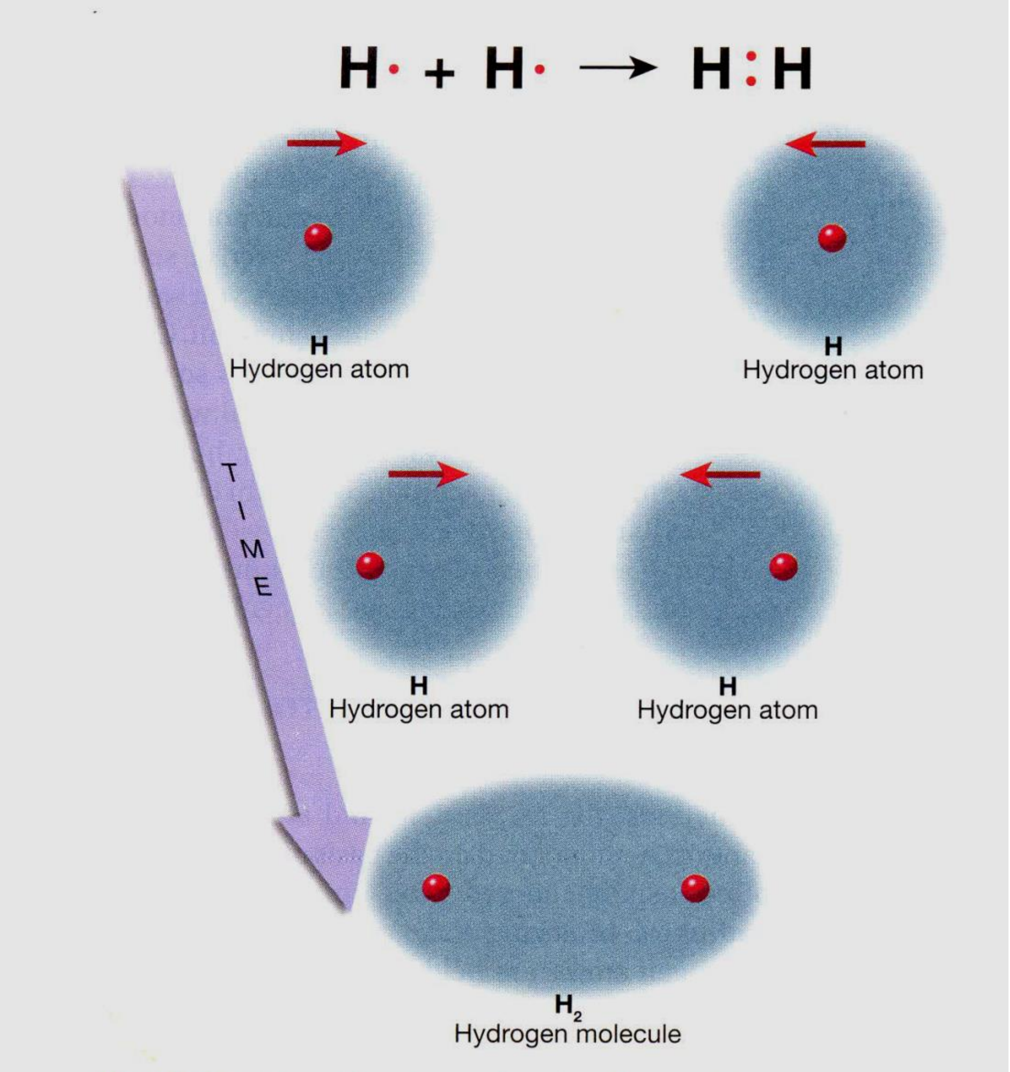


FIGURE 2.9 Formation of a covalent bond between two hydrogen atoms (H) to form a hydrogen molecule (H_2). When hydrogen atoms bond, the electrons are shared by both hydrogen atoms and attracted simultaneously by the positive charge of the proton in the nucleus of each atom. The attraction between electrons and both nuclei holds (bonds) these atoms together.

The attraction between the electrons and both nuclei holds these atoms together.

Although ions do not exist in hydrogen molecules, the force that holds these atoms together arises from the attraction of oppositely charged particles—protons in the nuclei and electrons shared by the atoms.

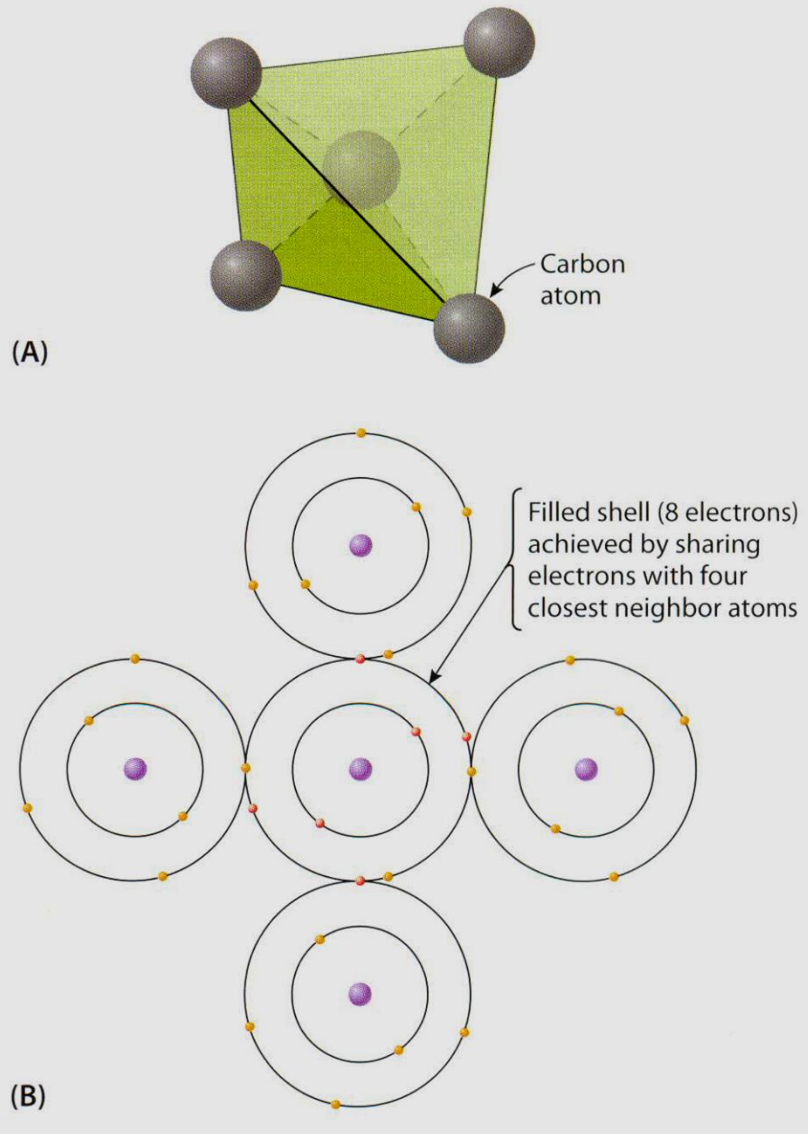


Figure 4.17 (**A**) Tetrahedral coordination of a central carbon with four closest carbon neighbors in the structure of diamond. (**B**) The sharing of one electron with each of four closest carbon neighbors in the structure of diamond.

Metallic Bonds: Electrons Free to Move

In metallic bonds, the valence electrons are free to move from one atom to another so that all atoms share the available valence electrons.

This type of bonding is found in metals such as copper, gold, aluminum, and silver, and in alloys such as brass and bronze.

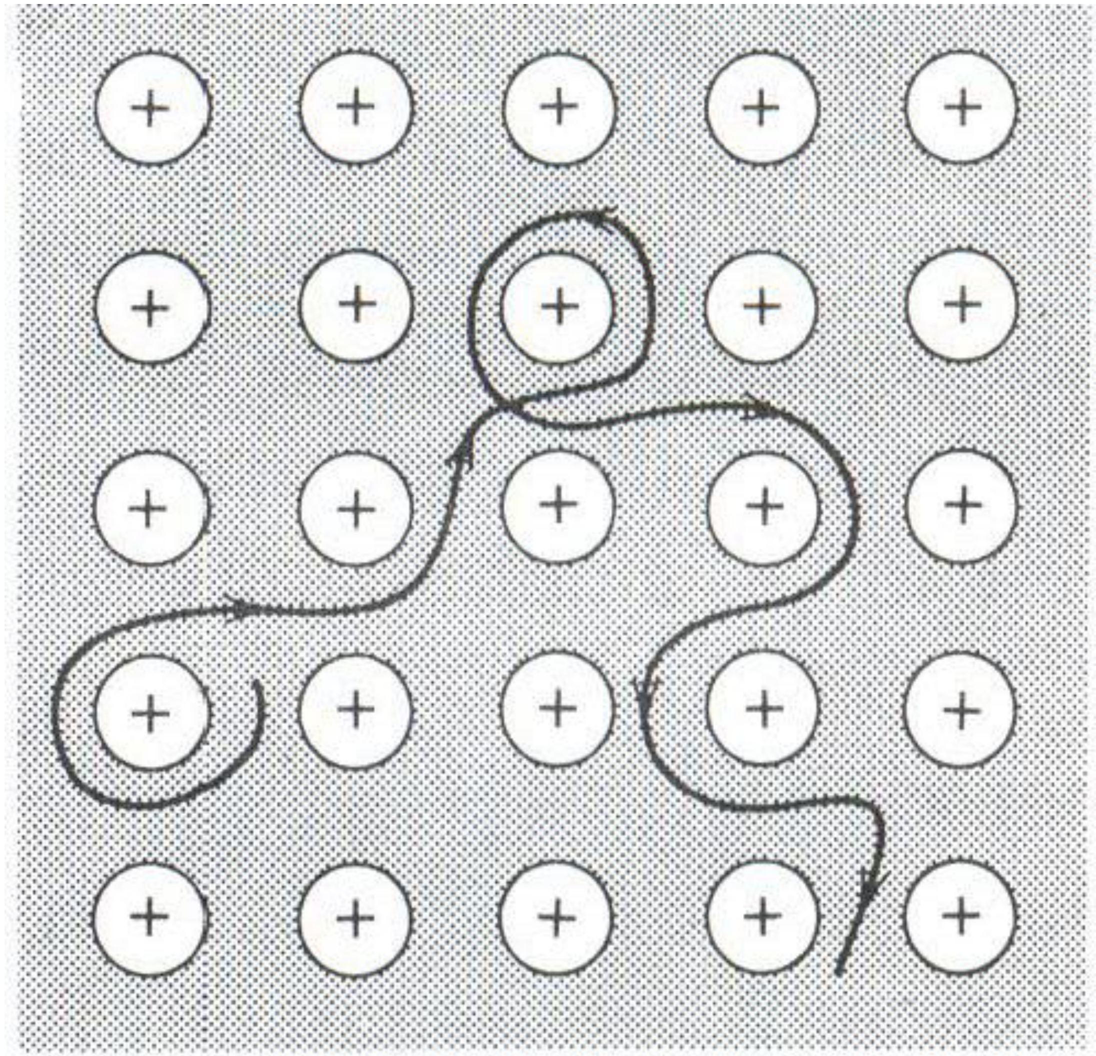


Fig. 4.36 A: A schematic cross section through the structure of a metal. Each circle with a positive charge represents a nucleus with filled, nonvalance electron orbitals of the metal atoms. The mobile electors are represented by the cloud around the atoms (light gray shading). A possible electron path between the nuclei is sown.

Metallic bond is a covalent bond in which electrons are freely shared.

This bond type occurs among metallic elements which have strong tendencies to lose electrons while freely mobile electrons are shared & dispersed among the ions.

Metallic bonding accounts for the high electrical conductivity of metals, the ease with which metals are shaped, and numerous other special properties.

Table 4.8 Characteristic properties resulting from the principal chemical bond types.

Examples and properties	Covalent	Ionic	Metallic	Van der Waals
Examples	Diamond, C Sphalerite, ZnS Organic molecules	Halite, NaCl Fluorite, CaF_2 Most minerals	Most metals	Weakest bond in minerals; clays and graphite
Hardness	Very hard; brittle	Medium to high	Low to medium; sectile, ductile, malleable	Very low; crystals soft
Electrical conductivity	Insulators	Poor conductors	Good conductors	Insulators
Melting point (m.p.)	High m.p.	Moderate to high m.p.	Variable m.p.	Low m.p.
Structure and symmetry	Generally lower coordination and lower symmetry	High coordination and symmetry	Very high coordination and symmetry	Low symmetry

HOW DO MINERALS FORM?

- Minerals are formed by the process of Crystallization, the growth of a solid from a material whose constituent atoms can come together in the proper chemical proportions and crystalline arrangement.

- Crystallization occurs when T of a solution is lowered to below its freezing point; Similarly, magma crystallizes into solid minerals when it cools to below its melting point, which is at about 1000 degrees C

- **Can result from Evaporation or Cooling**

- **Crystal also form when atoms & ions in solids become mobile & rearrange themselves at high T;**

For most minerals, temperatures must reach at least 250 degrees C before this rearrangement forms new minerals with different crystal structures.

- **Two major factors control the rearrangment of atoms and ions in a crystal structure:**

- **Number of neighbouring atoms or ions & and their**
- **size**

Thank you

Ionic Radious

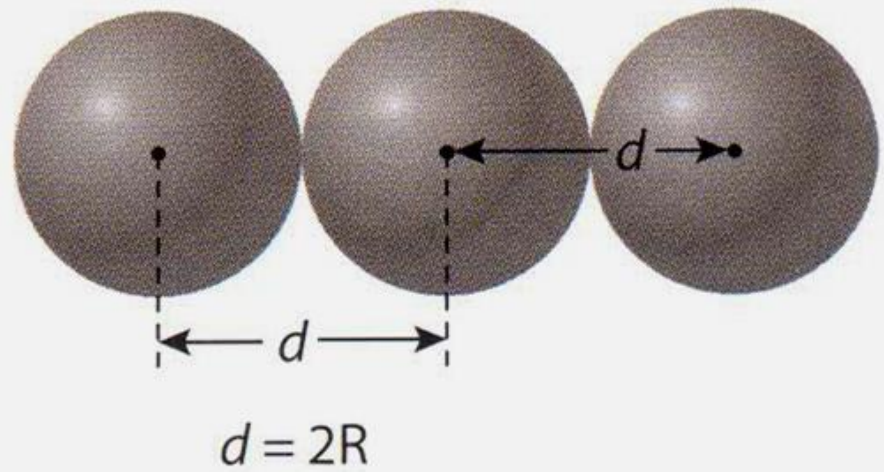


Figure 4.1 Schematic illustration of the determination of the radius of a metal atom in a close-packed structure. $R_X = d/2$

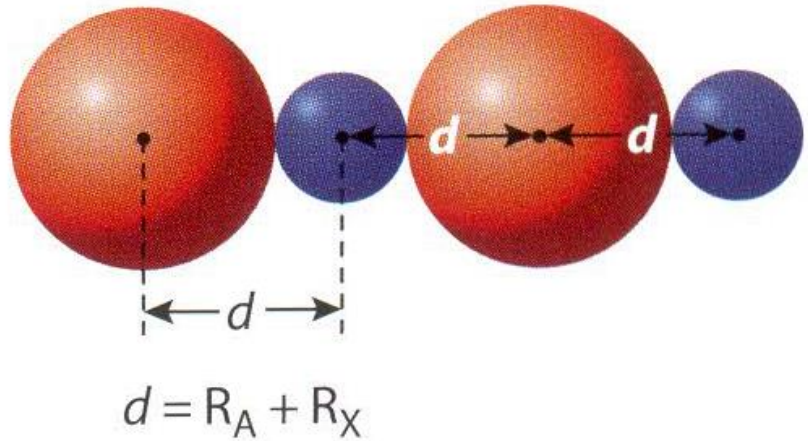
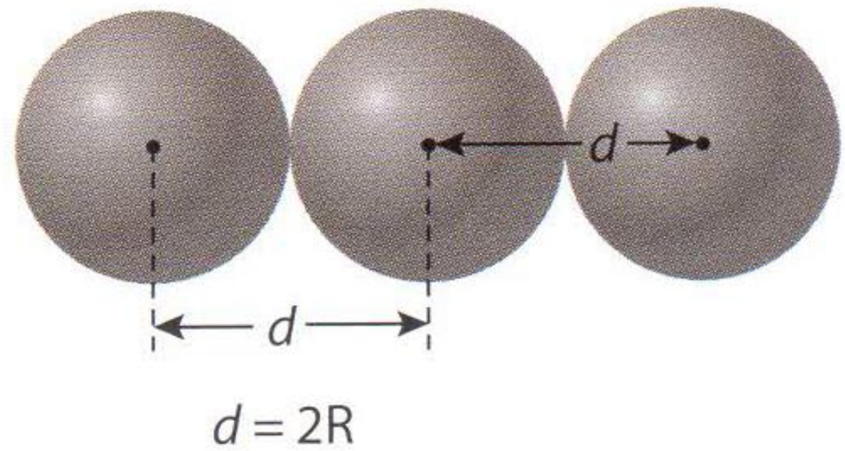


Figure 4.2 Schematic illustration of the determination of the radius of a cation (R_X) when the distance (d) between the centers of an anion-cation pair, as well as the radius of the anion (R_A), is known. $R_X = d - R_A$.



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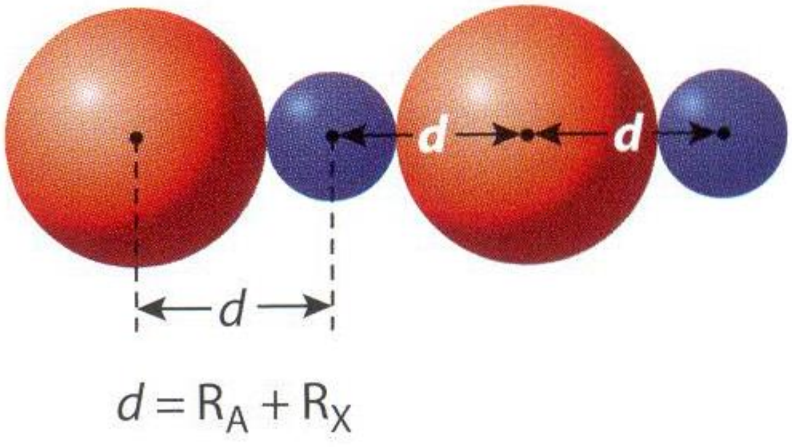


Figure 4.2 Schematic illustration of the determination of the radius of a cation (R_X) when the distance (d) between the centers of an anion-cation pair, as well as the radius of the anion (R_A), is known. $R_X = d - R_A$.

MINERALOGY

- A geological science dealing with the study of minerals using both physical and optical characteristics
- Over 2000 minerals are known to exists although only about 30 are commonly encoutered

WHAT IS A MINERAL?

- A mineral is a naturally occuring, neutral, solid, inorganic substance that is crystalline, has a fixed chemical composition and a regular atomic arrangement.
- Minerals singularly or collectively are the building blocks of rocks.

VALUE OF MINERALS

- **Aesthetic value (beauty)** e.g. gemstones
- **Value as an ore (metal source)** e.g. bornite (Cu), galena (Pb), sphalerite (Zn), cassiterite (Sn), beryl (Be) etc.
- **Unique structural pattern** e.g. the value of diamond (whether for adornment or as an abrassive lies in its hardness) & of graphite, the other form of carbon, whether as a lubricant or as a lead-pencil, depends on it softness.

ATOMS

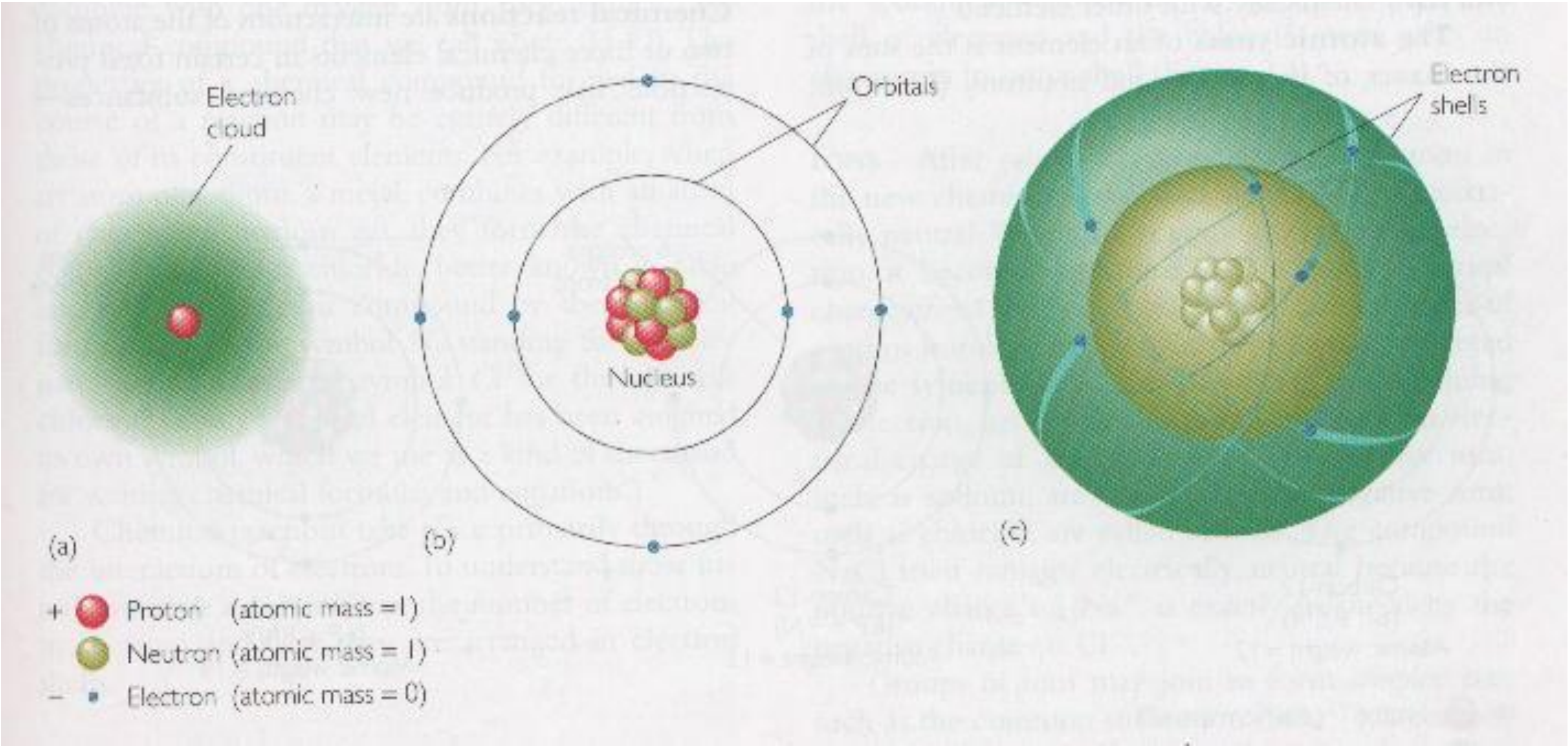
- MINERALS ARE COMPOSED OF ELEMENTS (E.G. Fe, Cu; C, Zn ETC), WHICH IN TURN ARE MADE UP OF ATOMS
- ATOM WAS IN THE EARLY DAYS CONSIDERED AS THE SMALLEST POSSIBLE UNIT OF ANY MATERIAL (NOT TRUE NOW)
- TO ANCIENT GREEKS AN ATOM WAS INDIVISIBLE (*ATOMOS*)
- JOHN DALTON (1766-1844; FATHER OF MODERN ATOMIC THEORY) DEFINED ATOMS AS PARTICLES OF MATTER THAT WERE SO SMALL THAT THEY COULD NOT BE SEEN WITH ANY MICROSCOPE & SO UNIVERSAL THAT THEY CONSTITUTED ALL SUBSTANCES
- AN ATOM TODAY IS DEFINED AS THE SMALLEST UNIT OF ANY ELEMENT THAT RETAINS THE PHYSICAL & CHEMICAL PROPERTIES OF THAT ELEMENT; ATOMS ARE THE SMALL UNITS OF MATTER THAT COMBINE IN CHEMICAL REACTIONS; ATOMS ARE DIVISIBLE INTO SMALLER UNITS (PROTONS, NEUTRONS & ELECTRONS)

ATOMIC STRUCTURE

AN ATOM IS COMPOSED OF A NUCLEUS AND A CLOUD OF ELECTRONS AROUND

NUCLEUS = PROTONS (POSITIVELY CHARGED PARTICLES)+ NEUTRONS (NEUTRALLY CHARGED PARTICLES); ELECTRONS ARE NEGATIVELLY CHARGED

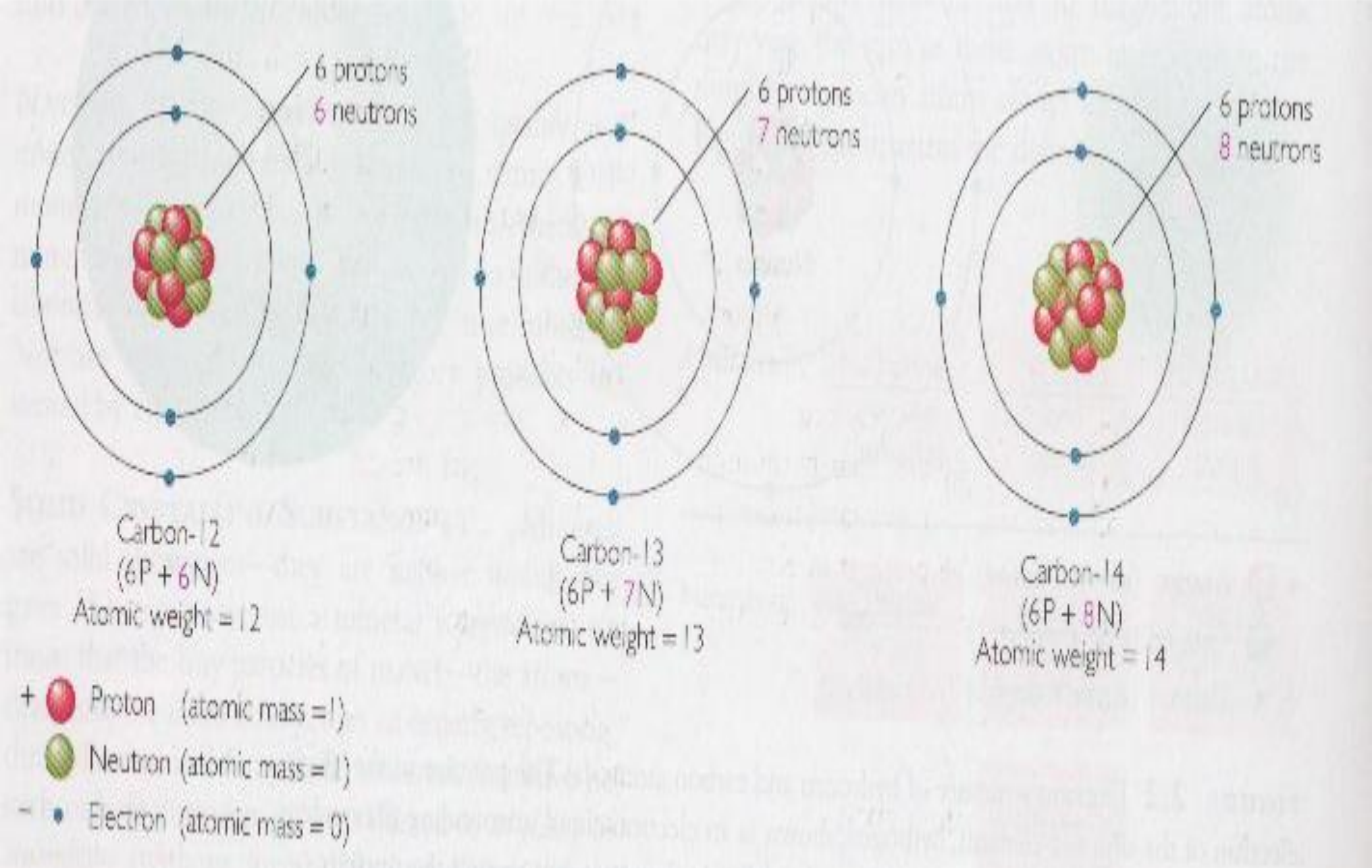
ATOMS OF THE SAME ELEMENT HAVE A CONSTANT NUMBER OF PROTONS & A VARYING NUMBER OF NEUTRONS; ELEMENTS HAVE DIFFERENT ISOTOPES



ATOMIC STRUCTURE

- PROTON HAS AN ATOMIC MASS UNIT OF 1
- NEUTRON HAS AN ATOMIC MASS UNIT OF 1
- ELECTRON HAS AN ATOMIC MASS UNIT OF 0
- ATOMIC MASS UNIT = 1/12 OF THE ACTUAL MASS OF A CARBON ATOM WITH MASS NUMBER 12 (ABOUT 1.6604×10^{-24} grams)
- ATOMIC NUMBER = NUMBER OF PROTONS
- ATOMIC MASS = SUM OF MASSES OF PROTONS & NEUTRONS
- ALTHOUGH THE NUMBER OF PROTONS IS CONSTANT, ATOMS OF THE SAME ELEMENT MAY HAVE DIFFERENT NUMBERS OF NEUTRONS & THUS DIFFERENT ATOMIC MASSES. THESE VARIOUS ATOMS ARE CALLED **ISOTOPES**
- **ISOTOPES OF CARBON ALL WITH 6 PROTONS EXIST WITH 6, 7, & 8 NEUTRONS GIVING ATOMIC MASSES OF 12, 13 & 14**

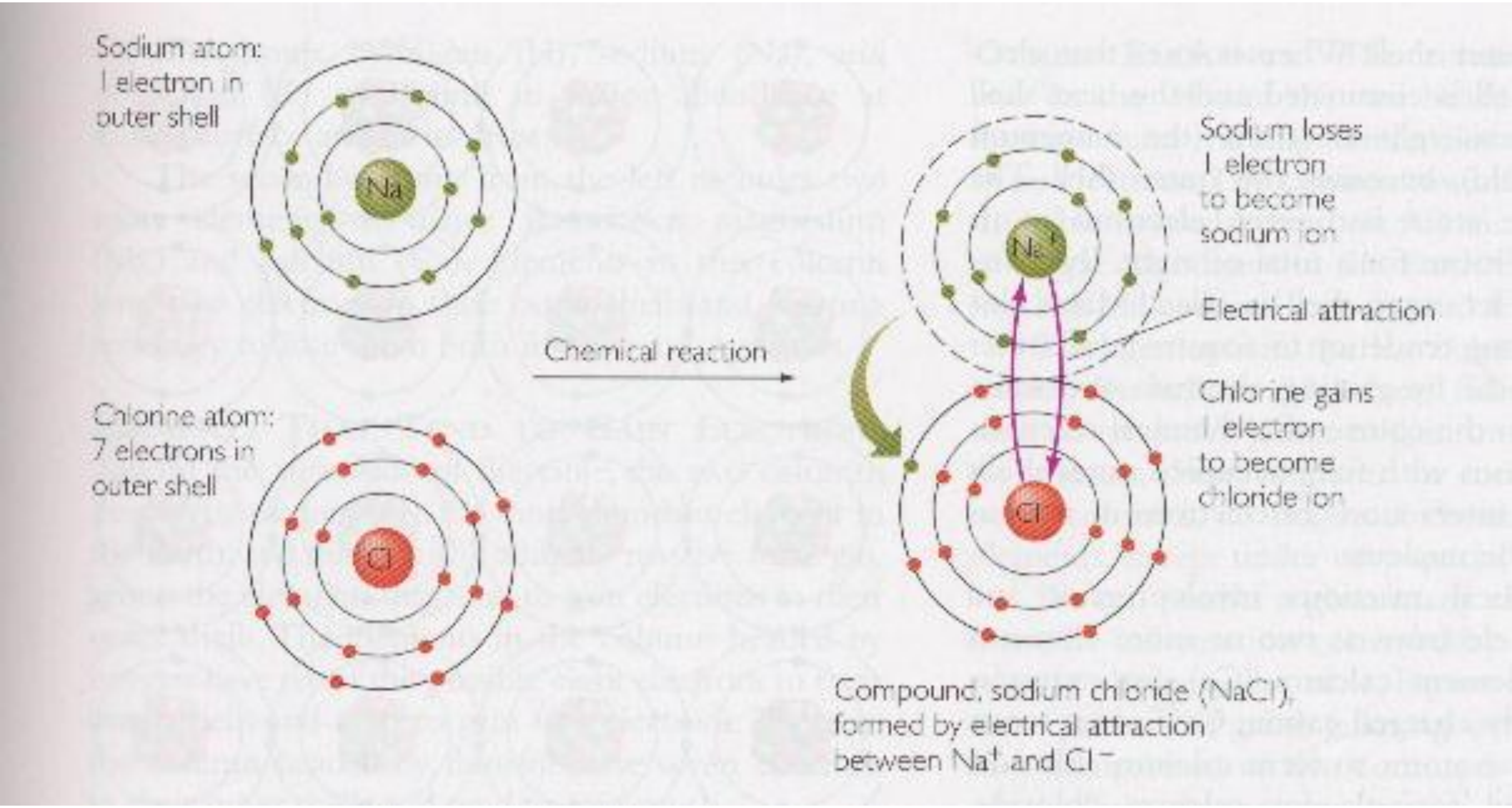
ISOTPOPES OF THE CARBON ELEMENT



CHEMICAL REACTIONS

- INTERACTIONS OF ATOMS OF TWO OR MORE ELEMENTS IN FIXED PROPORTIONS PRODUCE NEW CHEMICAL SUBSTANCES – CHEMICAL COMPOUNDS
- E.G. A COMPOUND CALLED WATER FORMS WHEN TWO HYDROGEN & ONE OXYGEN ATOMS COMBINE; THE MINERAL PYRITE IS COMPOUND OF Fe & S (FeS_2)
- CHEMICAL REACTIONS OCCUR THROUGH INTERACTIONS OF ELECTRONS

CHEMICAL REACTIONS



FORMATION OF COMMON SALT

LECTURES, 2004

CHEMICAL REACTIONS

- 1 FACILITATED BY ATOMS GAINING OR LOSING ELECTRONS OR BY ATOMS SHARING THEIR ELECTRONS
- E.G. IN THE REACTION BETWEEN Na (EXPLOSIVE WHEN EXPOSED IN AIR) & Cl (HIGHLY POISONOUS GAS) TO FORM NaCl (SODIUM CHLORIDE) THE Na ATOM LOSES AN ELECTRON TO BECOME A CATION (POSITIVELY CHARGED ION) & Cl GAINS AN ELECTRON TO BECOME AN ANION (NEGATIVELY CHARGED ION) & THE FORMED COMPOUND IS NEUTRAL & EDIBLE.
- ELEMENTS THAT TEND TO LOSE ELECTRONS ARE IN THE FIRST & SECOND COLUMNS OF THE PERIODIC TABLE
- ELEMENTS THAT TEND TO GAIN ELECTRONS ARE THOSE IN COLUMNS HEADED BY OXYGEN & FLUORINE
- ELEMENTS IN COLUMNS 3 TO 15 OF THE PERIODIC TABLE HAVE VARYING TENDENCIES TO GAIN, LOSE OR SHARE ELECTRONS
- ELEMENTS IN THE LAST COLUMN HAVE NO TENDENCY TO LOSE, GAIN OR SHARE ELECTRONS BECAUSE THEIR OUTER SHELLS ARE FULL (NOBLE ELEMENTS)

CHEMICAL REACTIONS

- WHEN AN ATOM LOSES ELECTRONS ITS SIZE DECREASES WHILE THE ATOM GAINING ELECTRONS INCREASES IN SIZE.

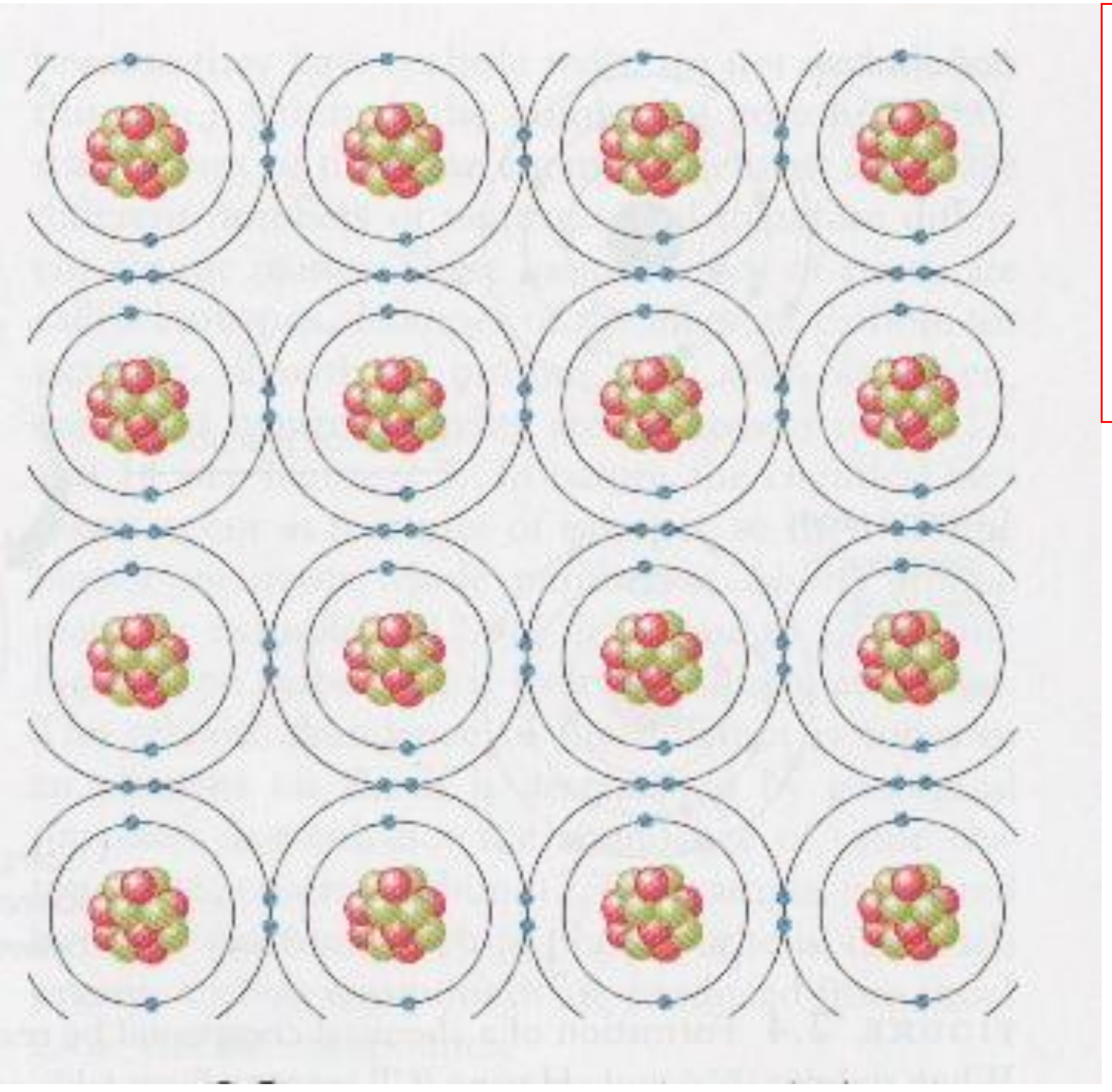
- WHY?

- THROUGH LOSING & GAINING ELECTRONS EACH ATOM ATTAINS A STABLE ATOMIC CONFIGURATION

CHEMICAL REACTIONS

- 2. SOME REACTIONS ARE FACILITATED BY SHARING OF ELECTRONS SO THAT EACH ATOM GAINS A STABLE CONFIGURATION
- ELECTRON SHARING MAY OCCUR AMONG ATOMS OF THE SAME ELEMENT OR AMONG ATOMS OF DIFFERENT ELEMENTS

CHEMICAL REACTIONS



ELECTRON SHARING IN DIAMOND WHOSE CHEMICAL ELEMENT IS CARBON; ONE OF EACH OF THE SIX ELECTRONS IN THE OUTERMOST SHELL OF EACH ATOM IS SHARED

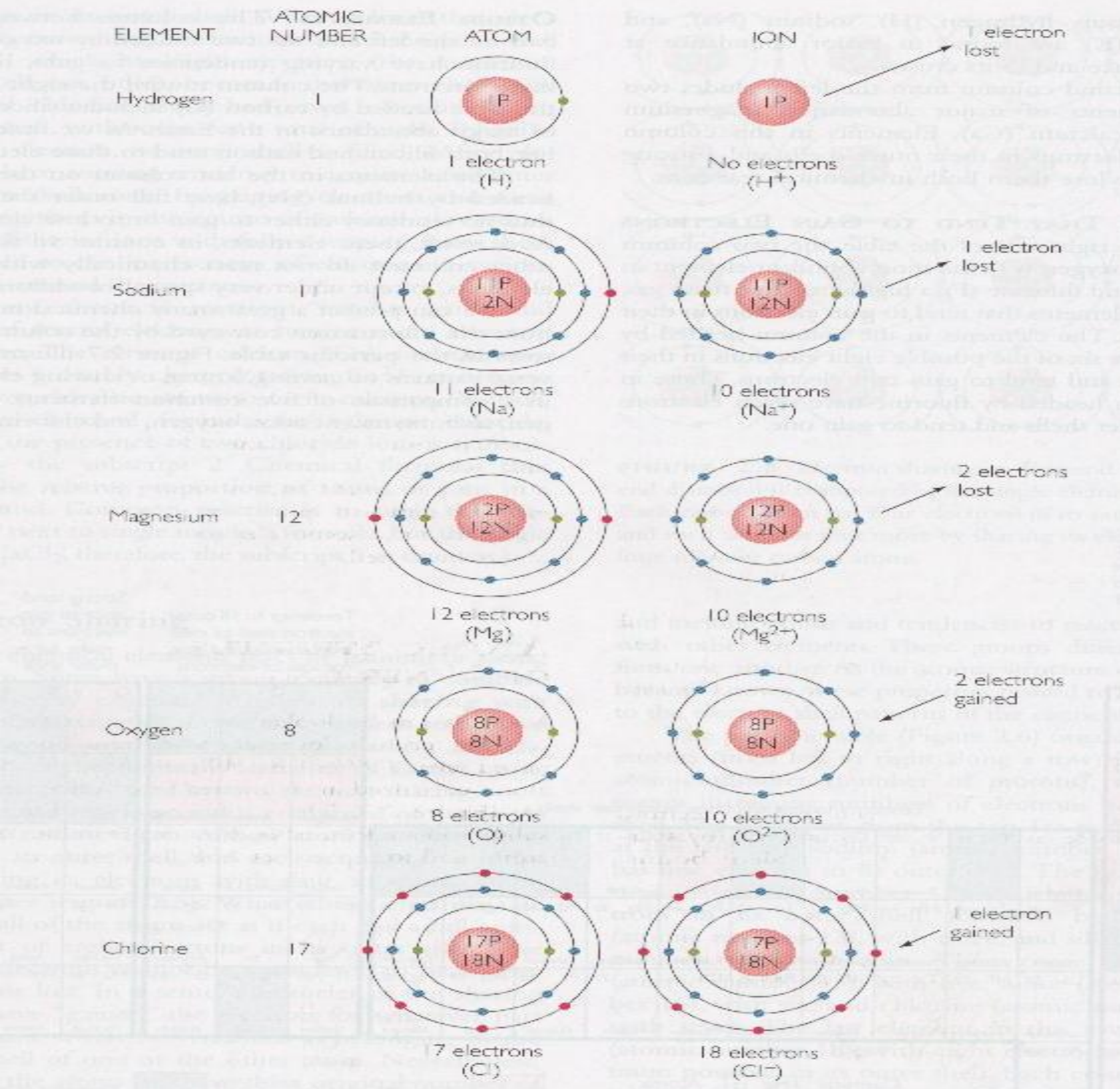


FIGURE 2.7 These models of the atoms and ions of five common elements illustrate the diversity of electron shells. Ions are formed as electrons are gained or lost from outer shells. (P stands for proton, N for neutron.)

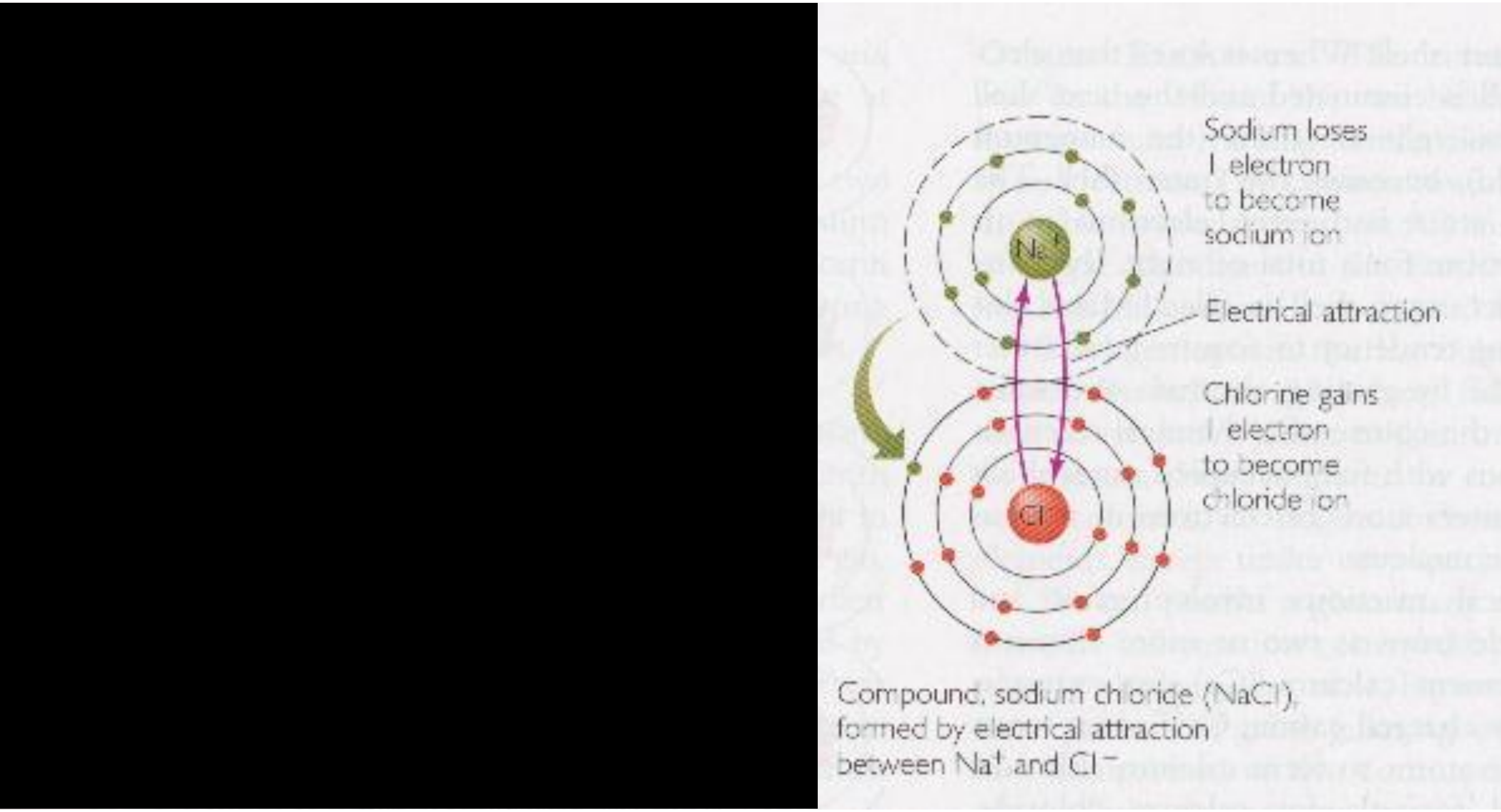
MODELS OF ATOMS & IONS OF FIVE COMMON ELEMENTS ILLUSTRATING THE DIVERSITY OF ELECTRON SHELLS. IONS ARE FORMED VIA GAIN OR LOSS OF ELECTRONS FROM OUTER SHELLS

CHEMICAL BONDS

- IONS OR ATOMS CONSTITUTING COMPOUNDS ARE HELD TOGETHER BY ELECTRICAL FORCES BETWEEN ELECTRONS & PROTONS WHICH ARE CALLED CHEMICAL BONDS
- ELECTRICAL ATTRACTIONS MAY STRONG OR WEAK & THUS RESULTING BONDS MAY BE WEAK OR STRONG
- STRONG BONDS PREVENT A SUBSTANCE FROM DECOMPOSING INTO ITS ELEMENTS OR OTHER COMPOUNDS
- STRONG BONDS ALSO MAKE MINERALS HARD & KEEP THEM FROM CRACKING OR SPLITTING
- THERE ARE TWO MAIN BOND TYPES: IONIC & COVALENT

IONIC BONDS

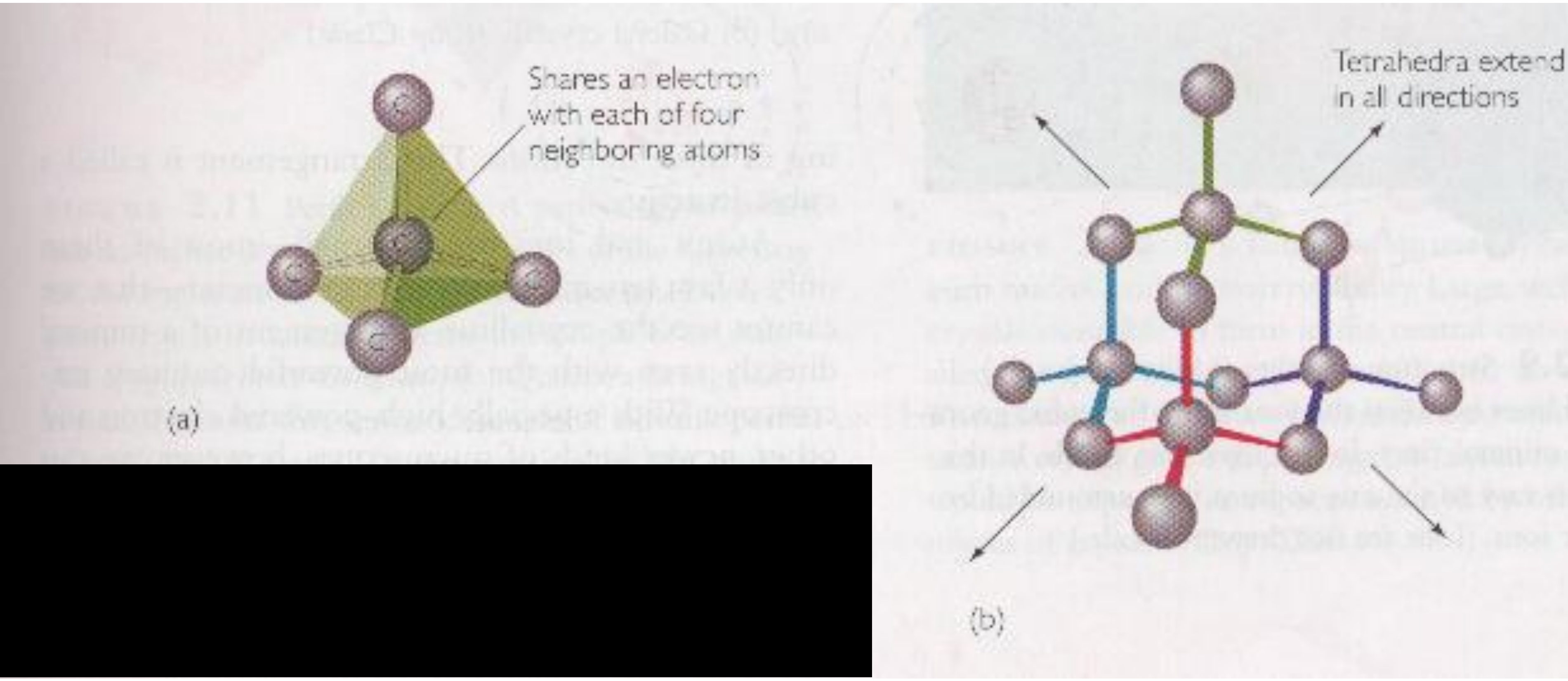
- FORMED BY ELECTRICAL ATTRACTIONS BETWEEN IONS OF OPPOSITE CHARGE SUCH AS Na^+ & Cl^- IN SODIUM CHLORIDE
- THE ATTRACTION IS SIMILAR TO STATIC ELECTRICITY THAT MAKES NYLON OR SILK CLOTHING CLING TO ONES BODY
- BOND STRENGTH DECREASES WITH INCREASING DISTANCE BETWEEN IONS
- BOND STRENGTH INCREASES WITH INCREASING CHARGE
- MOST DOMINANT BONDS IN MINERAL STRUCTURES; ABOUT 90% OF ALL MINERALS ARE IONICALLY BONDED



IONIC BOND BETWEEN Na+ & Cl- IONS

COVALENT BONDS

- ELEMENTS THAT FORM IONS BY SHARING OF ELECTRONS ARE HELD TOGETHER BY COVALENT BONDS
- ARE GENERALLY STRONGER THAN IONIC BONDS E.G. BONDS IN DIAMOND
- IN DIAMOND EVERY CARBON ATOM SHARES AN ELECTRON WITH EACH OF THE 4 ADJUCENT ATOMS IN A TETRAHEDRON
-



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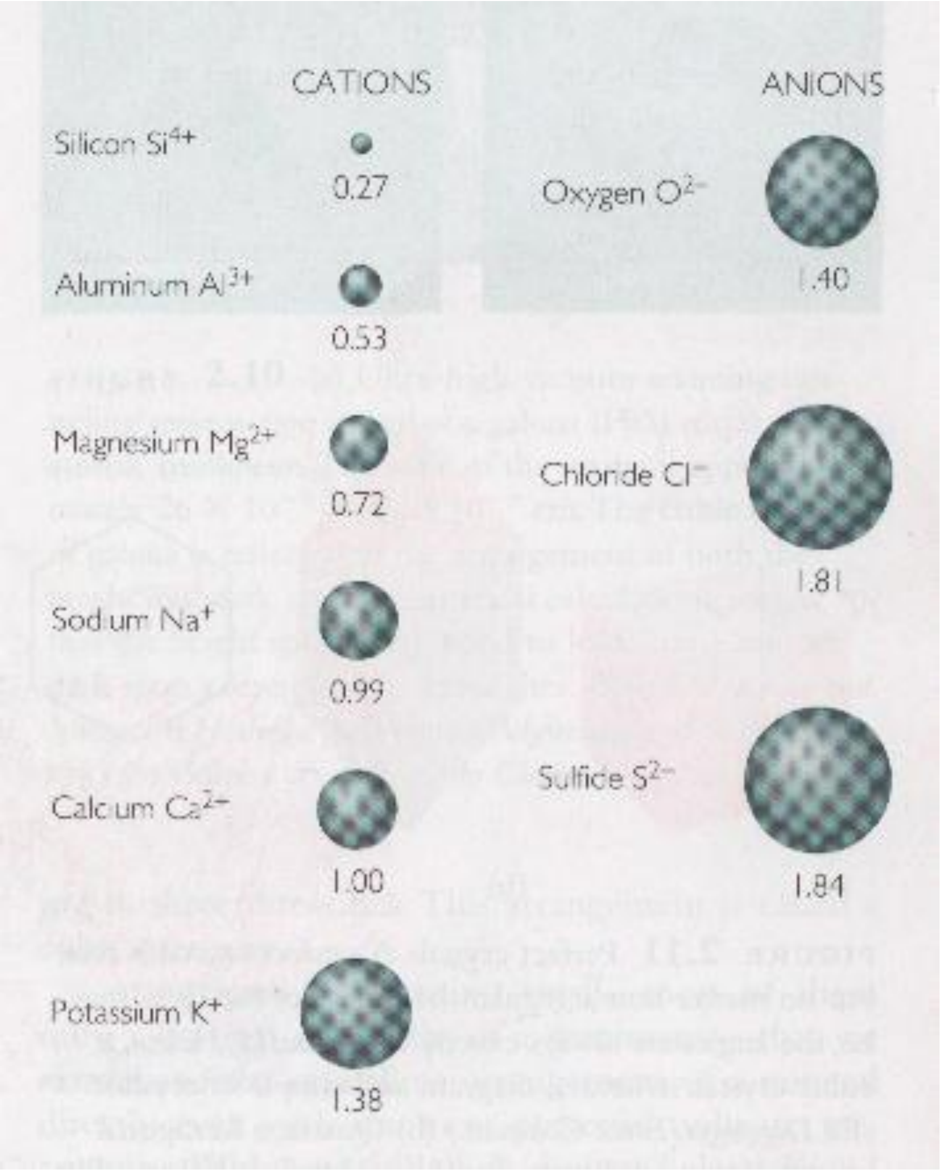
CARBON TETRAHEDRON ILLUSTRATING THE COVALENT BOND AMONG CARBON ATOMS

- METALLIC BOND IS A COVALENT BOND IN WHICH ELECTRONS ARE FREELY SHARED
- THIS BOND TYPE OCCURS AMONG METALLIC ELEMENTS WHICH HAVE STRONG TENDENCIES TO LOSE ELECTRONS WHILE FREELY MOBILE ELECTRONS ARE SHARED & DISPERSED AMONG THE IONS
- CHEMICAL BONDS OF CERTAIN MINERALS ARE INTERMEDIATE BETWEEN IONIC & COVALENT AS SOME ELECTRONS ARE EXCHANGED & OTHERS ARE SHARED

HOW DO MINERALS FORM?

- Minerals are formed by the process of C**RYSTALLISATION**, the growth of a solid from a material whose constituent atoms can come together in the proper chemical proportions and crystalline arrangement.
- Crystallization occurs when T of a solution is lowered to below its freezing point; Similarly, magma crystallizes into solid minerals when it cools to below its melting point, which is at about 1000 degrees C
- Can result from EVAPOURATION or COOLING
- Crystal also form when atoms & ions in solids become mobile & rearrange themselves at high T; For most minerals, temperatures must reach at least 250 degrees C before thsi rearrangement forms new minerals with different crystal structures.
- Two major factors control the rearrangment of atoms and ions in a crystal structure:
- Number of neighbouring atoms or ions & their size

IONIC SIZES



IONIC RADII ARE IN 10^{-8} cm

ACCORDING TO GOLDSCHMIT GEOCHEMICAL RULES ATOMS MAY REPLACE ONE ANOTHER IN A MINERAL BECAUSE OF:

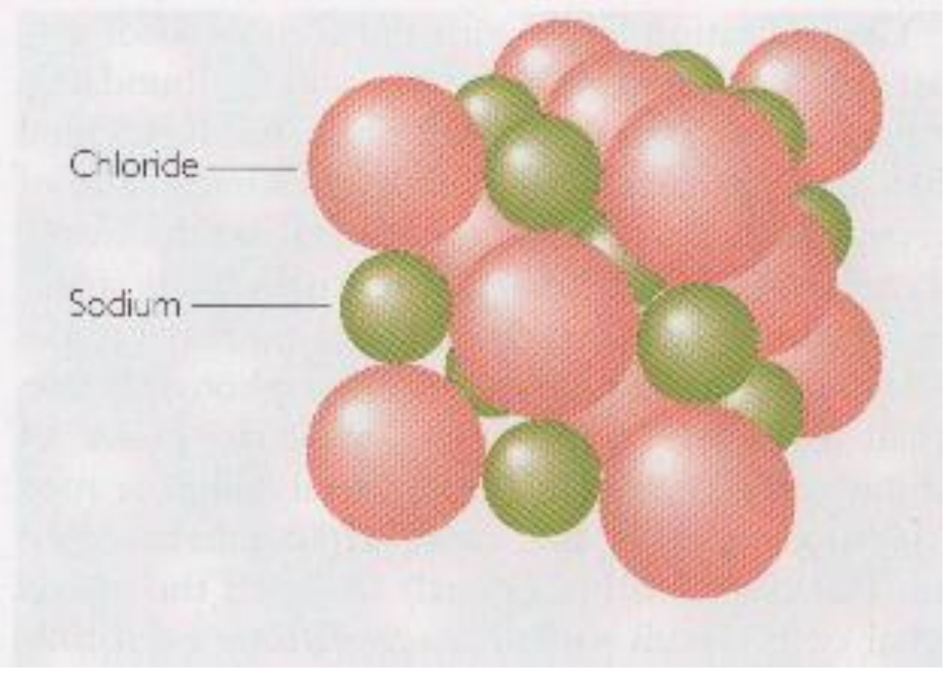
SIMILAR SIZE

SIMILAR CHARGE

E.G. SODIUM & POTASSIUM IN A MINERAL WILL REPLACE EACH OTHER DUE TO THEIR SIMILAR SIZE AND CHARGE

THE IONIC SIZE ALSO DETERMINES THE PACKING OF IONS & THE COORDINATION NUMBER = NUMBER OF ANIONS AROUND A CATION

THE PACKING OF ATOMS IN SODIUM CHLORIDE



CATION SUBSTITUTION

- SAME CRYSTAL STRUCTURE BUT DIFFERENT CHEMICAL COMPOSITION
- CATIONS WITH SIMILAR SIZES & CHARGES SUBSTITUTE FOR ONE ANOTHER & FORM MINERALS WITH THE SAME CRYSTAL STRUCTURE BUT DIFFERENT COMPOSITION
- CATION SUBSTITUTION IS COMMON IN SILICATE MINERALS E.G. OLIVINE
- Fe & Mg HAVE SIMILAR SIZES & CHARGES & SUBSTITUTE FOR EACH OTHER IN OLIVINE $(Mg,Fe)_2SiO_4$
- Si & Al HAVE SIMILAR SIZE & CHARGE & SUBSTITUTE FORM EACH OTHER IN MANY SILICATE MINERALS

POLYMORPHS

- MANY FORMS
- DIFFERENT CRYSTAL STRUCTURE BUT SAME COMPOSITION
- DIAMOND (3.5 g/cm3) & GRAPHITE (2.1 g/cm3) HAVE THE SAME CHEMICAL COMPOSITION & DIFFERENT STRUCTURES ARE POLYMORPHS

MINERAL CLASSIFICATION

- Minerals are classified on the basis of their chemical composition i.e. on the ANIONIC part of the composition e.g. Calcite is classified as a CARBONATE because of the carbonate anion (CO_3^{2-})
- There are 8 mineral classes.

MINERAL CLASSES

- 1. **Native Elements** (repeated atoms of one element e.g.
- C,Cu) e.g. diamond, copper etc
- 2. **<u>Carbonates</u>** (CO_3^{2-}) e.g. calcite
- 3. **Halides** (Cl-, F- etc) e.g. Halite or rock salt (NaCl), fluorite
- (CaF_2)
- 4. **<u>Sulphides</u>** (S^{2-}) e.g. pyrite (FeS_2)
- 5. **Sulphates** (SO_4^{2-}) e.g. anhydrite ($CaSO_4$)
- 6. **<u>Oxides</u>** (O^{2-})/ Hydroxides (OH^-) e.g. magnetite (Fe_3O_4),
- brucite ($Mg[OH]_2$)
- 7. **Phosphates** (PO_4^{2-}) e.g. apatite ($Ca_5[PO_4]_3(F,Cl,OH)$)
- 8. **<u>Silicates</u>** ($[SiO_4]^{4-}$) e.g. amethyst (SiO_2), beryl
- ($Be_3Al_2\{Si_6O_{18}\}$) etc

MINERAL CLASSES

- Because the most abundant elements constituting earth materials are oxygen (O) and silicon (Si), SILICATE MINERALS are the most common and important ROCK-FORMING MINERALS.
- Other common rock-forming mineral groups are CARBONATES, OXIDES, SULPHIDES & SULPHATES.

EARTH MATERIALS: MINERALS AND ROCKS

ELEMENTS

Elements of major abundance in Earth's crust

Elements of lesser abundance but of major geologic importance

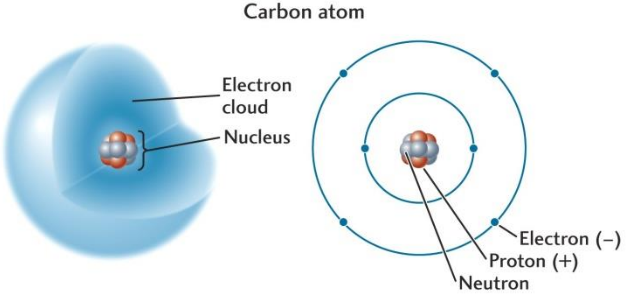
Carbon / 6 / C / 12.011 — Element name, Atomic number, Symbol, Atomic mass

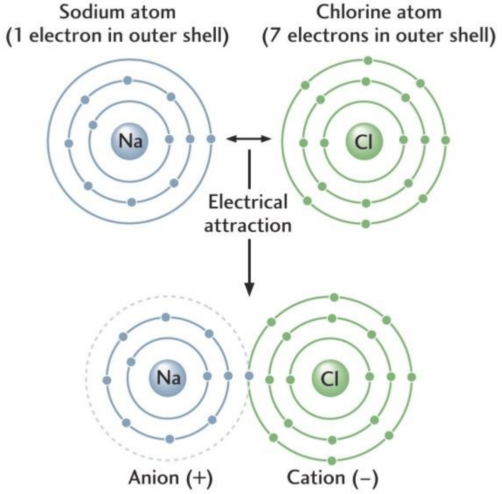
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hydrogen 1 H 1.0079																	Helium 2 He 4.0026
Lithium 3 Li 6.941	Beryllium 4 Be 9.0122											Boron 5 B 10.811	Carbon 6 C 12.011	Nitrogen 7 N 14.0067	Oxygen 8 O 15.9994	Fluorine 9 F 18.9984	Neon 10 Ne 20.1797
Sodium 11 Na 22.9898	Magnesium 12 Mg 24.3050											Aluminum 13 Al 26.9815	Silicon 14 Si 28.0855	Phosphorus 15 P 30.9738	Sulfur 16 S 32.066	Chlorine 17 Cl 35.4527	Argon 18 Ar 39.948
Potassium 19 K 39.0983	Calcium 20 Ca 40.078	Scandium 21 Sc 44.9559	Titanium 22 Ti 47.867	Vanadium 23 V 50.9415	Chromium 24 Cr 51.9961	Manganese 25 Mn 54.9380	Iron 26 Fe 55.845	Cobalt 27 Co 58.9332	Nickel 28 Ni 58.6934	Copper 29 Cu 63.546	Zinc 30 Zn 65.39	Gallium 31 Ga 69.723	Germanium 32 Ge 72.61	Arsenic 33 As 74.9216	Selenium 34 Se 78.96	Bromine 35 Br 79.904	Krypton 36 Kr 83.80
Rubidium 37 Rb 85.4678	Strontium 38 Sr 87.62	Yttrium 39 Y 88.9059	Zirconium 40 Zr 91.224	Niobium 41 Nb 92.9064	Molybdenum 42 Mo 95.94	Technetium 43 Tc (97.907)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.9055	Palladium 46 Pd 106.42	Silver 47 Ag 107.8682	Cadmium 48 Cd 112.411	Indium 49 In 114.818	Tin 50 Sn 118.710	Antimony 51 Sb 121.760	Tellurium 52 Te 127.60	Iodine 53 I 126.9045	Xenon 54 Xe 131.29
Cesium 55 Cs 132.9054	Barium 56 Ba 137.327	Lanthanum 57 La 138.9055	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.9479	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.2	Iridium 77 Ir 192.22	Platinum 78 Pt 195.08	Gold 79 Au 196.9665	Mercury 80 Hg 200.59	Thallium 81 Tl 204.3833	Lead 82 Pb 207.2	Bismuth 83 Bi 208.9804	Polonium 84 Po (208.98)	Astatine 85 At (209.99)	Radon 86 Rn (222.02)
Francium 87 Fr (223.02)	Radium 88 Ra (226.0254)	Actinium 89 Ac (227.0278)	Rutherfordium 104 Rf (261.11)	Dubnium 105 Db (262.11)	Seaborgium 106 Sg (263.12)	Bohrium 107 Bh (262.12)	Hassium 108 Hs (265)	Meitnerium 109 Mt (266)			Ununbium 112 Uub (277)						

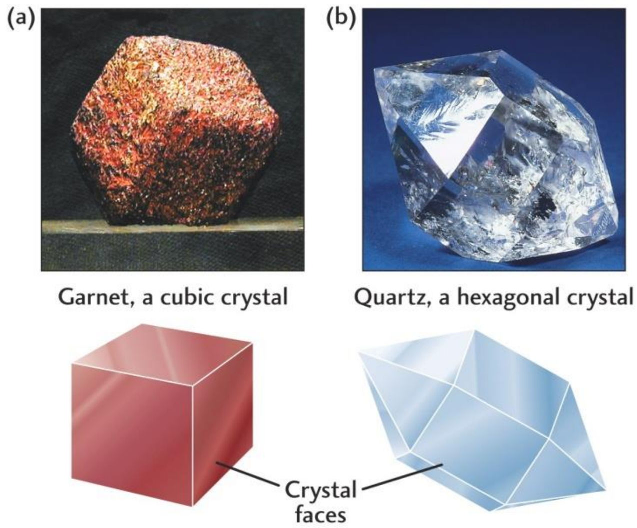
Cerium 58 Ce 140.115	Praseodymium 59 Pr 140.9076	Neodymium 60 Nd 144.24	Promethium 61 Pm (144.91)	Samarium 62 Sm 150.36	Europium 63 Eu 151.965	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.9253	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.9303	Erbium 68 Er 167.26	Thulium 69 Tm 168.9342	Ytterbium 70 Yb 173.04	Lutetium 71 Lu 174.967
Thorium 90 Th 232.0381	Protactinium 91 Pa 231.0388	Uranium 92 U 238.0289	Neptunium 93 Np (237.0482)	Plutonium 94 Pu (244.664)	Americium 95 Am (243.061)	Curium 96 Cm (247.07)	Berkelium 97 Bk (247.07)	Californium 98 Cf (251.08)	Einsteinium 99 Es (252.08)	Fermium 100 Fm (257.10)	Mendelevium 101 Md (258.10)	Noblelium 102 No (259.10)	Lawrencium 103 Lr (262.11)

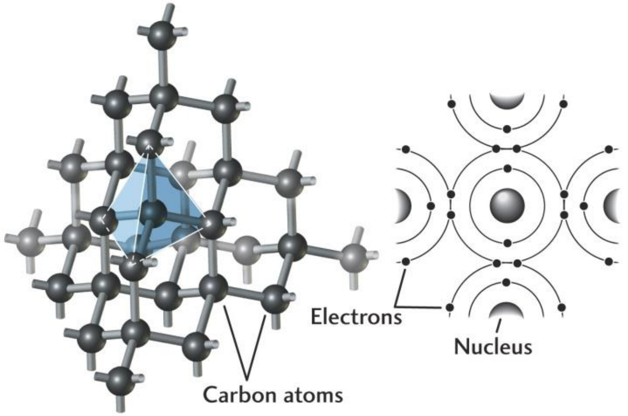
CRYSTALS

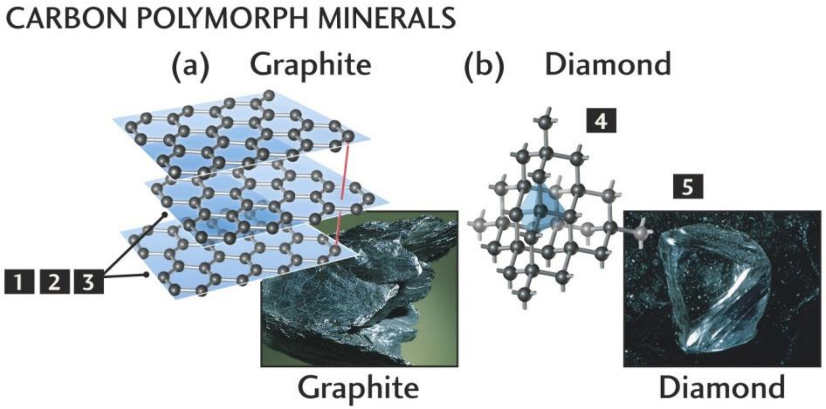
Atoms => Ions (cations/anions) => Molecules => Crystals/Crystalline solid => Minerals











MINERALS

A Mineral:

- is natural
- is inorganic
- is structurally homogeneous solid with definite crystalline structure
- has a well-defined regular internal arrangement of its constituent particles
- has a definite chemical composition which can be expressed by a chemical formula
- has a definite set of physical properties that are fixed within certain limits.

Groups of Minerals

- ***Native elements***-such as gold, silver, copper, iron, platinum, sulphur, diamond, etc.
- ***Sulphates*** - whose basic unit is $(SO_4)^{2-}$, such as gypsum, barite, etc.
- ***Oxides*** - whose basic unit is O^{2-}, such as magnetite, hematite, etc.
- ***Carbonates***- whose basic unit is $(CO_3)^{2-}$, such as calcite, dolomite, magnesite, etc.
- ***Halides***- such as halite, fluorite, sylvite, etc.
- ***Sulphides***- such as pyrite, galena, sphalerite, etc.
- ***Phosphates***- whose basic unit is $(PO_4)^{3-}$, such as apatite, etc.
- ***Arsenides***- such as realgar, orpiment, etc.
- ***Silicates***- whose basic unit is $(SiO_4)^{4-}$, such as quartz, pyroxene, amphibole, etc.

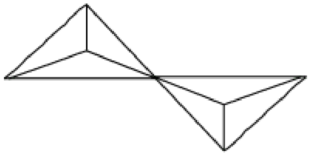
Silicates = Most important rock-forming minerals = Most abundant

Element	O	Si	Al	Fe	Ca	Na	Mg	K	Total	Others
Abundance (Wt. %)	46.40	28.15	8.23	5.63	4.15	2.36	2.33	2.09	99.34	0.66

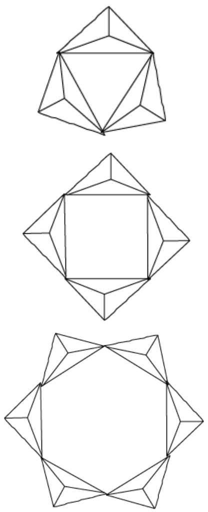
SILICATES/ROCK-FORMING MINERALS

Silicate Structures

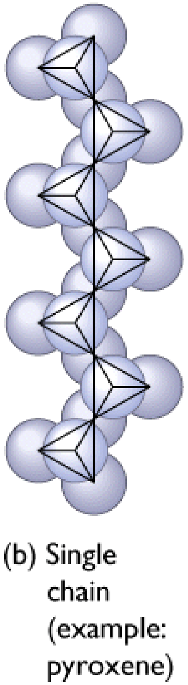
Nesosilicate



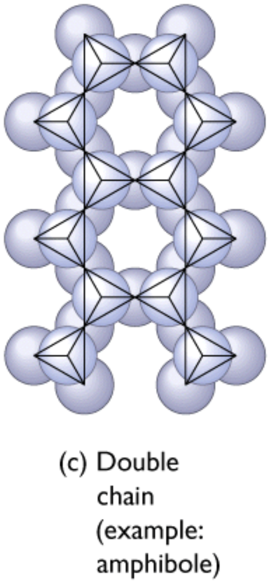
Sorosilicate



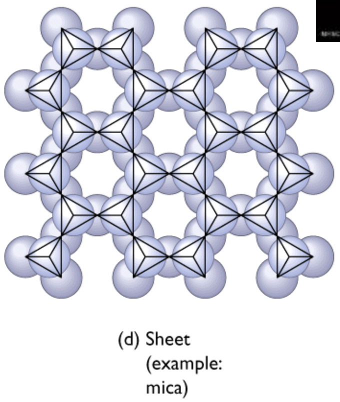
Cyclosilicate



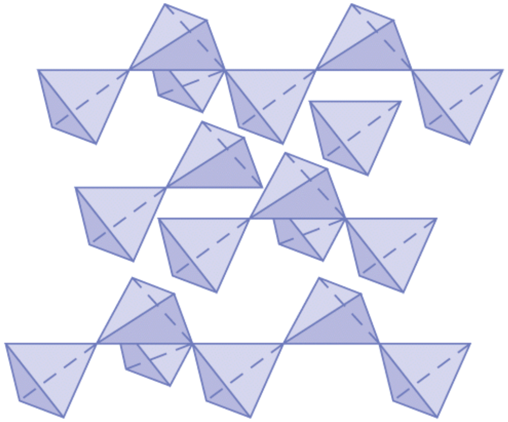
Single-chain Inosilicate



Double-chain Inosilicate

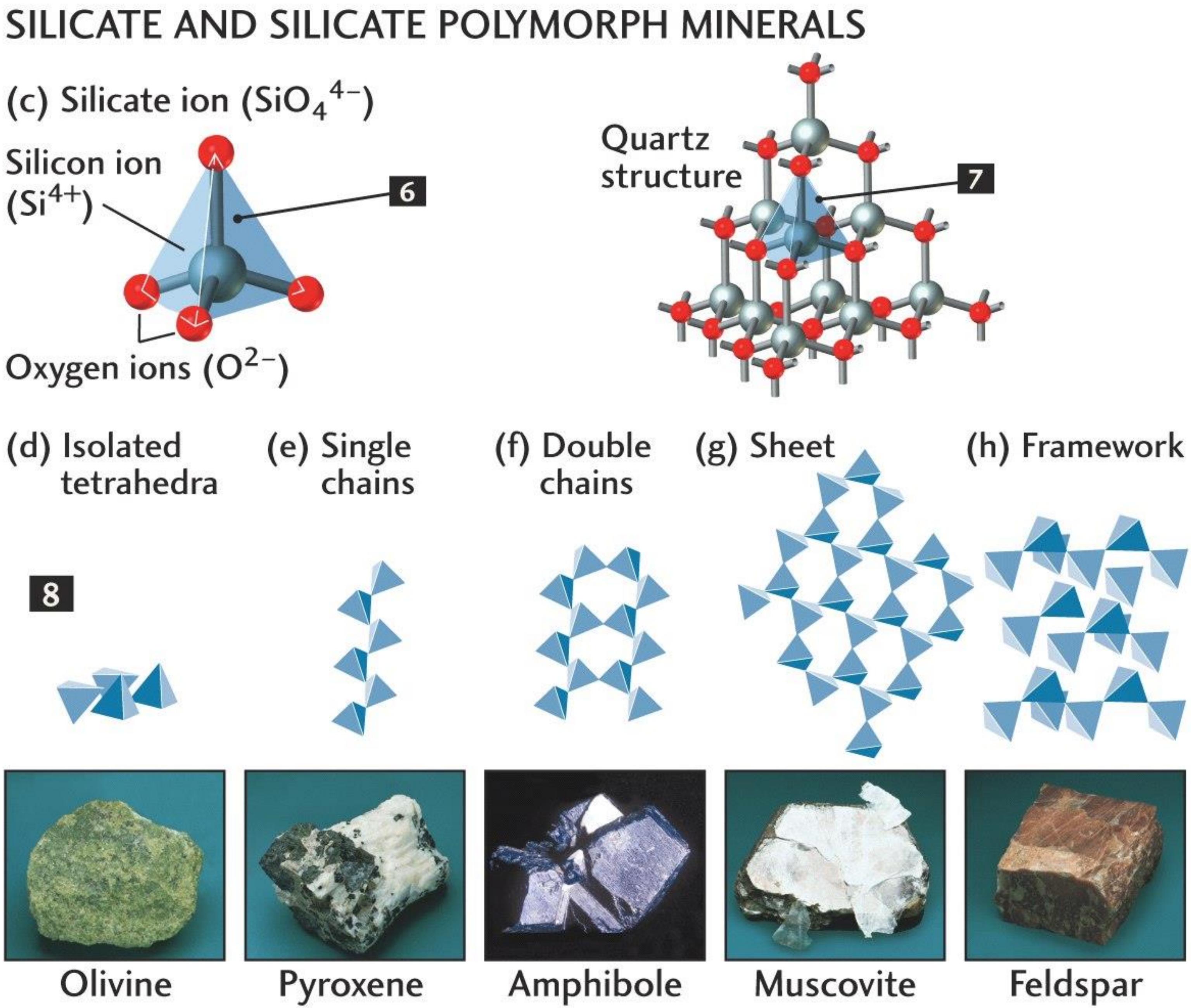


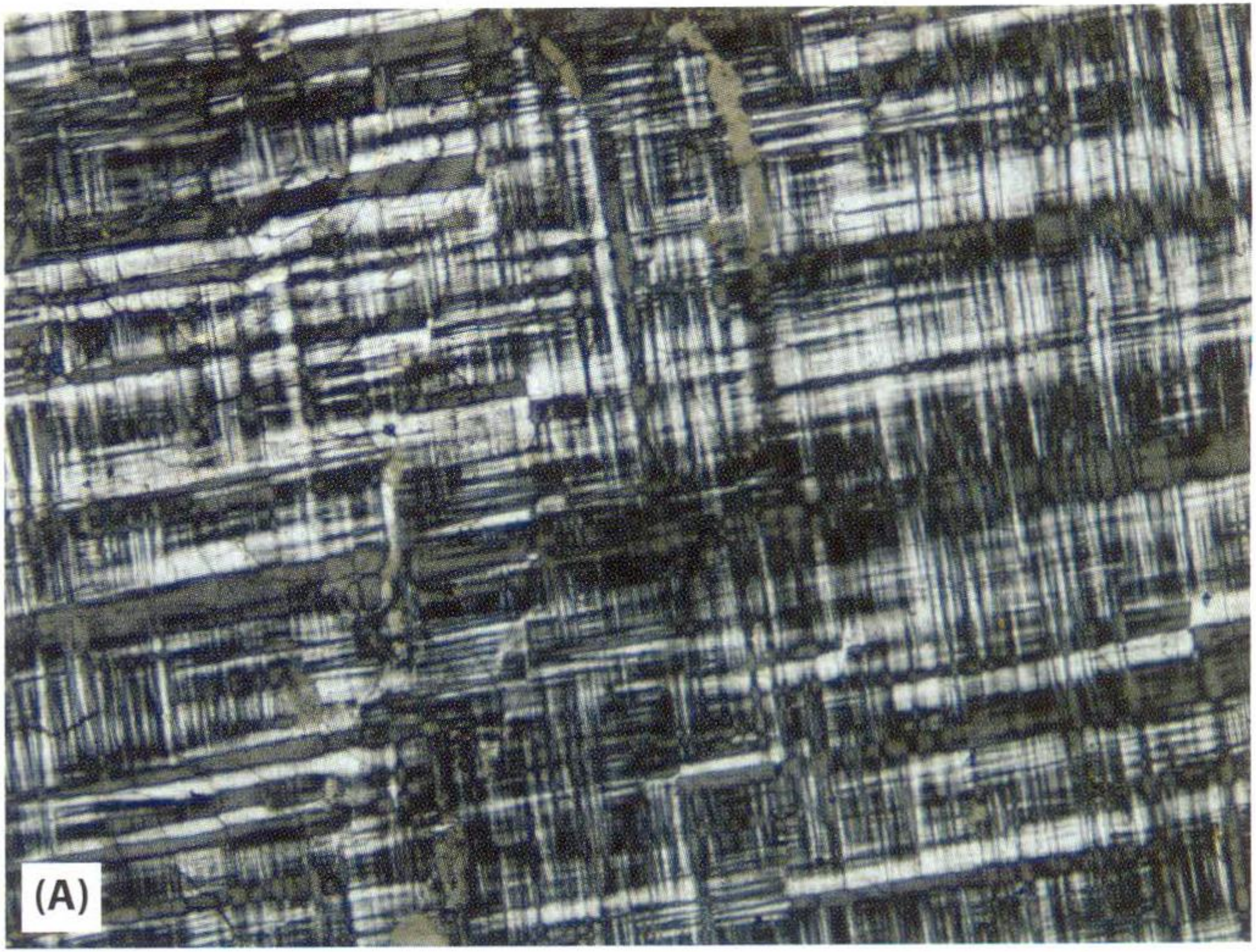
Phyllosilicate (Sheet silicate)



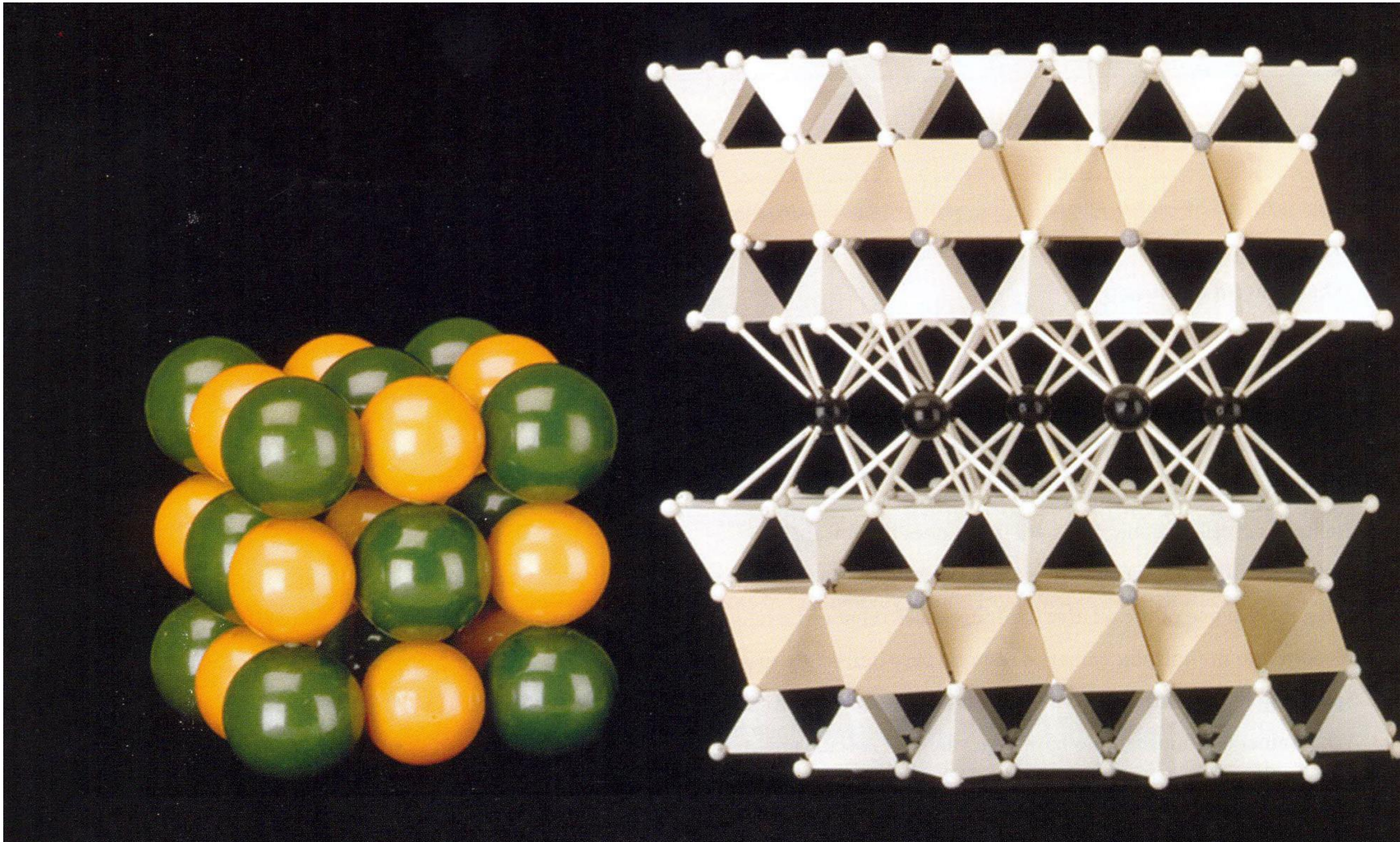
Tektosilicate (Framework silicate)

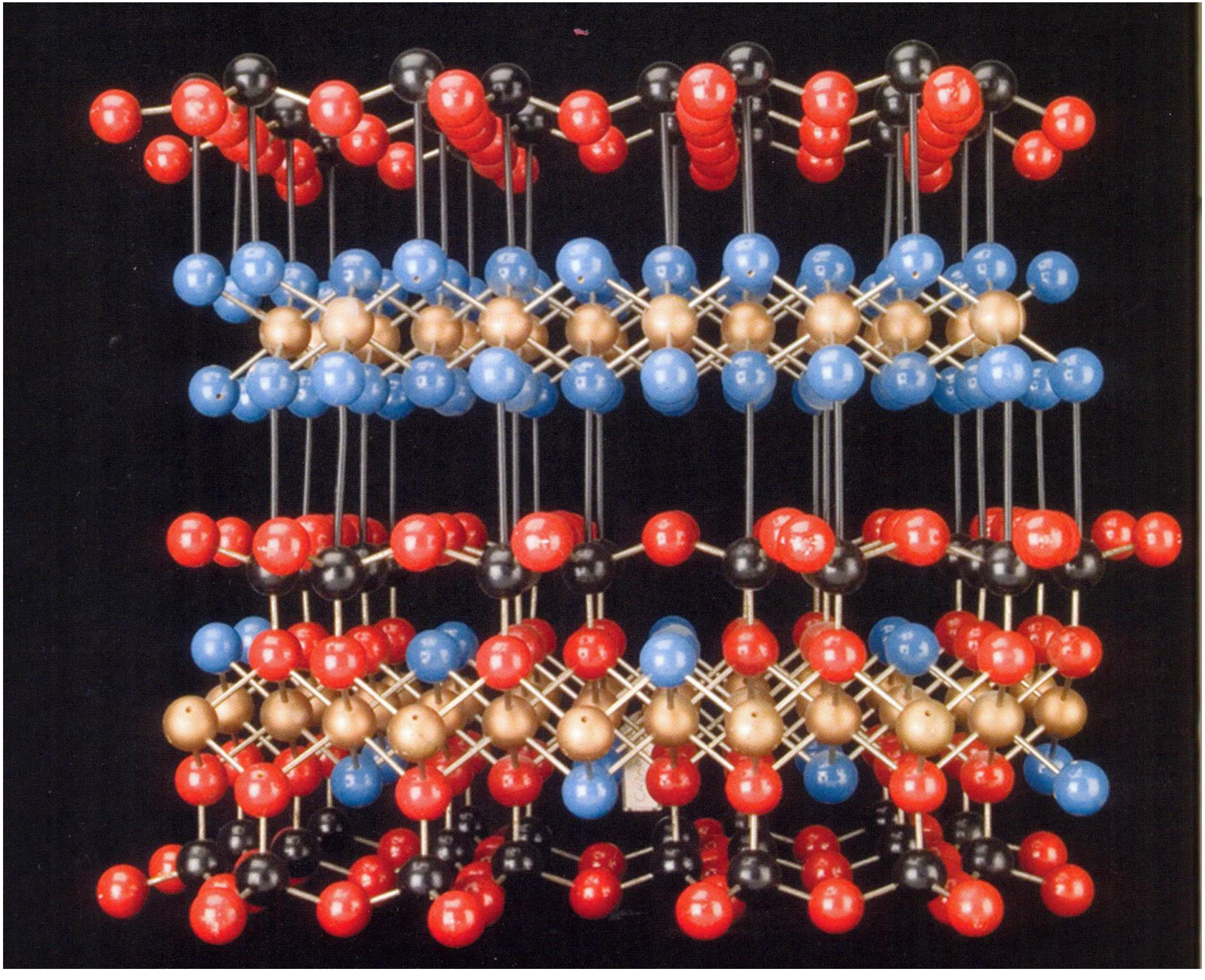
Groups of Silicate Minerals





1 mm





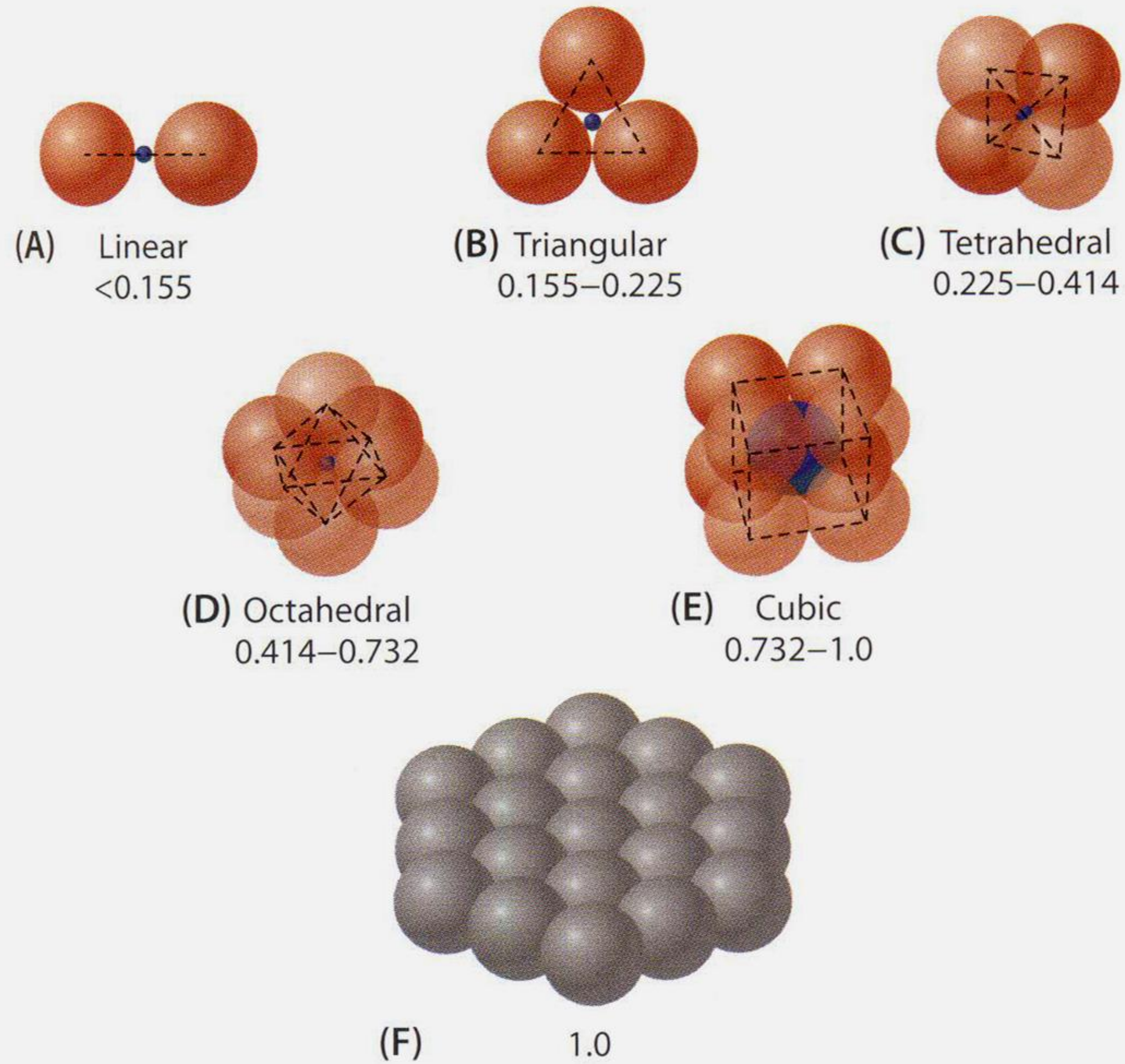
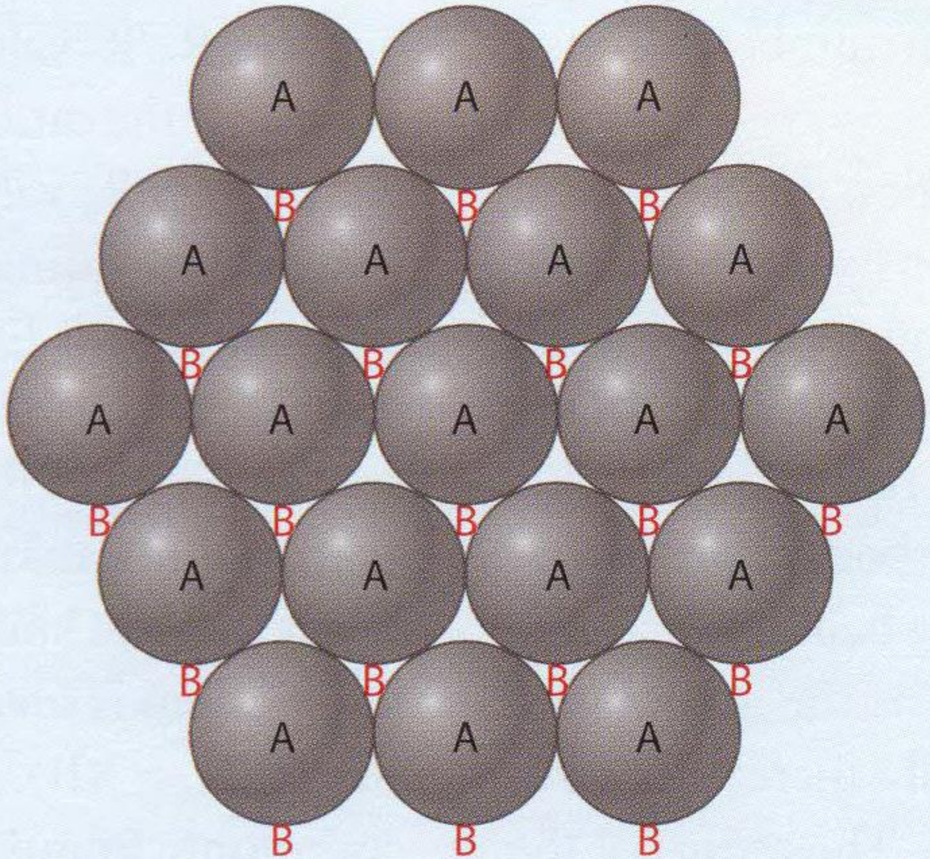
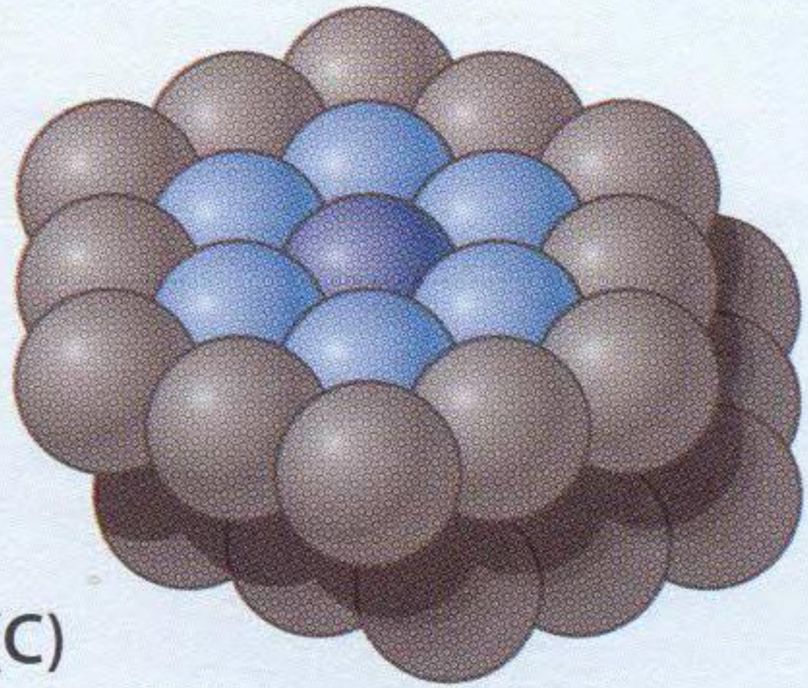
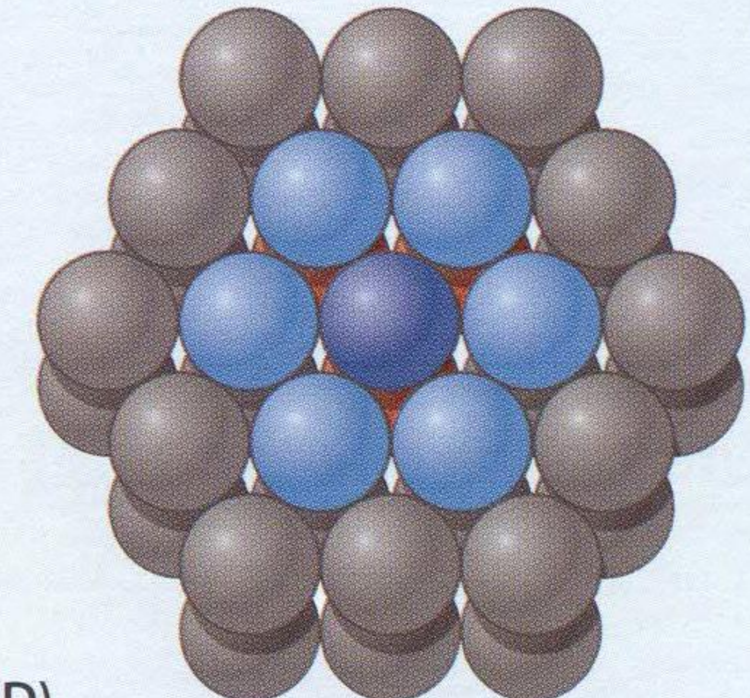


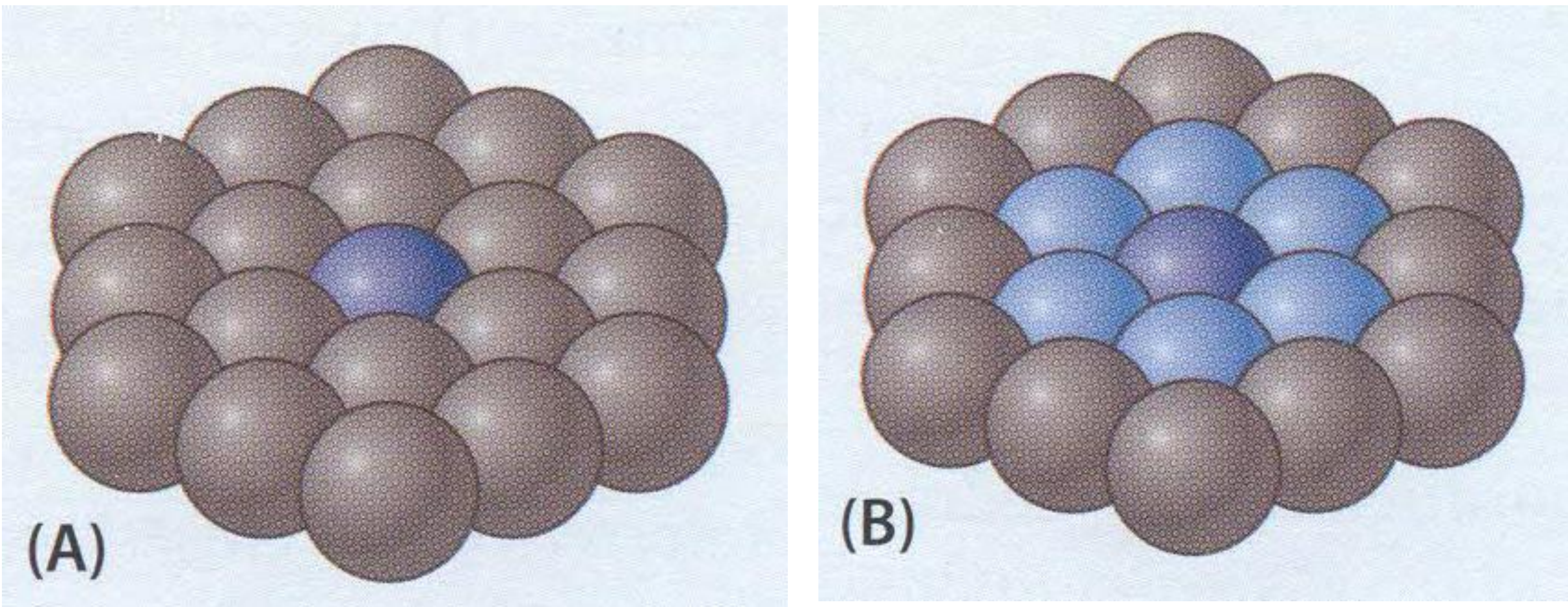
Figure 4.3 Coordination geometry as a function of limiting R_A(cation)/R_X(anion) ratios.

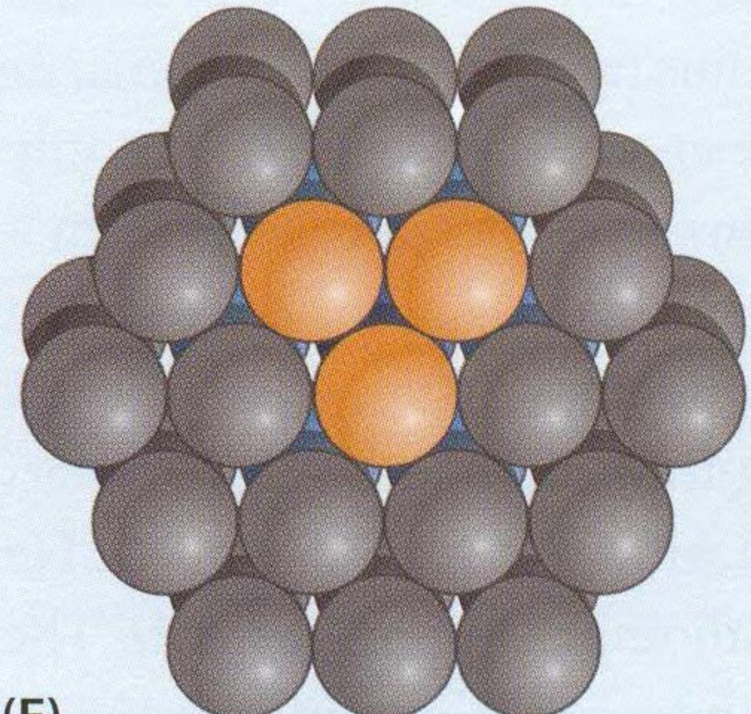
HEXAGONAL CLOSEST PACKING (HCP)




(C)


(D)


(A)
(B)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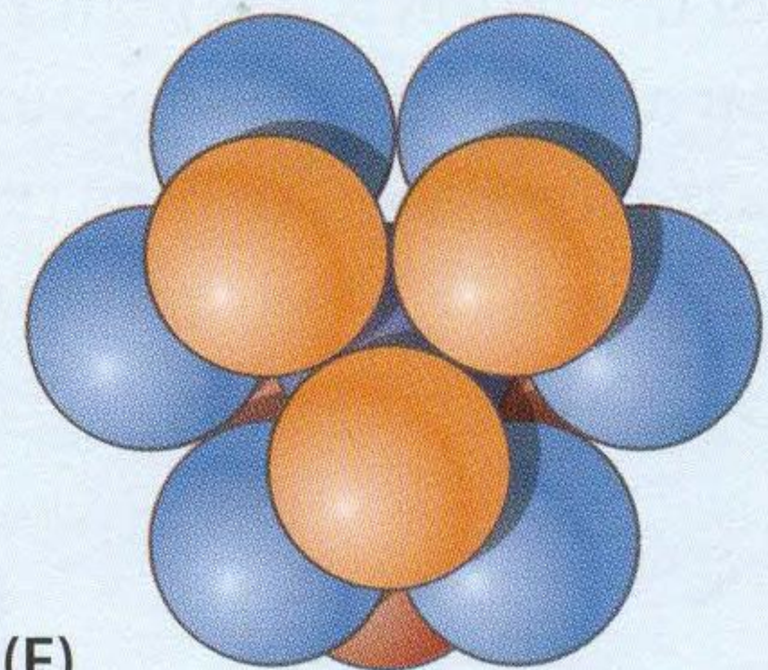
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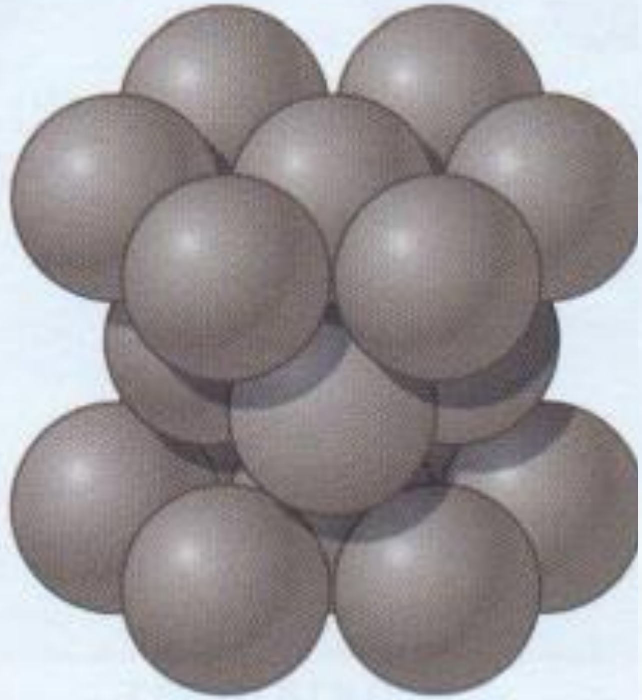
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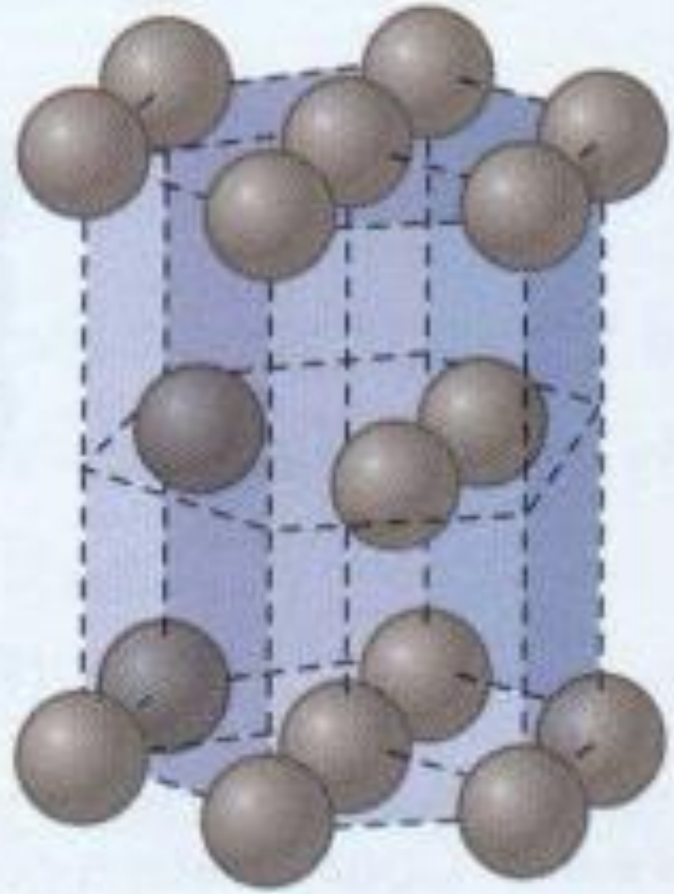
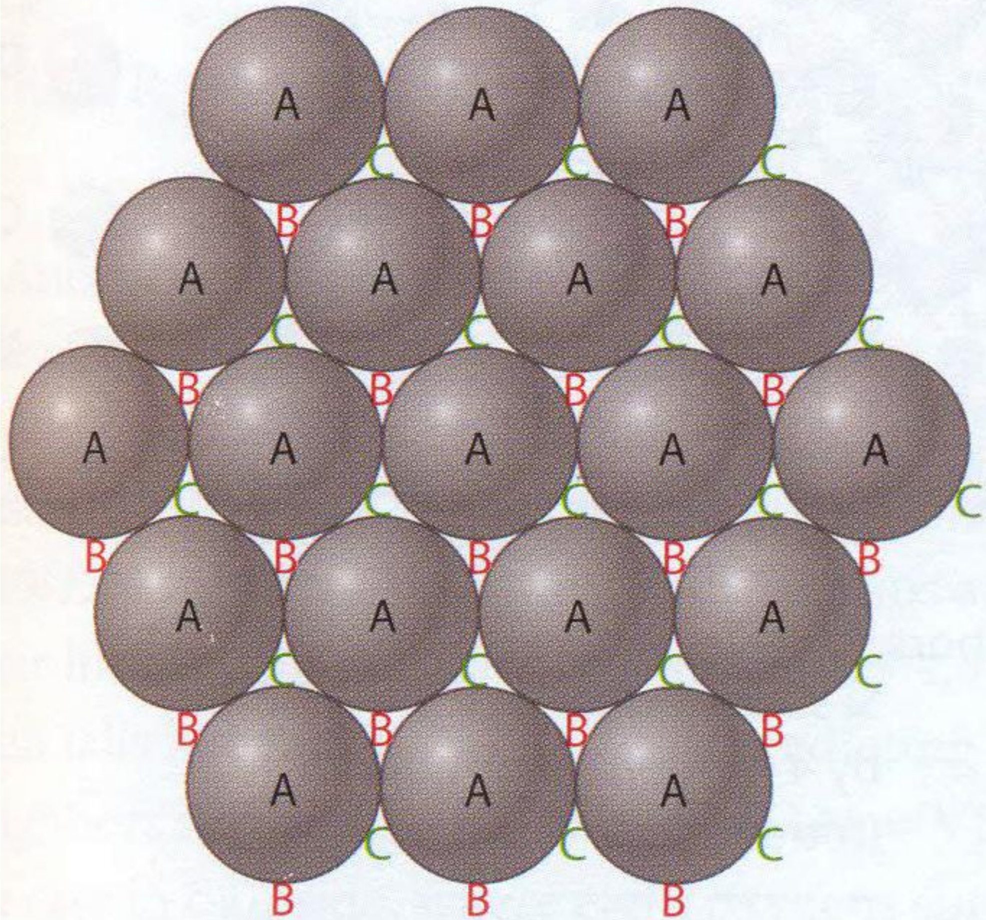
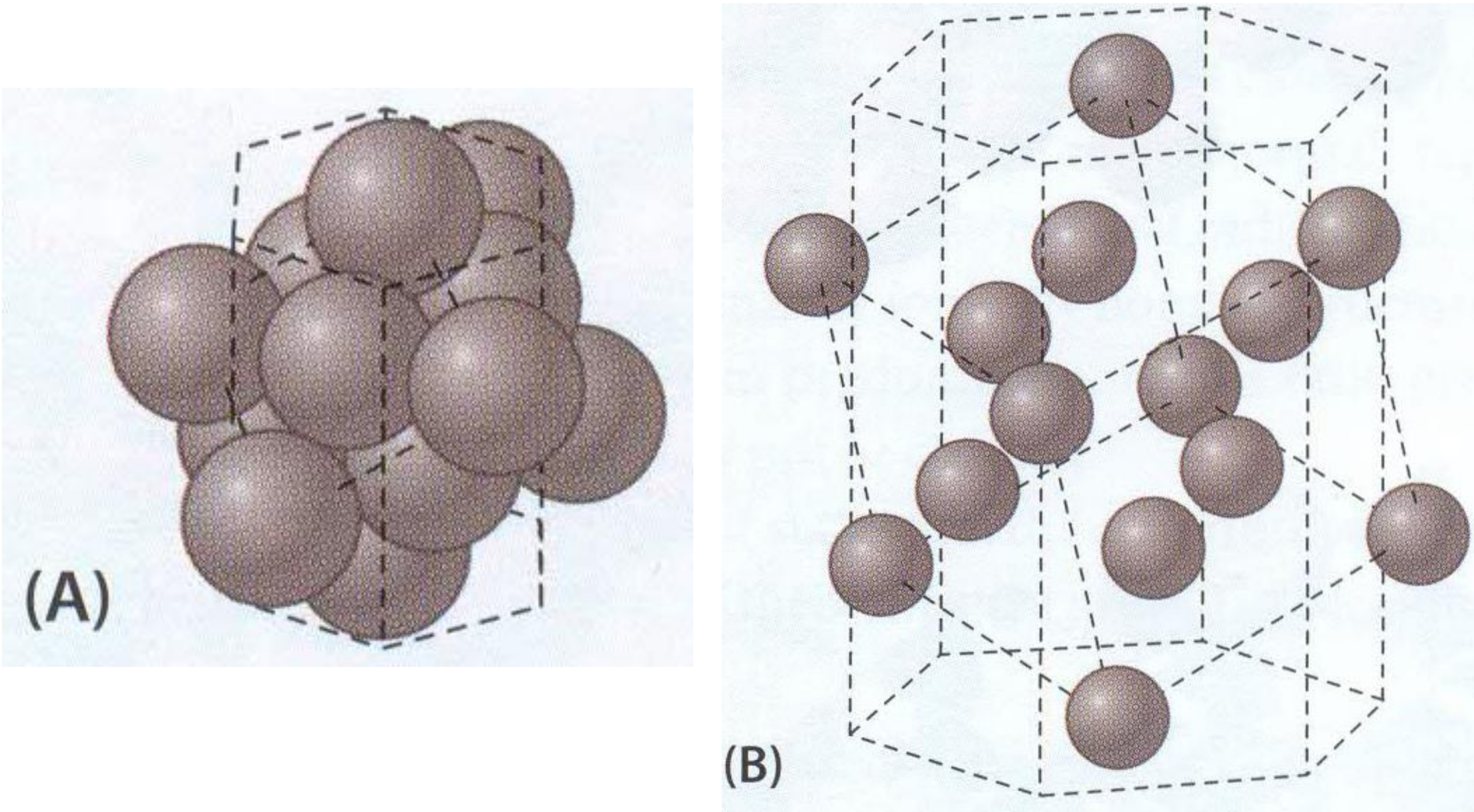
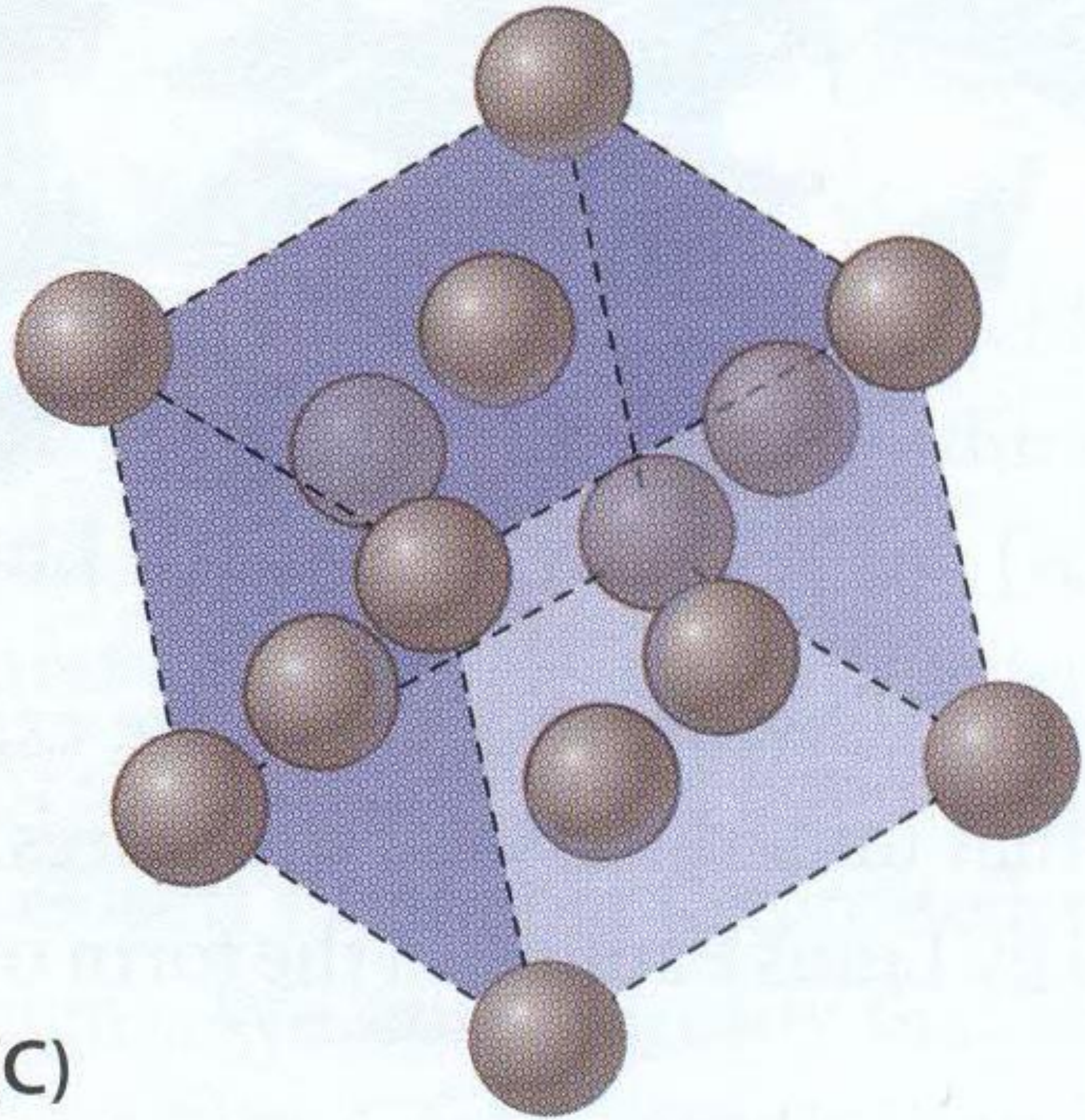

(H)

CUBIC CLOSEST PACKING (CCP)




(A)
(B)



(C)

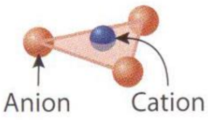
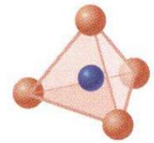
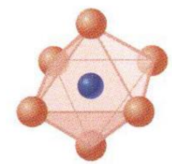
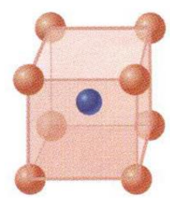
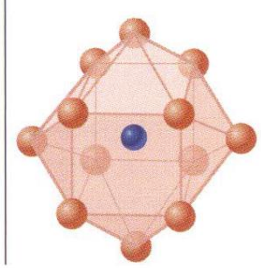
Radius ratio R_A/R_X limits	C.N.	Geometric shape	
0.155 to 0.225	III		Corners of an equilateral triangle (triangular coordination)
0.225 to 0.414	IV		Corners of a tetrahedron (tetrahedral coordination)
0.414 to 0.732	VI		Corners of an octahedron (octahedral coordination)
0.732 to 1.0	VIII		Corners of a cube (cubic coordination)
1.0	XII		Corners of a cuboctahedron (close packing)

Figure 4.5 Coordination numbers and their polyhedral representations.

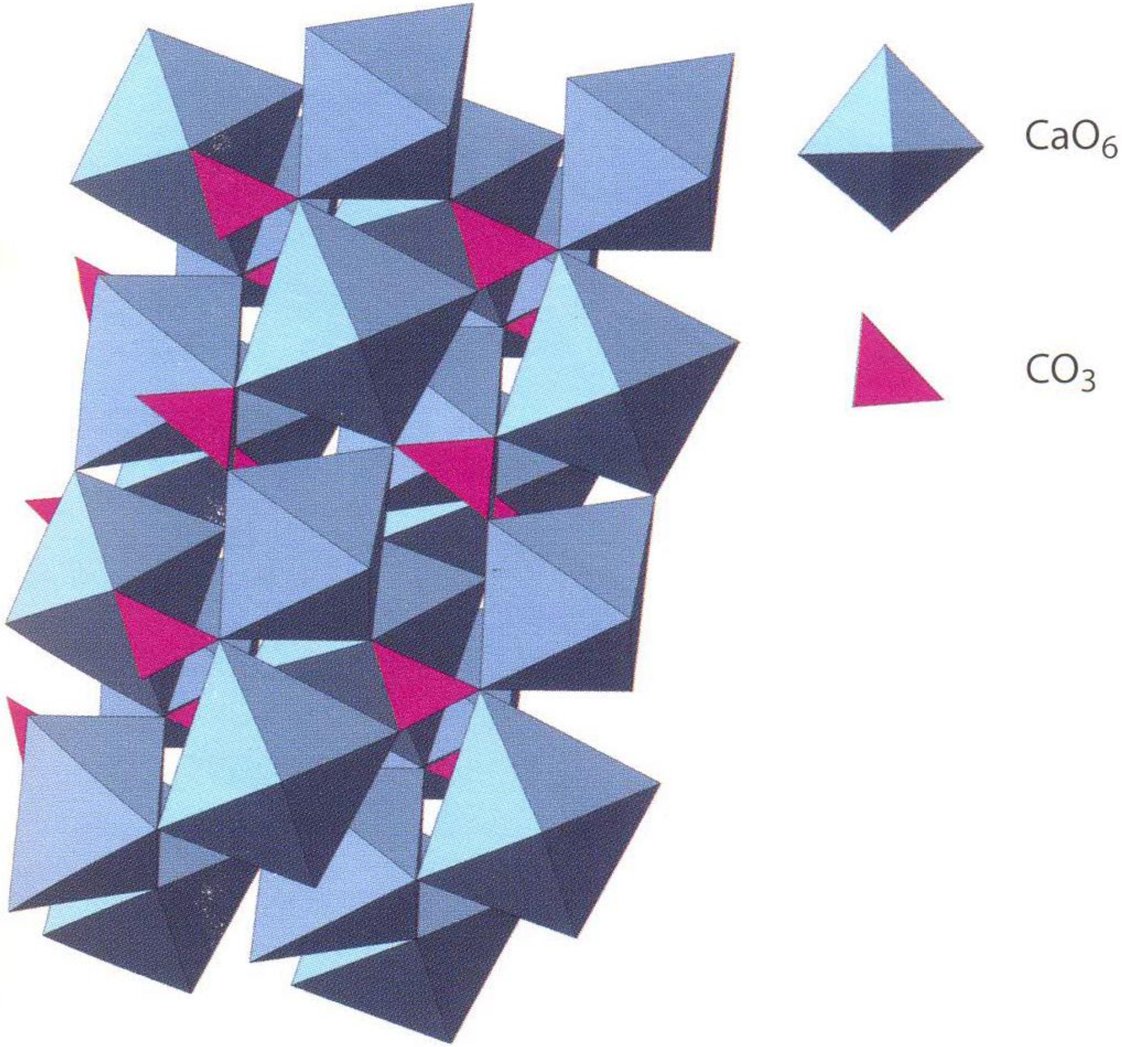


Figure 4.9 Perspective view of the polyhedral representation of the structure of calcite, $CaCO_3$. When looking into the inner part of this structure (not along the edges), it is clear that each corner of the triangular $(CO_3)^{2-}$ group is shared with two adjoining octahedra.

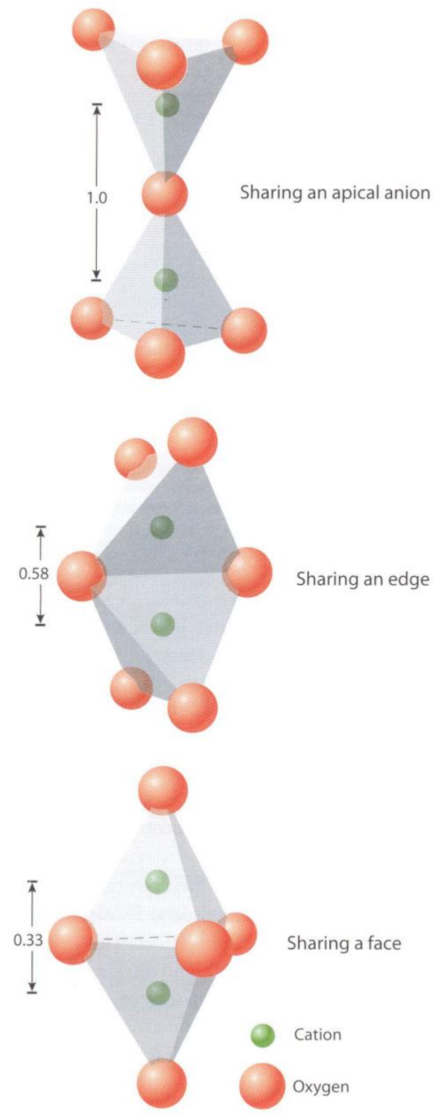


Figure 4.11 Change in the relative distance between two cations (each centered in a tetrahedron) when the geometry is changed from linking across an apex, an edge, and a face. The distances shown reflect the relative decrease in cation-cation distance due to sharing.

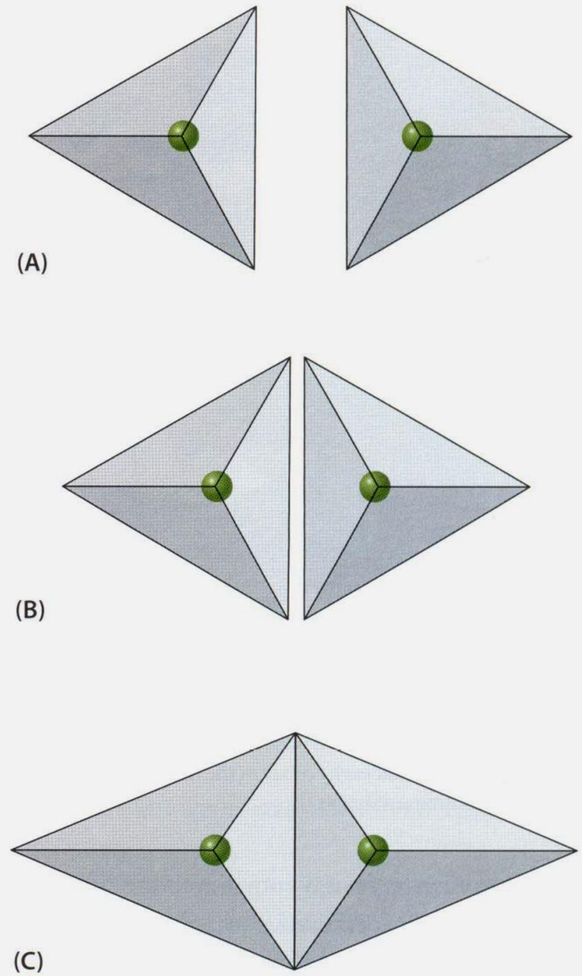


Figure 4.12 (**A**) Two well-shaped tetrahedra with a central ion of high valence. (**B**) The two tetrahedra approach each other but are still very regular in shape. (**C**) One edge is joined. The repulsion caused by the two high-valence cations shortens the shared edge and in the process distorts both tetrahedra so as to allow for larger separation between the two cations.

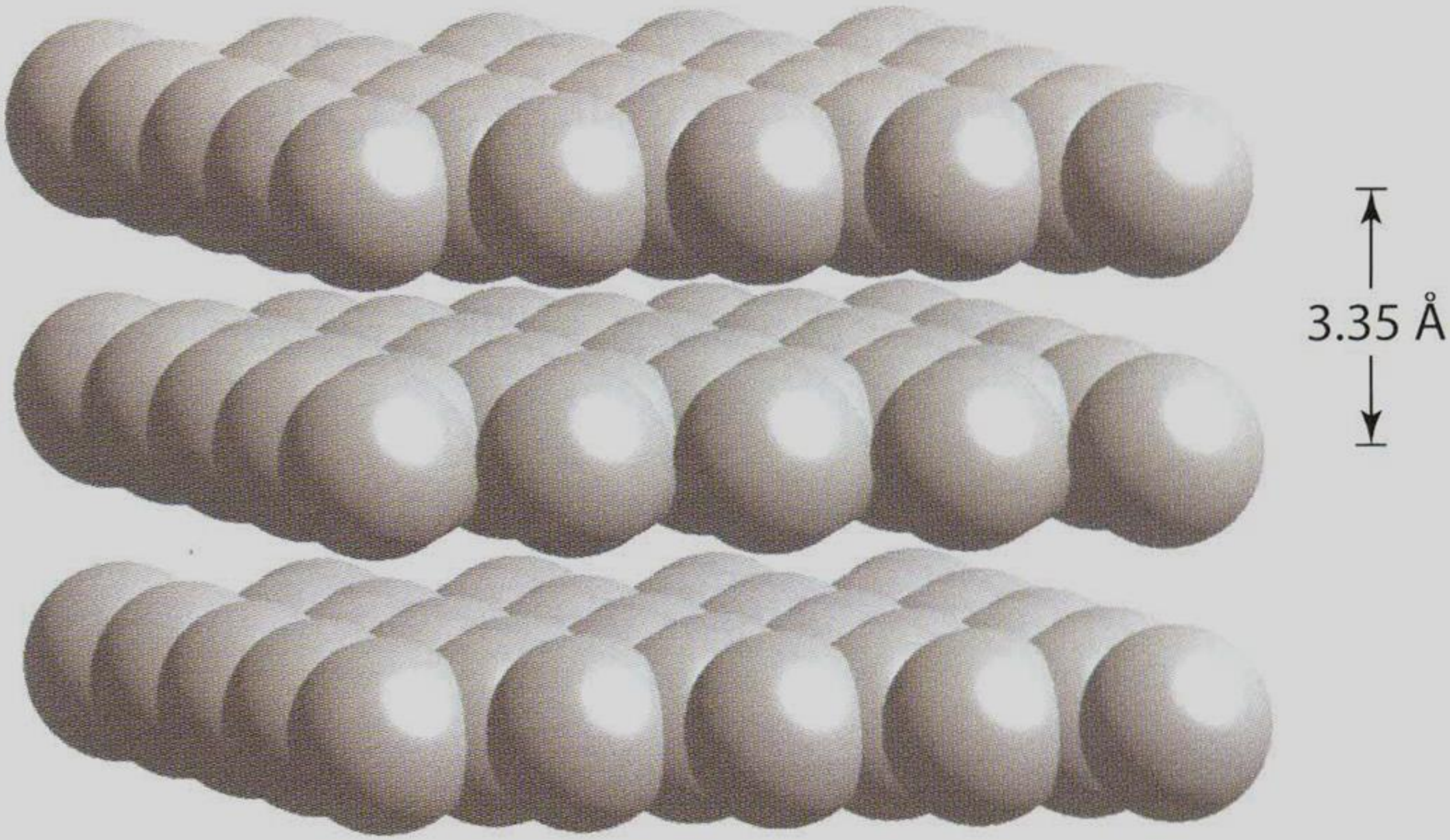


Figure 4.20 Perspective view of a close packed-structure representation of graphite. The spacing between successive layers is 3.35 Å.

Tendency to lose outermost electrons to uncover full outer shell

Tendency to lose electrons

Tendency to fill outer shell by sharing electrons

Tendency to gain electrons to make full outer shell

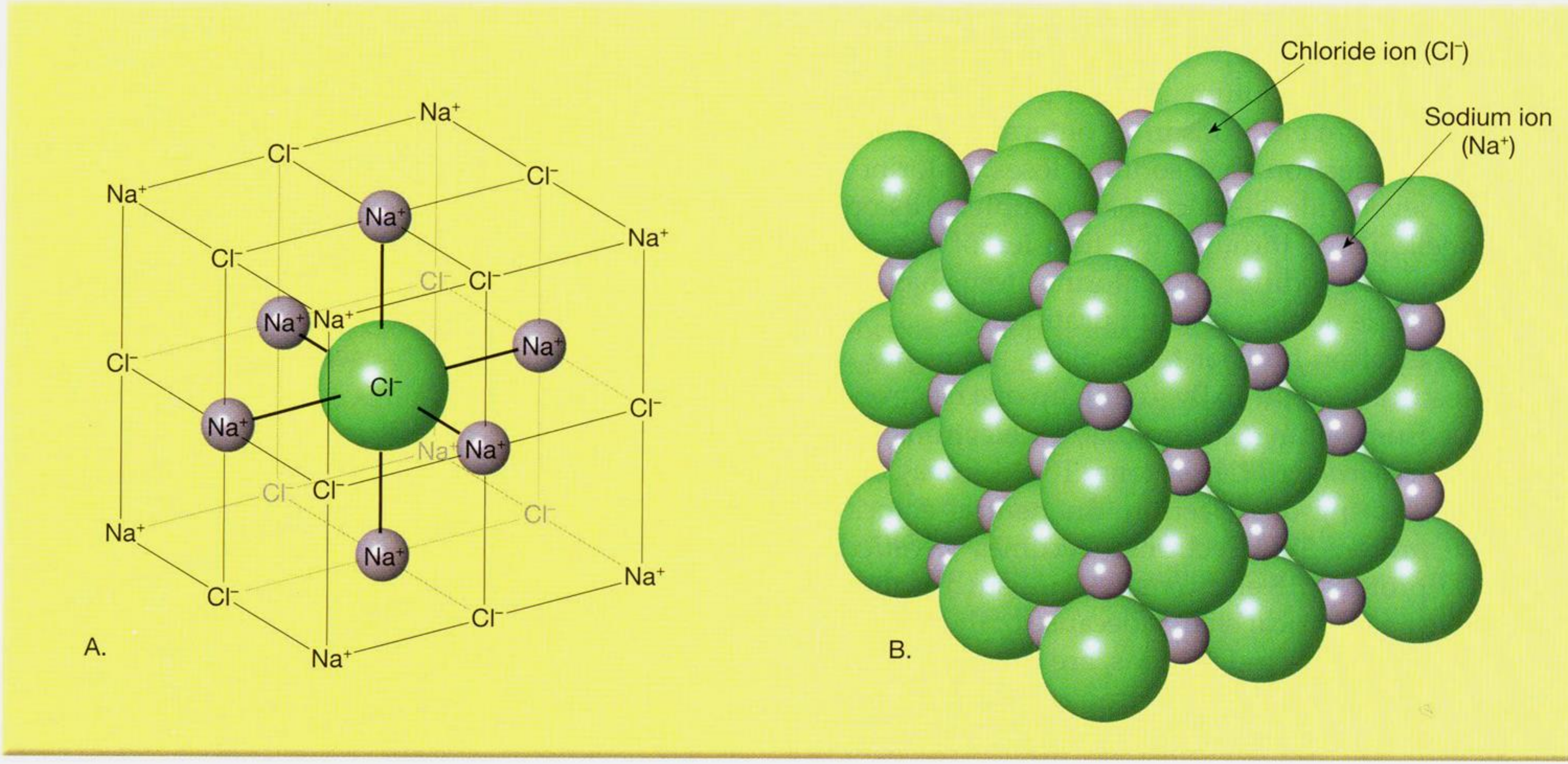
Noble gases (inert)

2	Atomic number
He	Symbol of element
4.003	Atomic weight
Helium	Name of element

Metals
Transition metals
Nonmetals
Noble gases
Lanthanide series
Actinide series

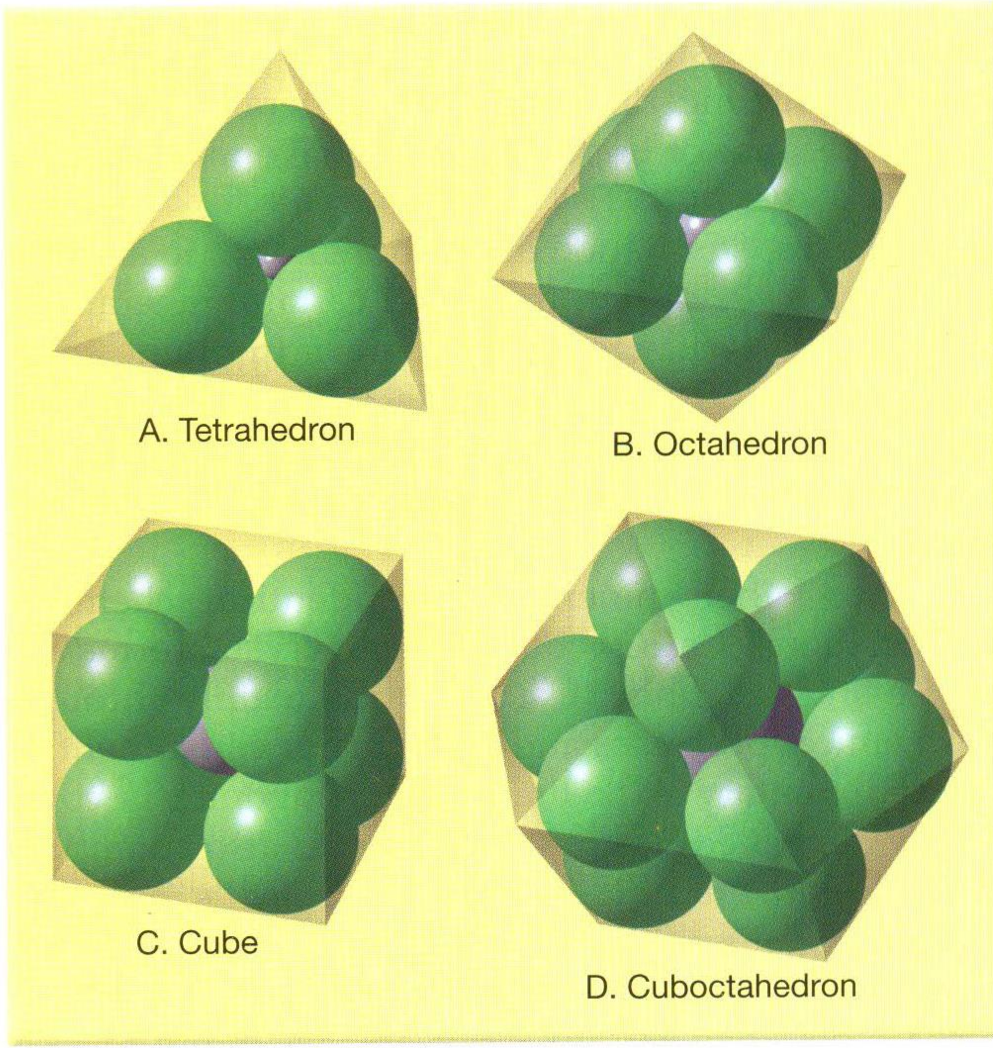
I A	II A	III B	IV B	V B	VI B	VII B	VIII B	VIII B	VIII B	I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1 H 1.0080 Hydrogen																	2 He 4.003 Helium
3 Li 6.939 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.011 Carbon	7 N 14.007 Nitrogen	8 O 15.9994 Oxygen	9 F 18.998 Fluorine	10 Ne 20.183 Neon
11 Na 22.990 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminum	14 Si 28.09 Silicon	15 P 30.974 Phosphorus	16 S 32.064 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
19 K 39.102 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.90 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.71 Nickel	29 Cu 63.54 Copper	30 Zn 65.37 Zinc	31 Ga 69.72 Gallium	32 Ge 72.59 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.909 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc (99) Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.90 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.87 Silver	48 Cd 112.40 Cadmium	49 In 114.82 Indium	50 Sn 118.69 Tin	51 Sb 121.75 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.30 Xenon
55 Cs 132.91 Cesium	56 Ba 137.34 Barium	#57 TO #71	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.85 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.09 Platinum	79 Au 197.0 Gold	80 Hg 200.59 Mercury	81 Tl 204.37 Thallium	82 Pb 207.19 Lead	83 Bi 208.98 Bismuth	84 Po (210) Polonium	85 At (210) Astatine	86 Rn (222) Radon
87 Fr (223) Francium	88 Ra 226.05 Radium	#89 TO #103															

57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (147) Promethium	62 Sm 150.35 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.92 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thullium	70 Yb 173.04 Ytterbium	71 Lu 174.97 Lutetium
89 Ac (227) Actinium	90 Th 232.04 Thorium	91 Pa (231) Protactinium	92 U 238.03 Uranium	93 Np (237) Neptunium	94 Pu (242) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (249) Berkelium	98 Cf (251) Californium	99 Es (254) Einsteinium	100 Fm (253) Fermium	101 Md (256) Mendelevium	102 No (254) Nobelium	103 Lw (257) Lawrencium



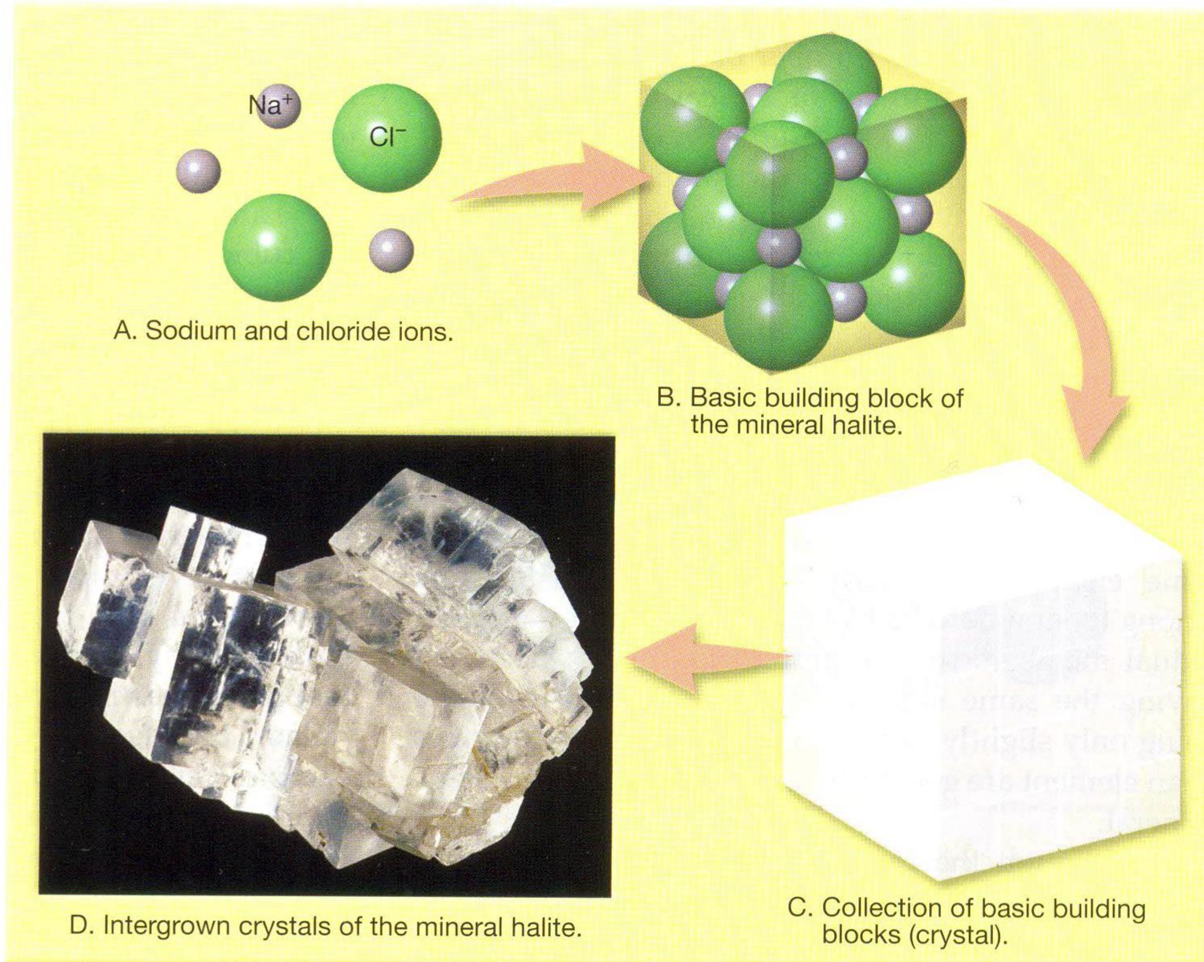
▲ **FIGURE 3.6** Schematic diagrams illustrating the arrangement of sodium and chloride ions in table salt. **A.** Structure has been opened up to show arrangement of ions. **B.** Actual ions are closely packed.

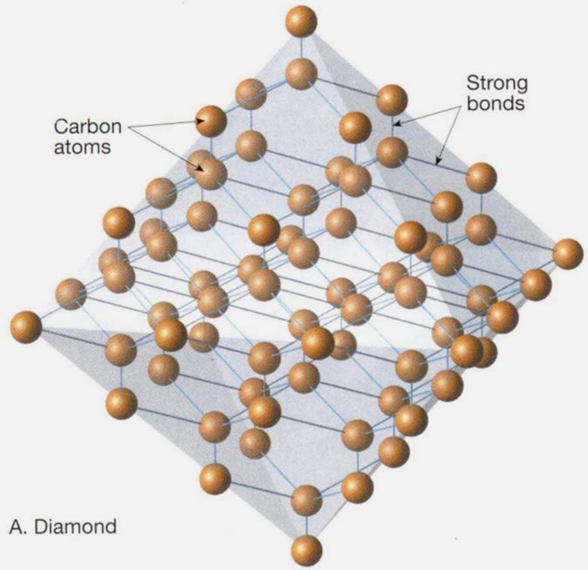
FIGURE 2.27 Aerial view of Bingham Canyon copper mine near Salt Lake City, Utah. Although the amount of copper in the rock is less than 1 percent, the huge volume of material removed and processed each day (about 200,000 tons) yields enough metal to be profitable. (Photo by Michael Collier)



▲ **FIGURE 3.8** Ideal geometrical packing for various-sized positive and negative ions.

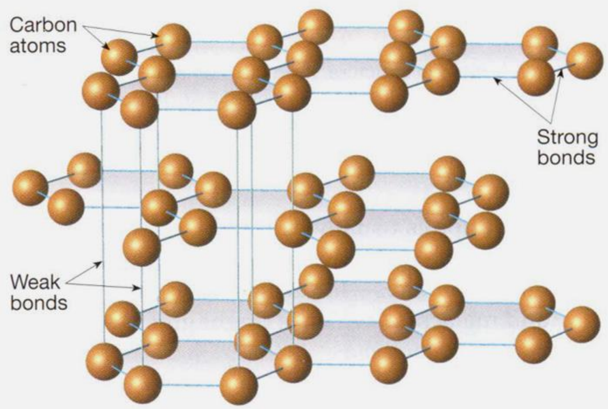
▶ **FIGURE 3.9** This diagram illustrates the orderly arrangement of sodium and chloride ions in the mineral halite. The arrangement of atoms into basic building blocks having a cubic shape results in regularly-shaped cubic crystals. (Photo by M. Claye/Jacana Scientific Control/Photo Researchers, Inc.)



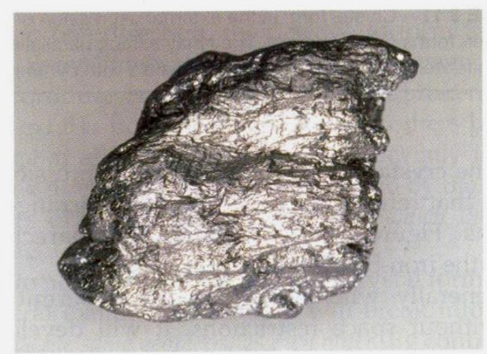


A. Diamond

Diamond



B. Graphite



Graphite

▲ **FIGURE 3.10** Comparing the structures of diamond and graphite. Both are natural substances with the same chemical composition—carbon atoms. Nevertheless, their internal structure and physical properties reflect the fact that each formed in a very different environment. **A.** All carbon atoms in diamond are covalently bonded into a compact, three-dimensional framework, which accounts for the extreme hardness of the mineral. (Photo courtesy of Smithsonian Institution) **B.** In graphite the carbon atoms are bonded into sheets that are joined in a layered fashion by very weak electrical forces. These weak bonds allow the sheets of carbon to readily slide past each other, making graphite soft and slippery, and thus useful as a dry lubricant. (**A.:** photographer Dane Pendland, courtesy of Smithsonian Institution; **B.:** E. J. Tarbuck)

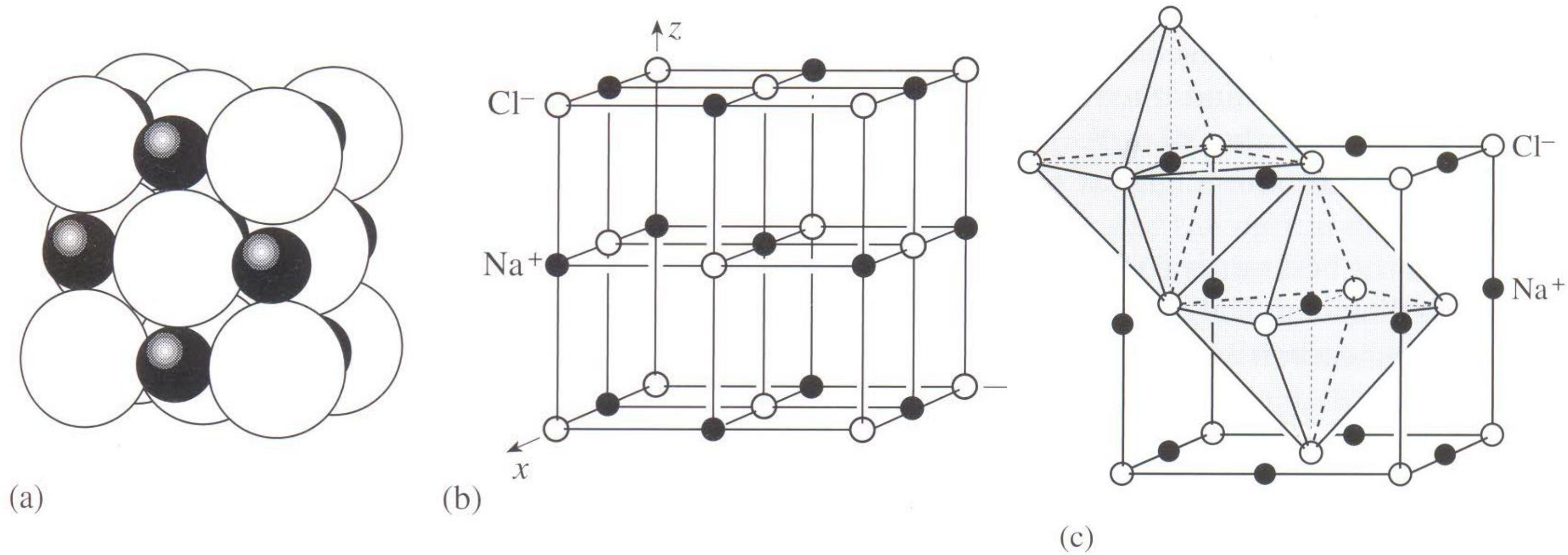


Fig. 2.10 (a) Structure of halite (NaCl) with alternating Na^+ (black) and Cl^- (white). (b) A cubic unit cell is outlined with Cl^- in the corners in a representation with reduced sizes of atoms. The structure can be viewed as a combination of two fcc structures that are translated. (c) Each Na^+ is surrounded by six Cl^- and we can display this relationship by drawing an octahedron (shaded), known as a coordination polyhedron.

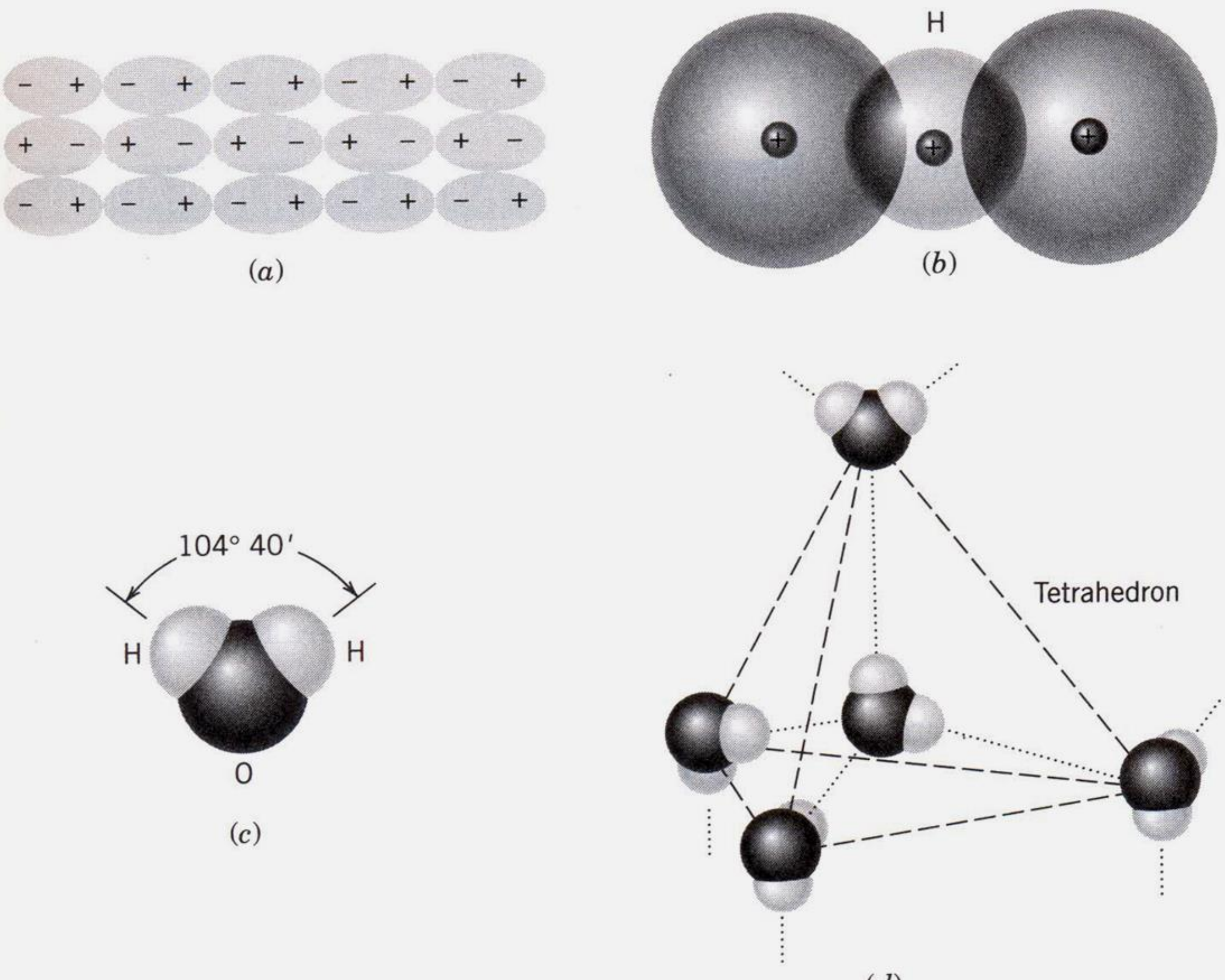


FIG. 3.26 (a) Schematic representation of the packing of polar molecules in a crystalline solid. Charges of opposite sign are arranged as closest neighbors. (b) Model of a hydrogen bond. (c) A water molecule and the bond angle between H–O–H. (d) Hydrogen bonding as shown by one of the polymorphs of ice. The coordination is tetrahedral and similar to that in diamond.

EARTH MATERIALS: MINERALS AND ROCKS

ELEMENTS

Elements of major abundance in Earth's crust

Elements of lesser abundance but of major geologic importance

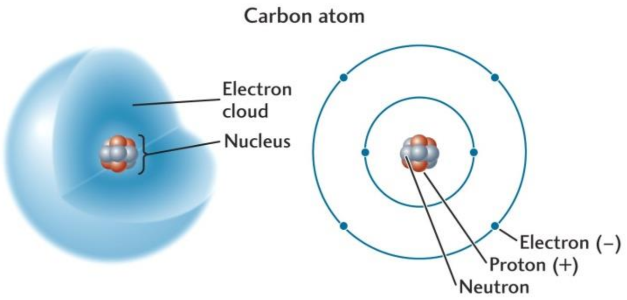
Carbon 6 C 12.011 — Element name, Atomic number, Symbol, Atomic mass

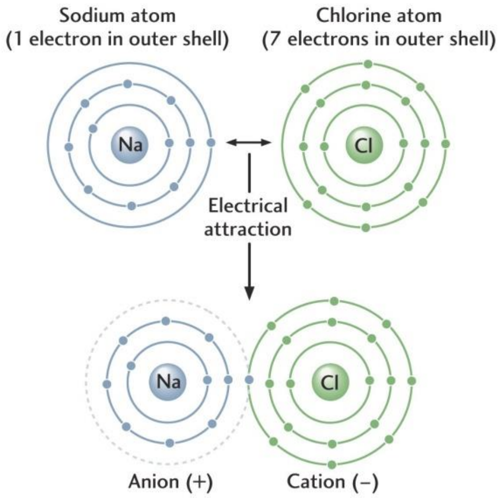
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hydrogen 1 H 1.0079																	Helium 2 He 4.0026
Lithium 3 Li 6.941	Beryllium 4 Be 9.0122											Boron 5 B 10.811	Carbon 6 C 12.011	Nitrogen 7 N 14.0067	Oxygen 8 O 15.9994	Fluorine 9 F 18.9984	Neon 10 Ne 20.1797
Sodium 11 Na 22.9898	Magnesium 12 Mg 24.3050											Aluminum 13 Al 26.9815	Silicon 14 Si 28.0855	Phosphorus 15 P 30.9738	Sulfur 16 S 32.066	Chlorine 17 Cl 35.4527	Argon 18 Ar 39.948
Potassium 19 K 39.0983	Calcium 20 Ca 40.078	Scandium 21 Sc 44.9559	Titanium 22 Ti 47.867	Vanadium 23 V 50.9415	Chromium 24 Cr 51.9961	Manganese 25 Mn 54.9380	Iron 26 Fe 55.845	Cobalt 27 Co 58.9332	Nickel 28 Ni 58.6934	Copper 29 Cu 63.546	Zinc 30 Zn 65.39	Gallium 31 Ga 69.723	Germanium 32 Ge 72.61	Arsenic 33 As 74.9216	Selenium 34 Se 78.96	Bromine 35 Br 79.904	Krypton 36 Kr 83.80
Rubidium 37 Rb 85.4678	Strontium 38 Sr 87.62	Yttrium 39 Y 88.9059	Zirconium 40 Zr 91.224	Niobium 41 Nb 92.9064	Molybdenum 42 Mo 95.94	Technetium 43 Tc (97.907)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.9055	Palladium 46 Pd 106.42	Silver 47 Ag 107.8682	Cadmium 48 Cd 112.411	Indium 49 In 114.818	Tin 50 Sn 118.710	Antimony 51 Sb 121.760	Tellurium 52 Te 127.60	Iodine 53 I 126.9045	Xenon 54 Xe 131.29
Cesium 55 Cs 132.9054	Barium 56 Ba 137.327	Lanthanum 57 La 138.9055	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.9479	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.2	Iridium 77 Ir 192.22	Platinum 78 Pt 195.08	Gold 79 Au 196.9665	Mercury 80 Hg 200.59	Thallium 81 Tl 204.3833	Lead 82 Pb 207.2	Bismuth 83 Bi 208.9804	Polonium 84 Po (208.98)	Astatine 85 At (209.99)	Radon 86 Rn (222.02)
Francium 87 Fr (223.02)	Radium 88 Ra (226.0254)	Actinium 89 Ac (227.0278)	Rutherfordium 104 Rf (261.11)	Dubnium 105 Db (262.11)	Seaborgium 106 Sg (263.12)	Bohrium 107 Bh (262.12)	Hassium 108 Hs (265)	Meitnerium 109 Mt (266)			Ununbium 112 Uub (277)						

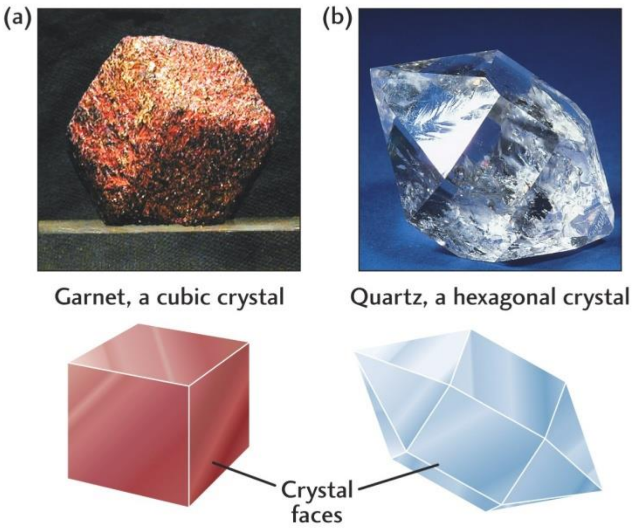
Cerium 58 Ce 140.115	Praseodymium 59 Pr 140.9076	Neodymium 60 Nd 144.24	Promethium 61 Pm (144.91)	Samarium 62 Sm 150.36	Europium 63 Eu 151.965	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.9253	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.9303	Erbium 68 Er 167.26	Thulium 69 Tm 168.9342	Ytterbium 70 Yb 173.04	Lutetium 71 Lu 174.967
Thorium 90 Th 232.0381	Protactinium 91 Pa 231.0388	Uranium 92 U 238.0289	Neptunium 93 Np (237.0482)	Plutonium 94 Pu (244.664)	Americium 95 Am (243.061)	Curium 96 Cm (247.07)	Berkelium 97 Bk (247.07)	Californium 98 Cf (251.08)	Einsteinium 99 Es (252.08)	Fermium 100 Fm (257.10)	Mendelevium 101 Md (258.10)	Noblelium 102 No (259.10)	Lawrencium 103 Lr (262.11)

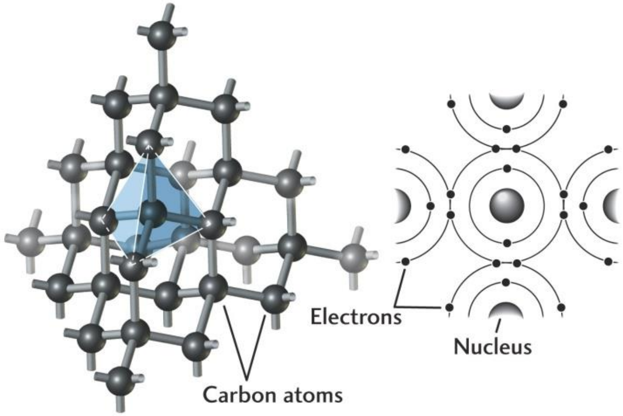
CRYSTALS

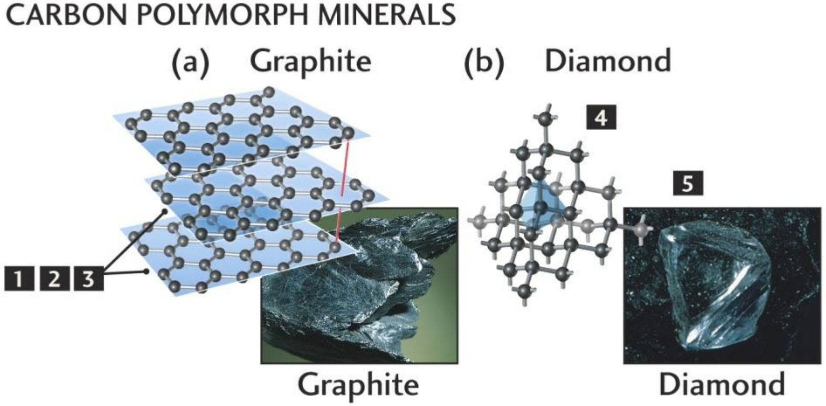
Atoms => Ions (cations/anions) => Molecules => Crystals/Crystalline solid => Minerals











MINERALS

A Mineral:

- is natural
- is inorganic
- is structurally homogeneous solid with definite crystalline structure
- has a well-defined regular internal arrangement of its constituent particles
- has a definite chemical composition which can be expressed by a chemical formula
- has a definite set of physical properties that are fixed within certain limits.

Groups of Minerals

- ***Native elements***-such as gold, silver, copper, iron, platinum, sulphur, diamond, etc.
- ***Sulphates*** - whose basic unit is $(SO_4)^{2-}$, such as gypsum, barite, etc.
- ***Oxides*** - whose basic unit is O^{2-}, such as magnetite, hematite, etc.
- ***Carbonates***- whose basic unit is $(CO_3)^{2-}$, such as calcite, dolomite, magnesite, etc.
- ***Halides***- such as halite, fluorite, sylvite, etc.
- ***Sulphides***- such as pyrite, galena, sphalerite, etc.
- ***Phosphates***- whose basic unit is $(PO_4)^{3-}$, such as apatite, etc.
- ***Arsenides***- such as realgar, orpiment, etc.
- ***Silicates***- whose basic unit is $(SiO_4)^{4-}$, such as quartz, pyroxene, amphibole, etc.

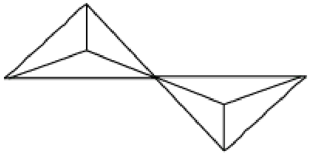
Silicates = Most important rock-forming minerals = Most abundant

Element	O	Si	Al	Fe	Ca	Na	Mg	K	Total	Others
Abundance (Wt. %)	46.40	28.15	8.23	5.63	4.15	2.36	2.33	2.09	99.34	0.66

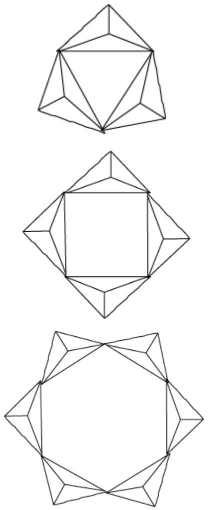
SILICATES/ROCK-FORMING MINERALS

Silicate Structures

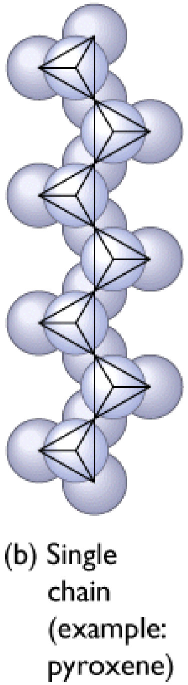
Nesosilicate



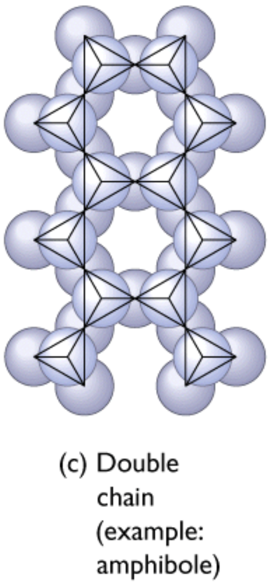
Sorosilicate



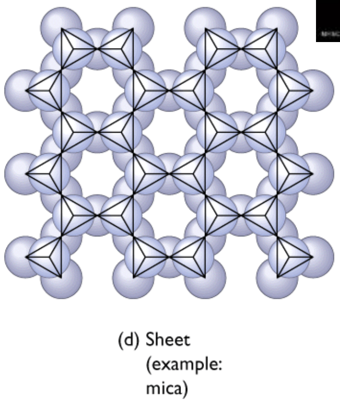
Cyclosilicate



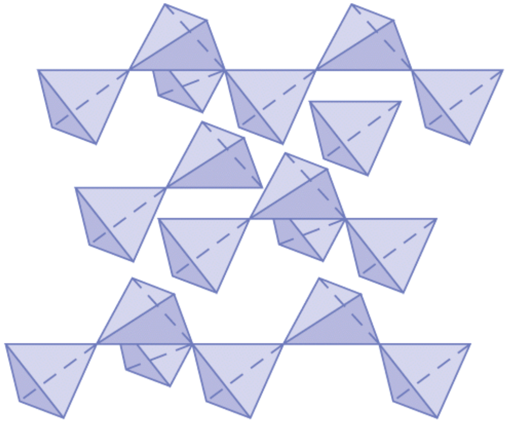
Single-chain Inosilicate



Double-chain Inosilicate

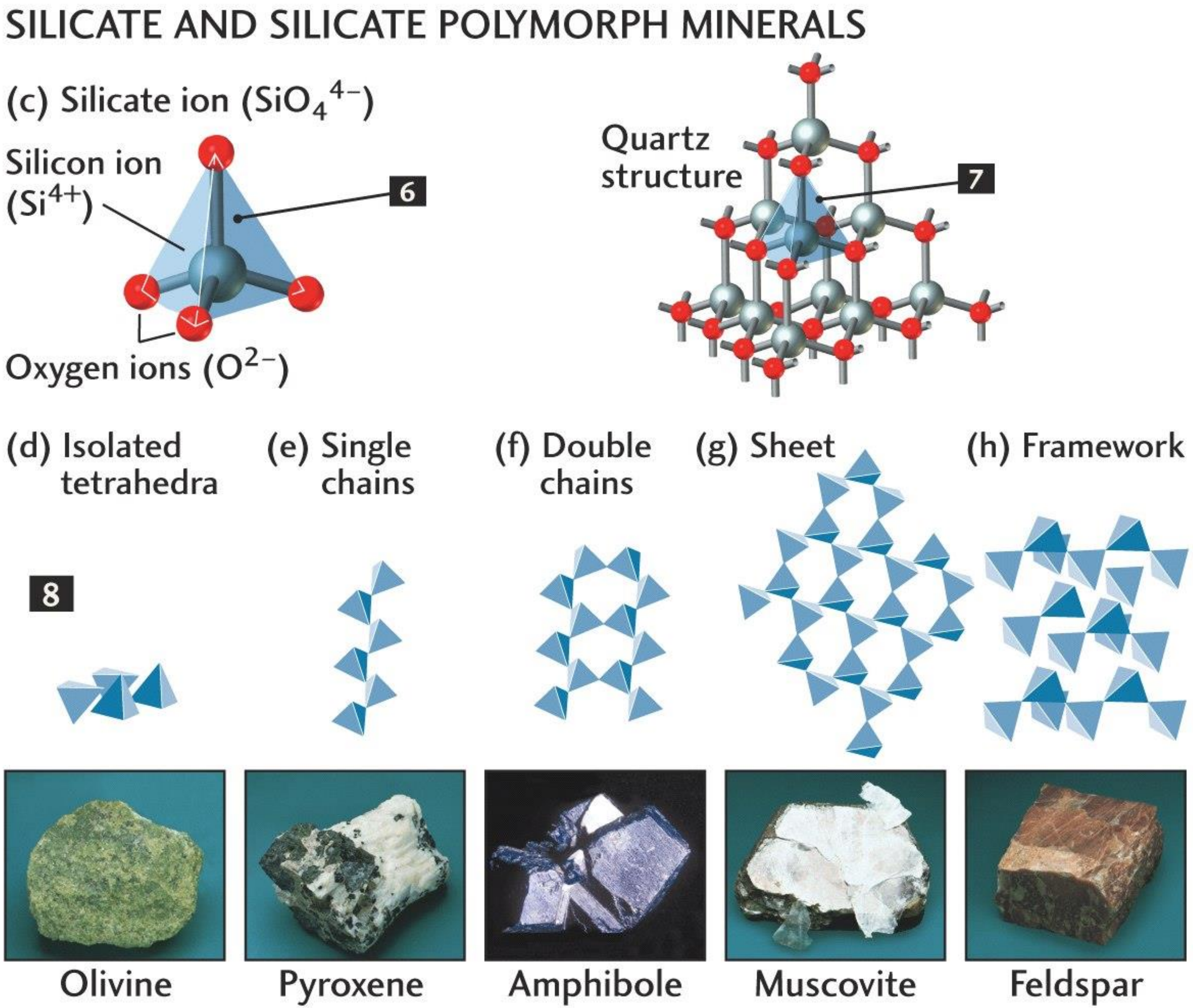


Phyllosilicate (Sheet silicate)

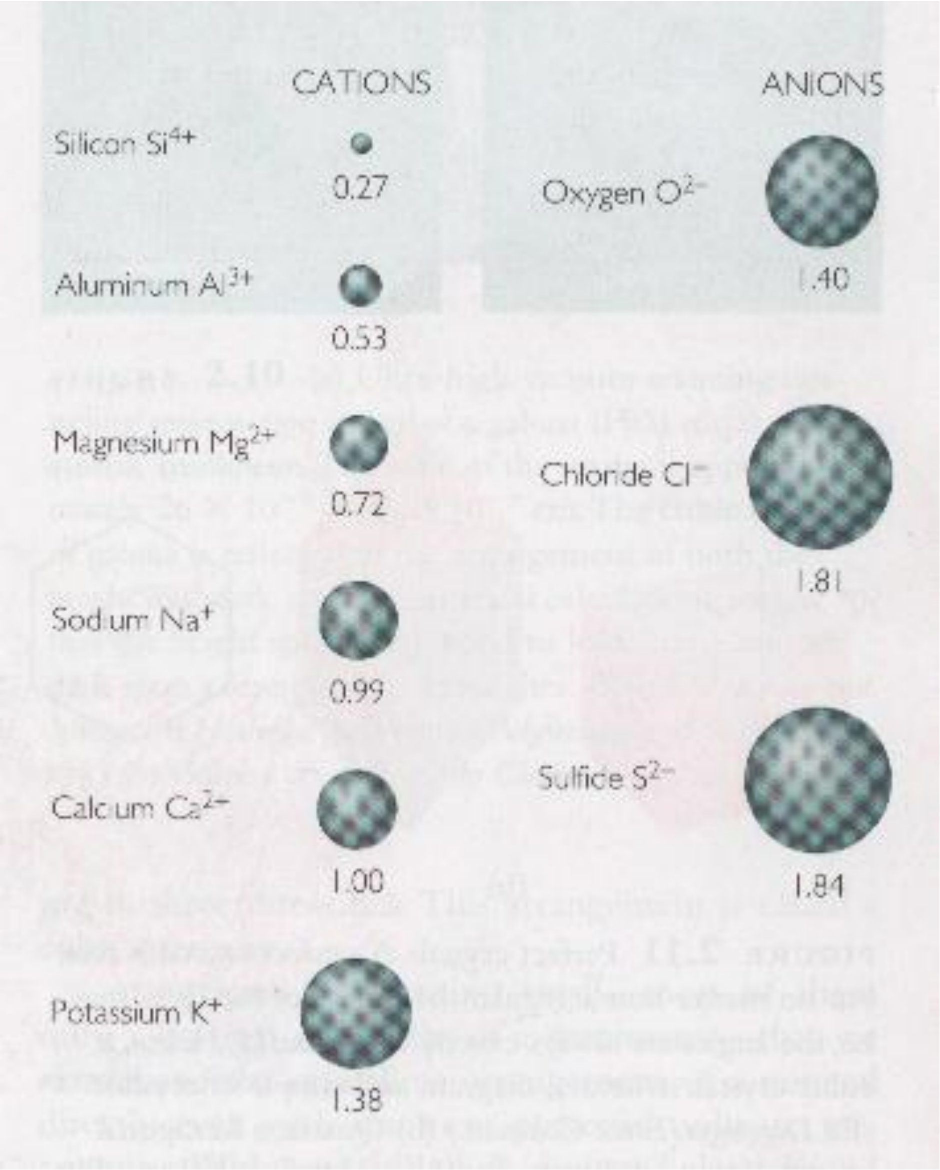


Tektosilicate (Framework silicate)

Groups of Silicate Minerals



IONIC SIZES



IONIC RADII ARE IN 10^{-8} cm

ACCORDING TO GOLDSCHMIT GEOCHEMICAL RULES ATOMS MAY REPLACE ONE ANOTHER IN A MINERAL BECAUSE OF:

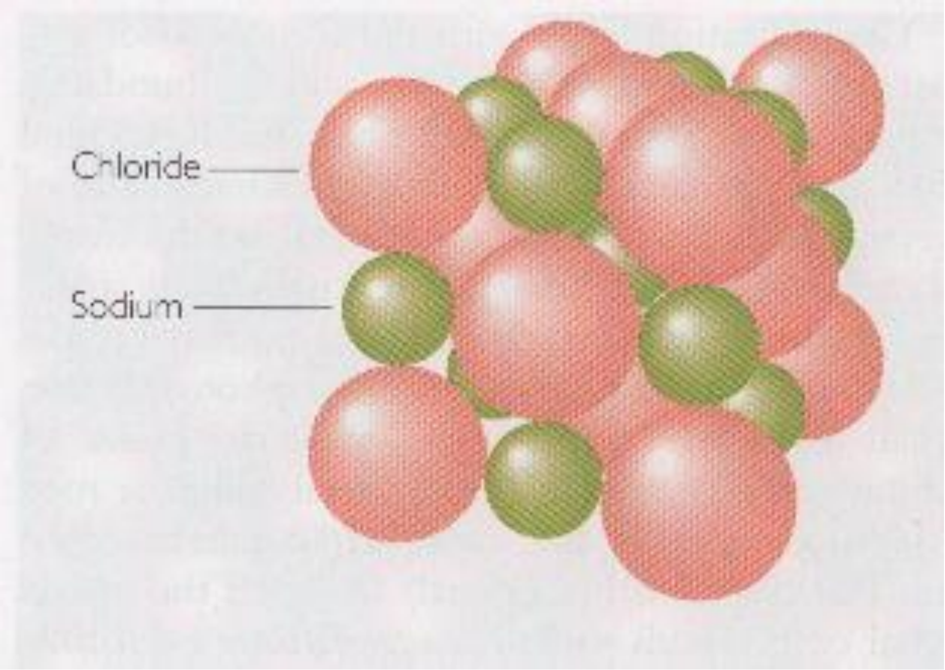
SIMILAR SIZE

SIMILAR CHARGE

E.G. SODIUM & POTASSIUM IN A MINERAL WILL REPLACE EACH OTHER DUE TO THEIR SIMILAR SIZE AND CHARGE

THE IONIC SIZE ALSO DETERMINES THE PACKING OF IONS & THE COORDINATION NUMBER = NUMBER OF ANIONS AROUND A CATION

THE PACKING OF ATOMS IN SODIUM CHLORIDE



CATION SUBSTITUTION

- SAME CRYSTAL STRUCTURE BUT DIFFERENT CHEMICAL COMPOSITION
- CATIONS WITH SIMILAR SIZES & CHARGES SUBSTITUTE FOR ONE ANOTHER & FORM MINERALS WITH THE SAME CRYSTAL STRUCTURE BUT DIFFERENT COMPOSITION
- CATION SUBSTITUTION IS COMMON IN SILICATE MINERALS E.G. OLIVINE
- Fe & Mg HAVE SIMILAR SIZES & CHARGES & SUBSTITUTE FOR EACH OTHER IN OLIVINE $(Mg,Fe)_2SiO_4$
- Si & Al HAVE SIMILAR SIZE & CHARGE & SUBSTITUTE FORM EACH OTHER IN MANY SILICATE MINERALS

MINERAL CLASSIFICATION

- Minerals are classified on the basis of their chemical composition i.e. on the ANIONIC part of the composition e.g. Calcite is classified as a CARBONATE because of the carbonate anion (CO_3^{2-})
- There are 8 mineral classes.

MINERAL CLASSES

- 1. **Native Elements** (repeated atoms of one element e.g.
- C,Cu) e.g. diamond, copper etc
- 2. **<u>Carbonates</u>** (CO_3^{2-}) e.g. calcite
- 3. **Halides** (Cl-, F- etc) e.g. Halite or rock salt (NaCl), fluorite
- (CaF_2)
- 4. **<u>Sulphides</u>** (S^{2-}) e.g. pyrite (FeS_2)
- 5. **Sulphates** (SO_4^{2-}) e.g. anhydrite ($CaSO_4$)
- 6. **<u>Oxides</u>** (O^{2-})/ Hydroxides (OH^-) e.g. magnetite (Fe_3O_4),
- brucite ($Mg[OH]_2$)
- 7. **Phosphates** (PO_4^{2-}) e.g. apatite ($Ca_5[PO_4]_3(F,Cl,OH)$)
- 8. **<u>Silicates</u>** ($[SiO_4]^{4-}$) e.g. amethyst (SiO_2), beryl
- ($Be_3Al_2\{Si_6O_{18}\}$) etc

Other classifications

There are, however, alternate classifications, such as those proposed by Liebau (1985) and Zoltai (1960).

Next to O and Si, the most important constituent of the crust is Al. Al^{3+} has a radius of 0.39 A and the radius ratio A1:0 = 0.286, corresponding to 4-coordination with oxygen.

This radius ratio is sufficiently close to the upper limit for 4-coordination so that 6-coordination is also possible.

It is this capacity for playing a double role in silicate minerals that gives Al,$^{+}$ its significance in the crystal chemistry of the silicates.

When Al coordinates four Os arranged at the apices of a regular tetrahedron, the resultant grouping occupies approximately the same space as a silicon-oxygen tetrahedron and may link with silicon tetrahedra in polymerized groupings.

On the other hand, Al^{3+} in 6-coordination serves to link the tetrahedral groupings through simple ionic bonds, weaker than those that unite the ions in the tetrahedra.

It is, thus, possible to have Al in silicate structures both in the tetrahedral sites, substituting for Si, and in the octahedral sites with 6-coordination, involved in solid solution with elements, such as Mg^{2+} and Fe^{2+}.

MINERALS

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LECTURES, 2004

MINERALOGY

- A geological science dealing with the study of minerals using both physical and optical characteristics
- Over 2000 minerals are known to exists although only about 30 are commonly encoutered

WHAT IS A MINERAL?

- A mineral is a naturally occuring, neutral, solid, inorganic substance that is crystalline, has a fixed chemical composition and a regular atomic arrangement.
- Minerals singularly or collectively are the building blocks of rocks.

VALUE OF MINERALS

- **Aesthetic value (beauty)** e.g. gemstones
- **Value as an ore (metal source)** e.g. bornite (Cu), galena (Pb), sphalerite (Zn), cassiterite (Sn), beryl (Be) etc.
- **Unique structural pattern** e.g. the value of diamond (whether for adornment or as an abrassive lies in its hardness) & of graphite, the other form of carbon, whether as a lubricant or as a lead-pencil, depends on it softness.

ATOMS

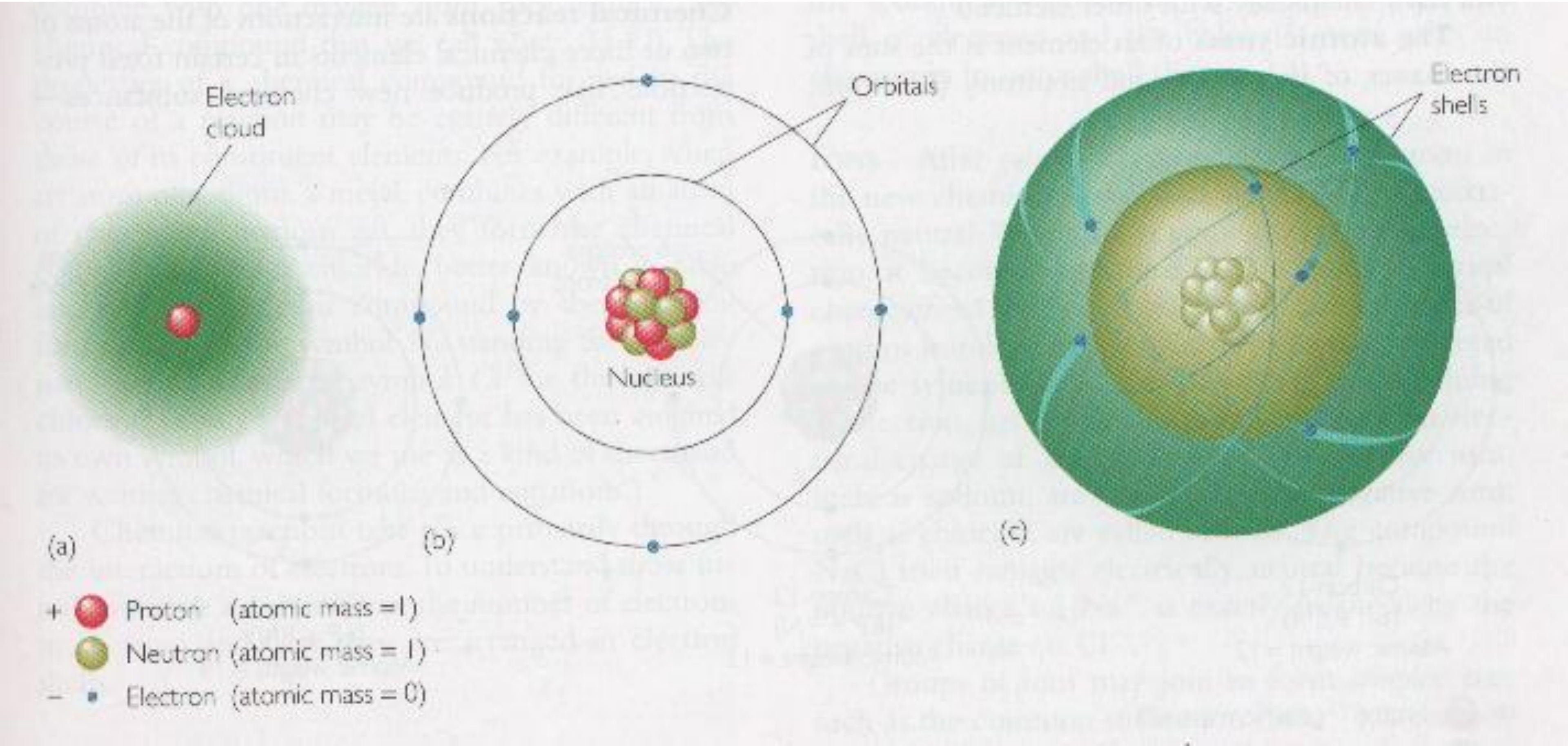
- MINERALS ARE COMPOSED OF ELEMENTS (E.G. Fe, Cu; C, Zn ETC), WHICH IN TURN ARE MADE UP OF ATOMS
- ATOM WAS IN THE EARLY DAYS CONSIDERED AS THE SMALLEST POSSIBLE UNIT OF ANY MATERIAL (NOT TRUE NOW)
- TO ANCIENT GREEKS AN ATOM WAS INDIVISIBLE (*ATOMOS*)
- JOHN DALTON (1766-1844; FATHER OF MODERN ATOMIC THEORY) DEFINED ATOMS AS PARTICLES OF MATTER THAT WERE SO SMALL THAT THEY COULD NOT BE SEEN WITH ANY MICROSCOPE & SO UNIVERSAL THAT THEY CONSTITUTED ALL SUBSTANCES
- AN ATOM TODAY IS DEFINED AS THE SMALLEST UNIT OF ANY ELEMENT THAT RETAINS THE PHYSICAL & CHEMICAL PROPERTIES OF THAT ELEMENT; ATOMS ARE THE SMALL UNITS OF MATTER THAT COMBINE IN CHEMICAL REACTIONS; ATOMS ARE DIVISIBLE INTO SMALLER UNITS (PROTONS, NEUTRONS & ELECTRONS)

ATOMIC STRUCTURE

AN ATOM IS COMPOSED OF A NUCLEUS AND A CLOUD OF ELECTRONS AROUND

NUCLEUS = PROTONS (POSITIVELY CHARGED PARTICLES)+ NEUTRONS (NEUTRALLY CHARGED PARTICLES); ELECTRONS ARE NEGATIVELLY CHARGED

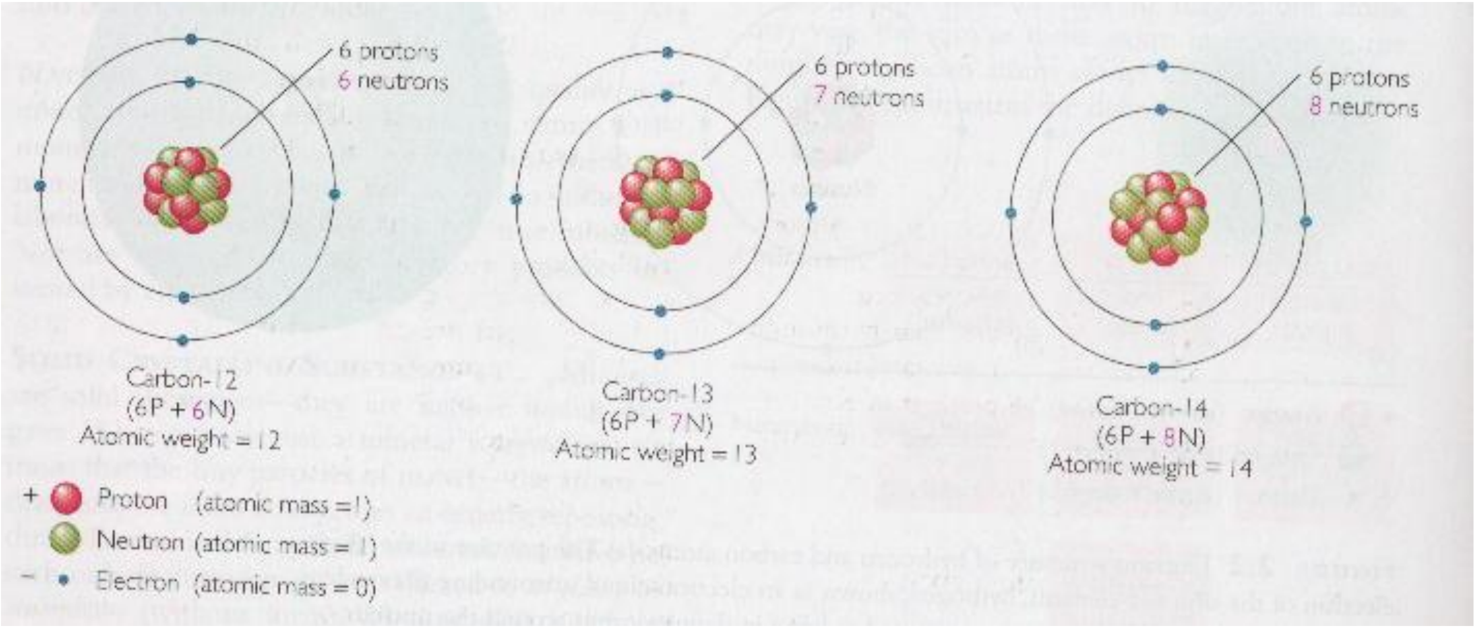
ATOMS OF THE SAME ELEMENT HAVE A CONSTANT NUMBER OF PROTONS & A VARYING NUMBER OF NEUTRONS; ELEMENTS HAVE DIFFERENT ISOTOPES



ATOMIC STRUCTURE

- PROTON HAS AN ATOMIC MASS UNIT OF 1
- NEUTRON HAS AN ATOMIC MASS UNIT OF 1
- ELECTRON HAS AN ATOMIC MASS UNIT OF 0
- ATOMIC MASS UNIT = 1/12 OF THE ACTUAL MASS OF A CARBON ATOM WITH MASS NUMBER 12 (ABOUT $1.6604 X 10^{-24}$ grams)
- ATOMIC NUMBER = NUMBER OF PROTONS
- ATOMIC MASS = SUM OF MASSES OF PROTONS & NEUTRONS
- ALTHOUGH THE NUMBER OF PROTONS IS CONSTANT, ATOMS OF THE SAME ELEMENT MAY HAVE DIFFERENT NUMBERS OF NEUTRONS & THUS DIFFERENT ATOMIC MASSES. THESE VARIOUS ATOMS ARE CALLED **ISOTOPES**
- **ISOTOPES OF CARBON ALL WITH 6 PROTONS EXIST WITH 6, 7, & 8 NEUTRONS GIVING ATOMIC MASSES OF 12, 13 & 14**

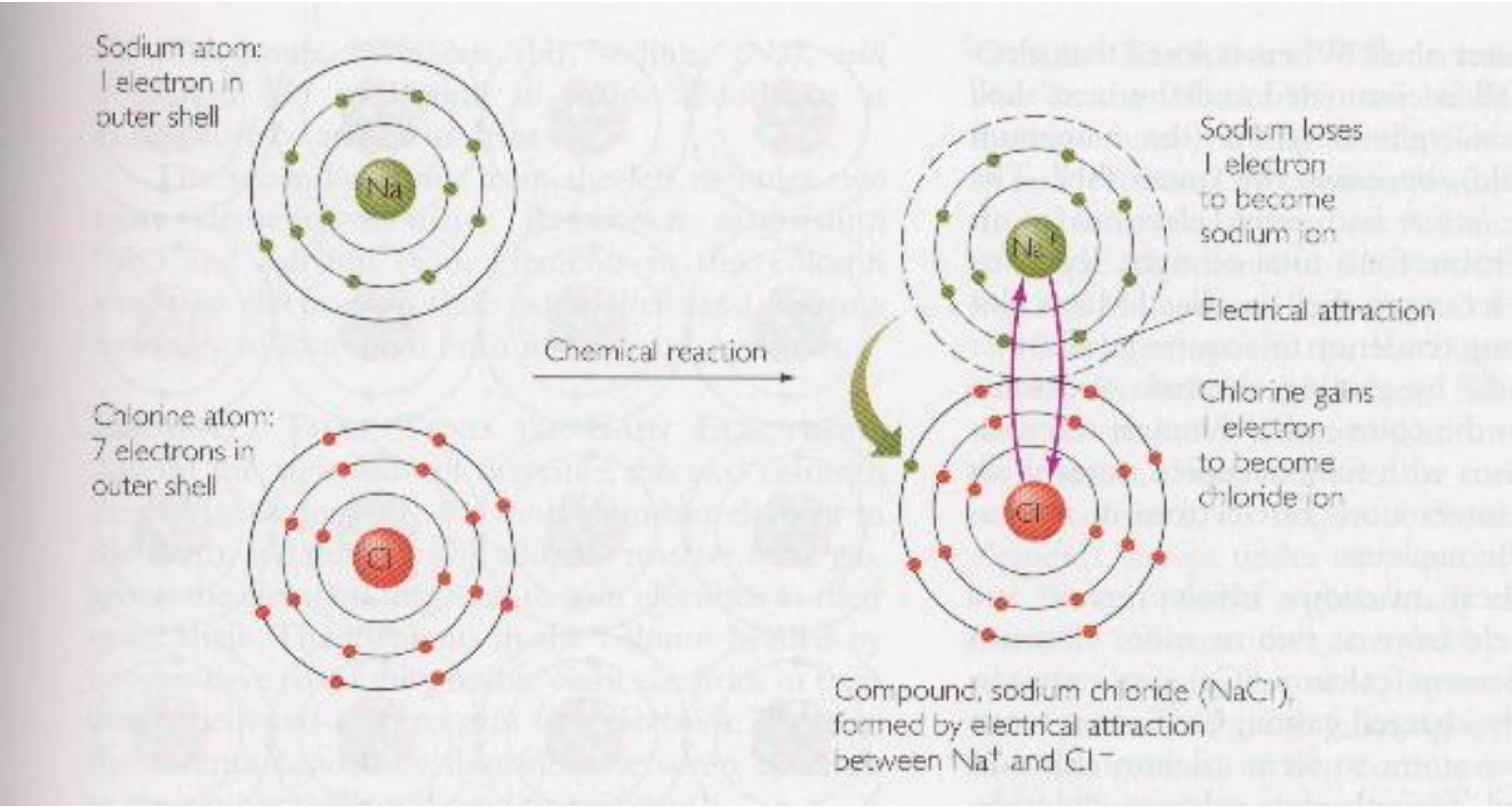
ISOTPOPES OF THE CARBON ELEMENT



CHEMICAL REACTIONS

- INTERACTIONS OF ATOMS OF TWO OR MORE ELEMENTS IN FIXED PROPORTIONS PRODUCE NEW CHEMICAL SUBSTANCES – CHEMICAL COMPOUNDS
- E.G. A COMPOUND CALLED WATER FORMS WHEN TWO HYDROGEN & ONE OXYGEN ATOMS COMBINE; THE MINERAL PYRITE IS COMPOUND OF Fe & S (FeS_2)
- CHEMICAL REACTIONS OCCUR THROUGH INTERACTIONS OF ELECTRONS

CHEMICAL REACTIONS



FORMATION OF COMMON SALT

LECTURES, 2004

CHEMICAL REACTIONS

- 1 FACILITATED BY ATOMS GAINING OR LOSING ELECTRONS OR BY ATOMS SHARING THEIR ELECTRONS
- E.G. IN THE REACTION BETWEEN Na (EXPLOSIVE WHEN EXPOSED IN AIR) & Cl (HIGHLY POISONOUS GAS) TO FORM NaCl (SODIUM CHLORIDE) THE Na ATOM LOSES AN ELECTRON TO BECOME A CATION (POSITIVELY CHARGED ION) & Cl GAINS AN ELECTRON TO BECOME AN ANION (NEGATIVELY CHARGED ION) & THE FORMED COMPOUND IS NEUTRAL & EDIBLE.
- ELEMENTS THAT TEND TO LOSE ELECTRONS ARE IN THE FIRST & SECOND COLUMNS OF THE PERIODIC TABLE
- ELEMENTS THAT TEND TO GAIN ELECTRONS ARE THOSE IN COLUMNS HEADED BY OXYGEN & FLUORINE
- ELEMENTS IN COLUMNS 3 TO 15 OF THE PERIODIC TABLE HAVE VARYING TENDENCIES TO GAIN, LOSE OR SHARE ELECTRONS
- ELEMENTS IN THE LAST COLUMN HAVE NO TENDENCY TO LOSE, GAIN OR SHARE ELECTRONS BECAUSE THEIR OUTER SHELLS ARE FULL (NOBLE ELEMENTS)

CHEMICAL REACTIONS

- WHEN AN ATOM LOSES ELECTRONS ITS SIZE DECREASES WHILE THE ATOM GAINING ELECTRONS INCREASES IN SIZE.

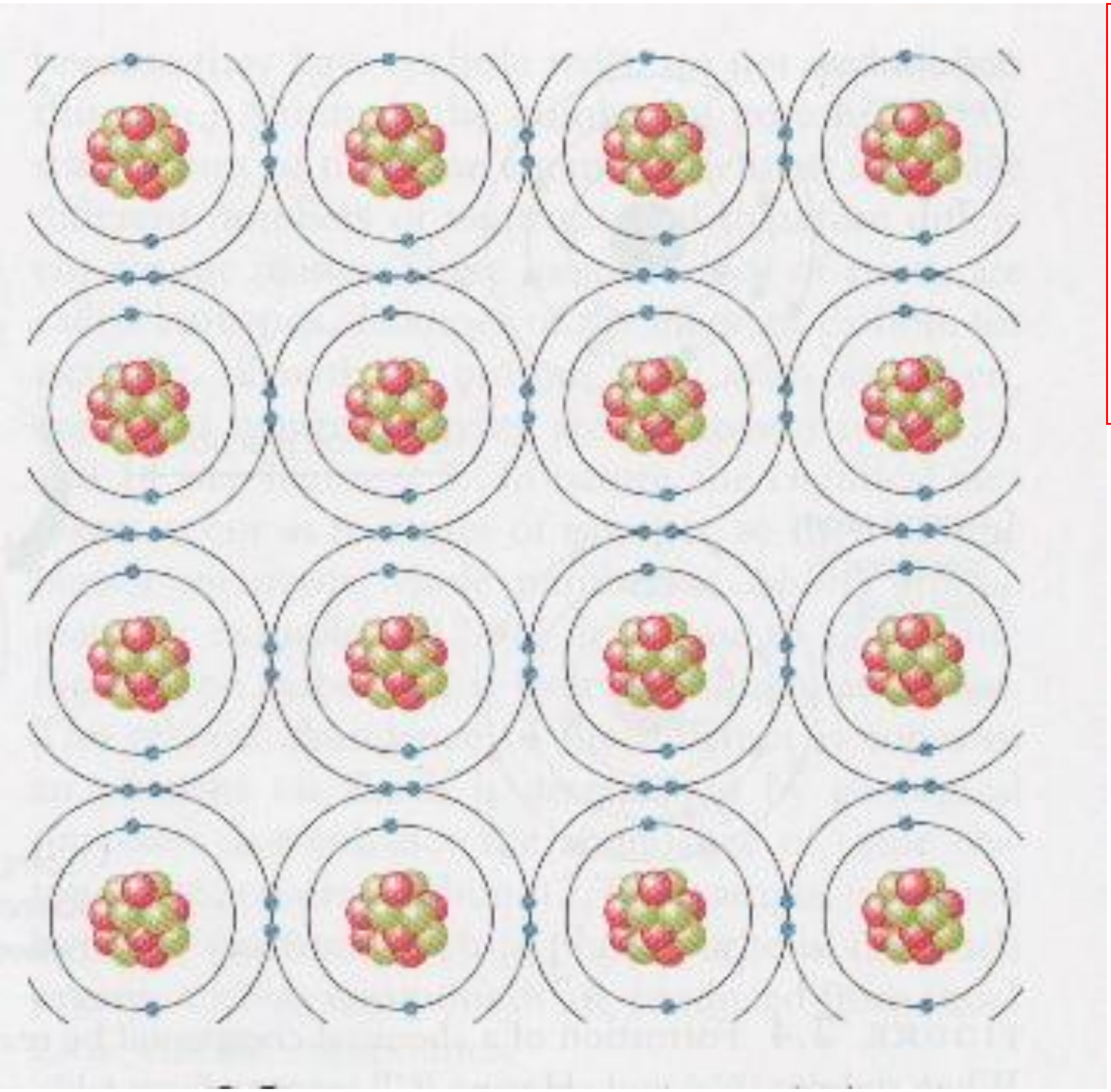
- WHY?

- THROUGH LOSING & GAINING ELECTRONS EACH ATOM ATTAINS A STABLE ATOMIC CONFIGURATION

CHEMICAL REACTIONS

- 2. SOME REACTIONS ARE FACILITATED BY SHARING OF ELECTRONS SO THAT EACH ATOM GAINS A STABLE CONFIGURATION
- ELECTRON SHARING MAY OCCUR AMONG ATOMS OF THE SAME ELEMENT OR AMONG ATOMS OF DIFFERENT ELEMENTS

CHEMICAL REACTIONS



ELECTRON SHARING IN DIAMOND WHOSE CHEMICAL ELEMENT IS CARBON; ONE OF EACH OF THE SIX ELECTRONS IN THE OUTERMOST SHELL OF EACH ATOM IS SHARED

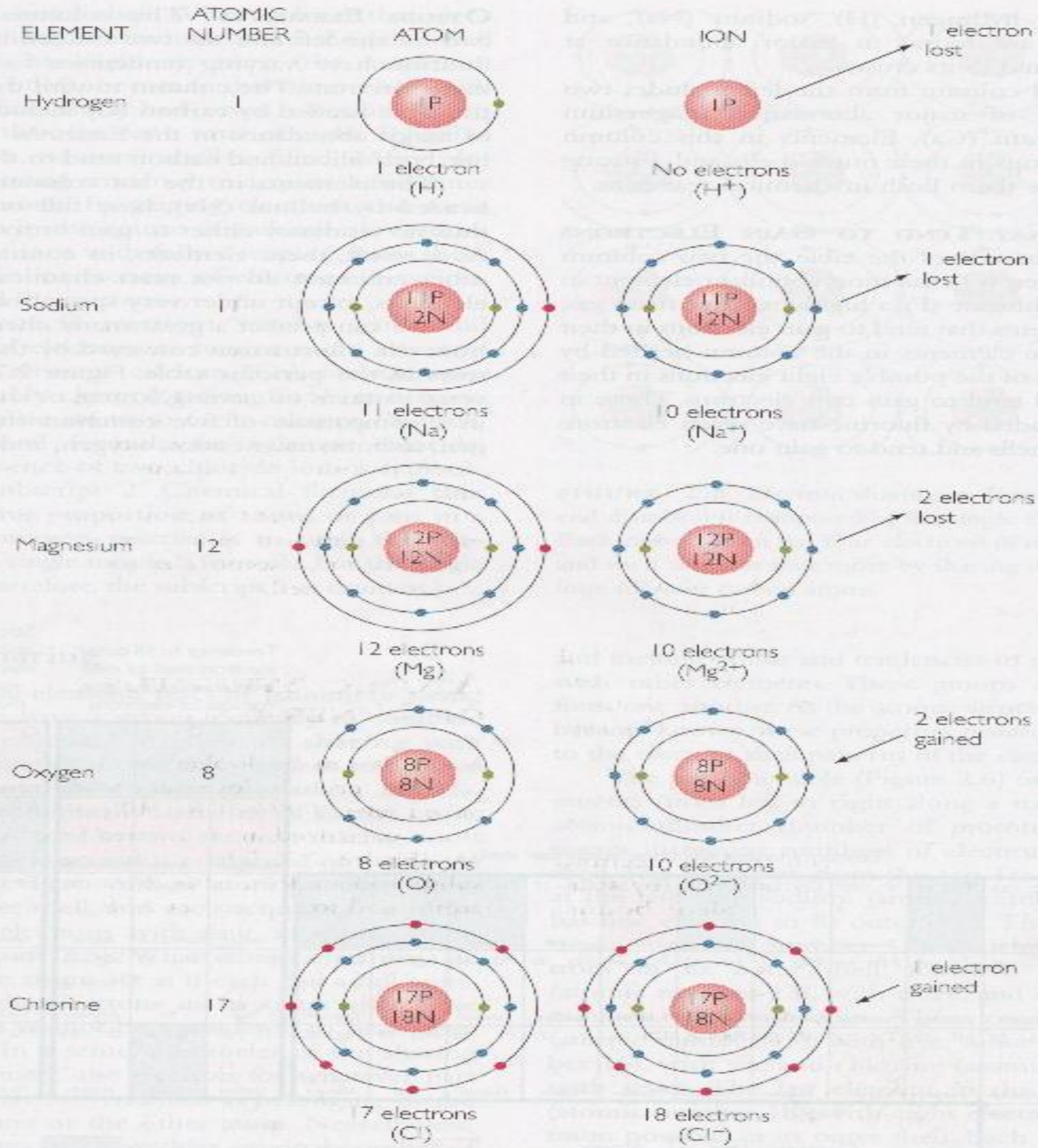


FIGURE 2.7 These models of the atoms and ions of five common elements illustrate the diversity of electron shells. Ions are formed as electrons are gained or lost from outer shells. (P stands for proton, N for neutron.)

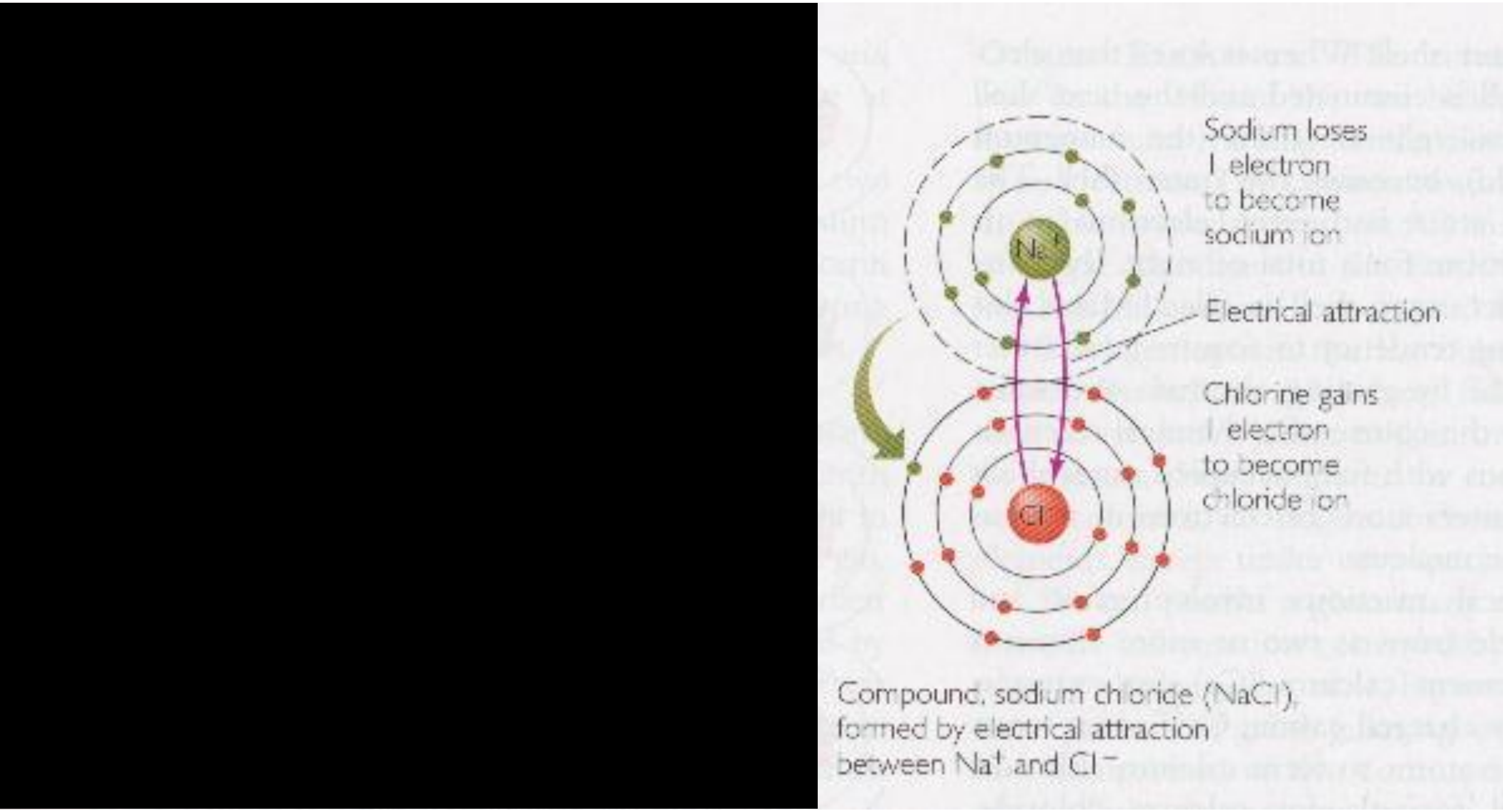
MODELS OF ATOMS & IONS OF FIVE COMMON ELEMENTS ILLUSTRATING THE DIVERSITY OF ELECTRON SHELLS. IONS ARE FORMED VIA GAIN OR LOSS OF ELECTRONS FROM OUTER SHELLS

CHEMICAL BONDS

- IONS OR ATOMS CONSTITUTING COMPOUNDS ARE HELD TOGETHER BY ELECTRICAL FORCES BETWEEN ELECTRONS & PROTONS WHICH ARE CALLED CHEMICAL BONDS
- ELECTRICAL ATTRACTIONS MAY STRONG OR WEAK & THUS RESULTING BONDS MAY BE WEAK OR STRONG
- STRONG BONDS PREVENT A SUBSTANCE FROM DECOMPOSING INTO ITS ELEMENTS OR OTHER COMPOUNDS
- STRONG BONDS ALSO MAKE MINERALS HARD & KEEP THEM FROM CRACKING OR SPLITTING
- THERE ARE TWO MAIN BOND TYPES: IONIC & COVALENT

IONIC BONDS

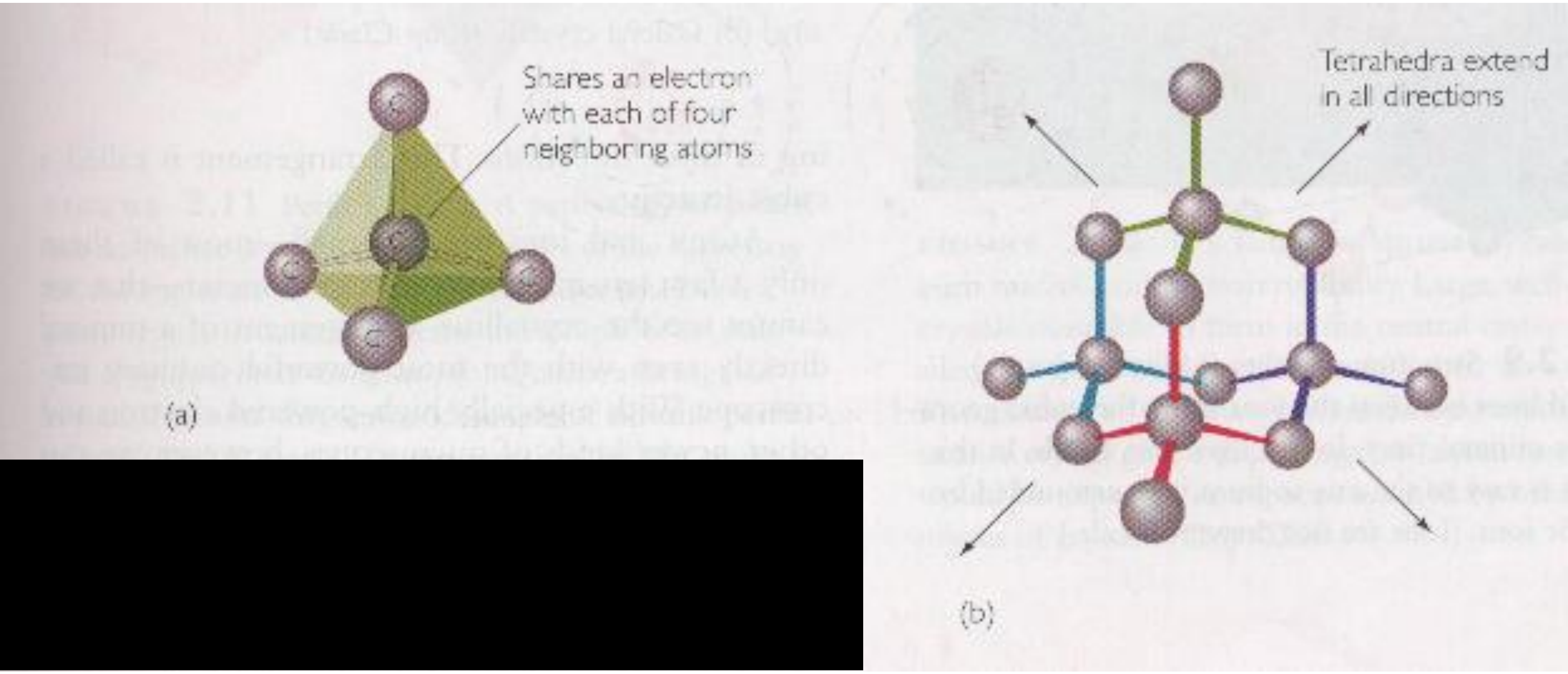
- FORMED BY ELECTRICAL ATTRACTIONS BETWEEN IONS OF OPPOSITE CHARGE SUCH AS Na^+ & Cl^- IN SODIUM CHLORIDE
- THE ATTRACTION IS SIMILAR TO STATIC ELECTRICITY THAT MAKES NYLON OR SILK CLOTHING CLING TO ONES BODY
- BOND STRENGTH DECREASES WITH INCREASING DISTANCE BETWEEN IONS
- BOND STRENGTH INCREASES WITH INCREASING CHARGE
- MOST DOMINANT BONDS IN MINERAL STRUCTURES; ABOUT 90% OF ALL MINERALS ARE IONICALLY BONDED



IONIC BOND BETWEEN Na+ & Cl- IONS

COVALENT BONDS

- ELEMENTS THAT FORM IONS BY SHARING OF ELECTRONS ARE HELD TOGETHER BY COVALENT BONDS
- ARE GENERALLY STRONGER THAN IONIC BONDS E.G. BONDS IN DIAMOND
- IN DIAMOND EVERY CARBON ATOM SHARES AN ELECTRON WITH EACH OF THE 4 ADJUCENT ATOMS IN A TETRAHEDRON
-



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CARBON TETRAHEDRON ILLUSTRATING THE COVALENT BOND AMONG CARBON ATOMS

- METALLIC BOND IS A COVALENT BOND IN WHICH ELECTRONS ARE FREELY SHARED
- THIS BOND TYPE OCCURS AMONG METALLIC ELEMENTS WHICH HAVE STRONG TENDENCIES TO LOSE ELECTRONS WHILE FREELY MOBILE ELECTRONS ARE SHARED & DISPERSED AMONG THE IONS
- CHEMICAL BONDS OF CERTAIN MINERALS ARE INTERMEDIATE BETWEEN IONIC & COVALENT AS SOME ELECTRONS ARE EXCHANGED & OTHERS ARE SHARED

- Minerals are formed by the process of C**RYSTALLISATION**, the growth of a solid from a material whose constituent atoms can come together in the proper chemical proportions and crystalline arrangement.
- Crystallization occurs when T of a solution is lowered to below its freezing point; Similarly, magma crystallizes into solid minerals when it cools to below its melting point, which is at about 1000 degrees C
- Can result from EVAPOURATION or COOLING
- Crystal also form when atoms & ions in solids become mobile & rearrange themselves at high T; For most minerals, temperatures must reach at least 250 degrees C before thsi rearrangement forms new minerals with different crystal structures.
- Two major factors control the rearrangment of atoms and ions in a crystal structure:
- Number of neighbouring atoms or ions & their size

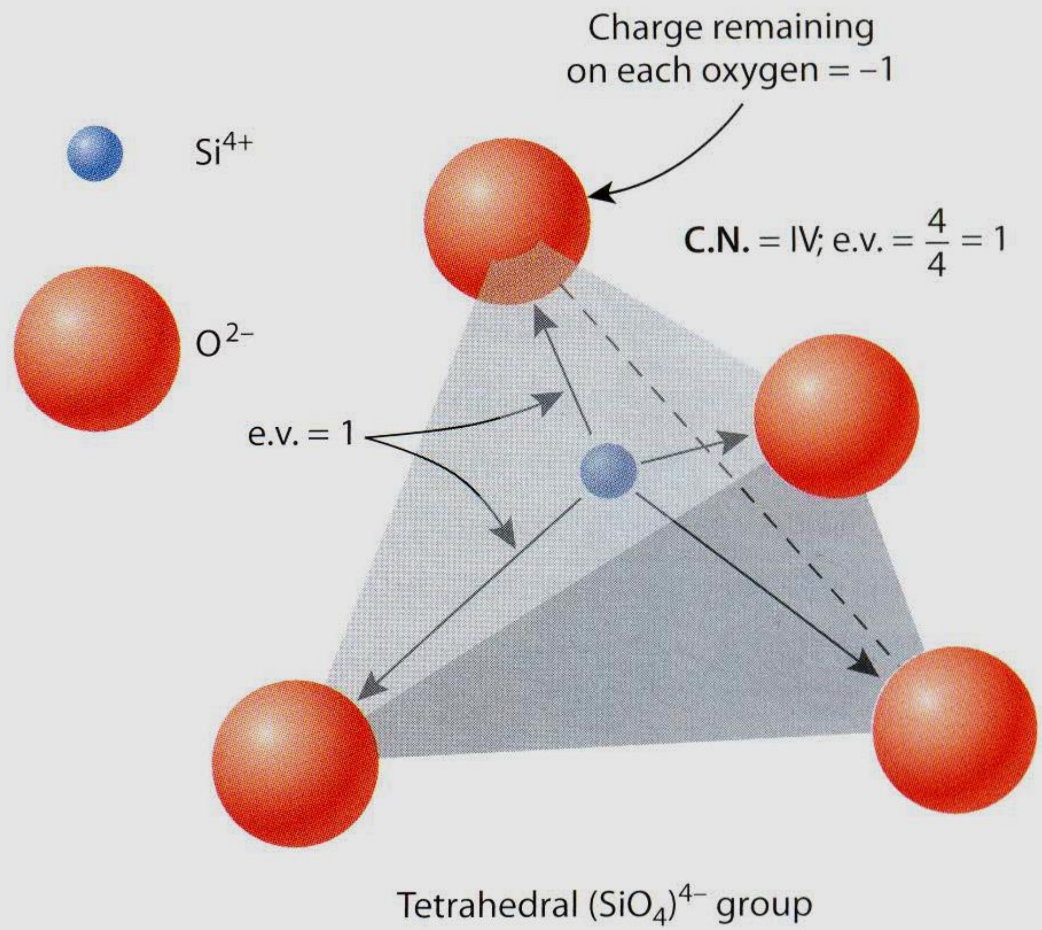

Figure 4.10 Illustration of the central Si^{4+} cation in a tetrahedral $(SiO_4)^{4-}$ group and the e.v. of the four bonds that radiate from the Si^{4+}. The e.v. of each of these bonds is $4/4 = 1$, which is exactly equal to one-half of the total bonding energy available on each oxygen ion ($\frac{1}{2} \times 2 = 1$). This allows for an apical oxygen linking up with another (SiO_4) tetrahedron. Such a linked oxygen is known as a bridging oxygen.