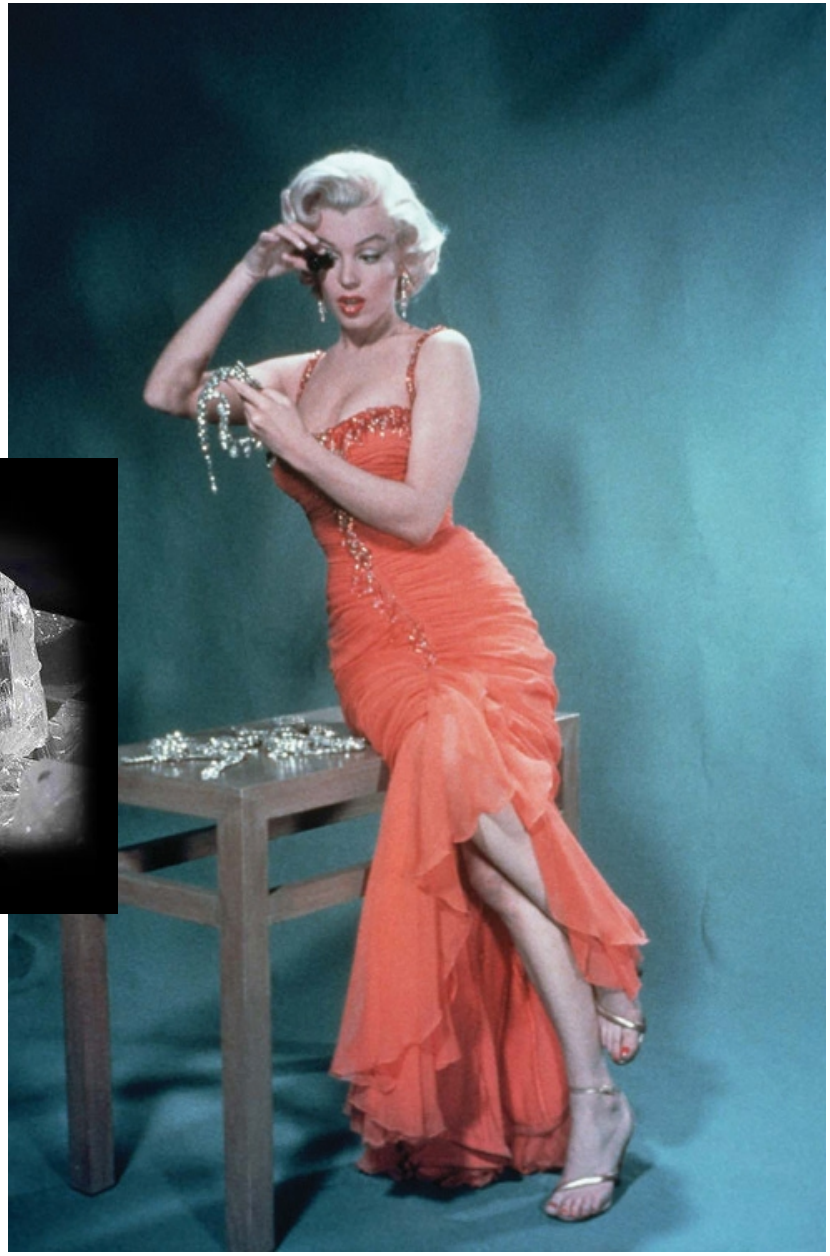
Earth Materials: Minerals and Rocks
Chapter 4



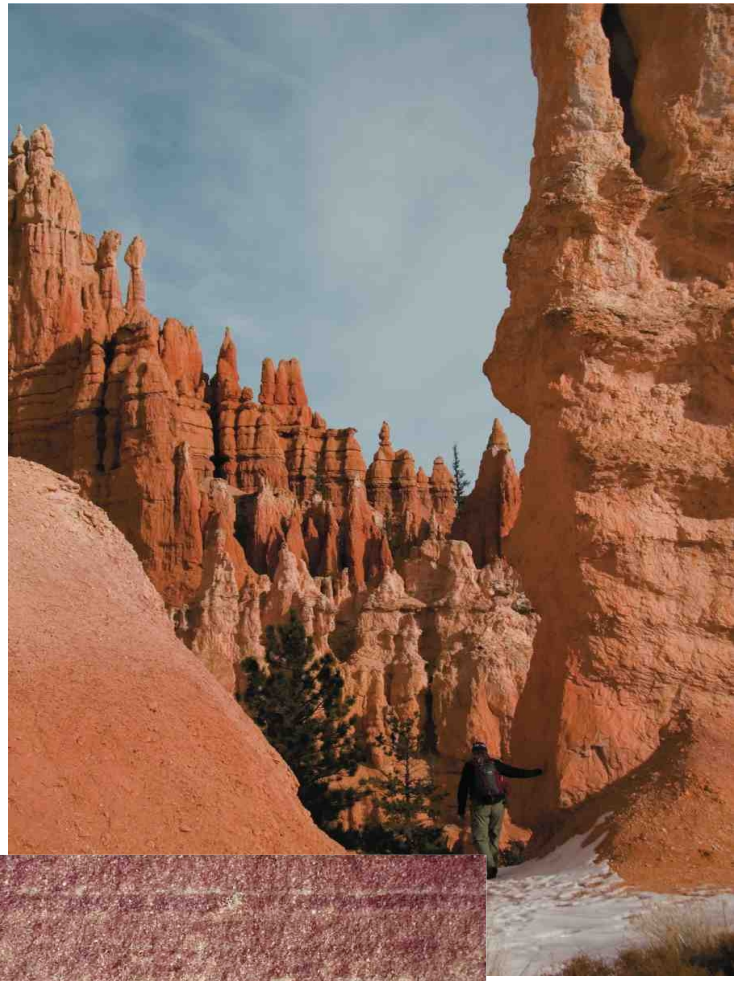
The French are bred to die for love
They delight in fighting duels
But I prefer a man who lives
And gives expensive jewls
A kill on the hand may be quite continental
But diamonds are a girl's best friend...

Earth Materials: Minerals and Rocks

Red diamond

- Red diamond on display at the **Los Angeles, Natural History Museum (near USC)**
- The gem company, De Beers campaign strategy in the 1953 film, "Gentlemen Prefer Blonds", romanticized diamonds as a symbol of love.
- Gaining complete control of the market, their price grew with demand.

Lauterbrunnen valley
Switzerland



Bryce Canyon
Utah

Rocks in the Earth's crust and mantle are made up of mineral assemblages with chemical compounds, elements, molecular bonds which are formed from ordered atomic structures.

Examples of Minerals

Halite (NaCl)
-Table salt

Gold (Au)

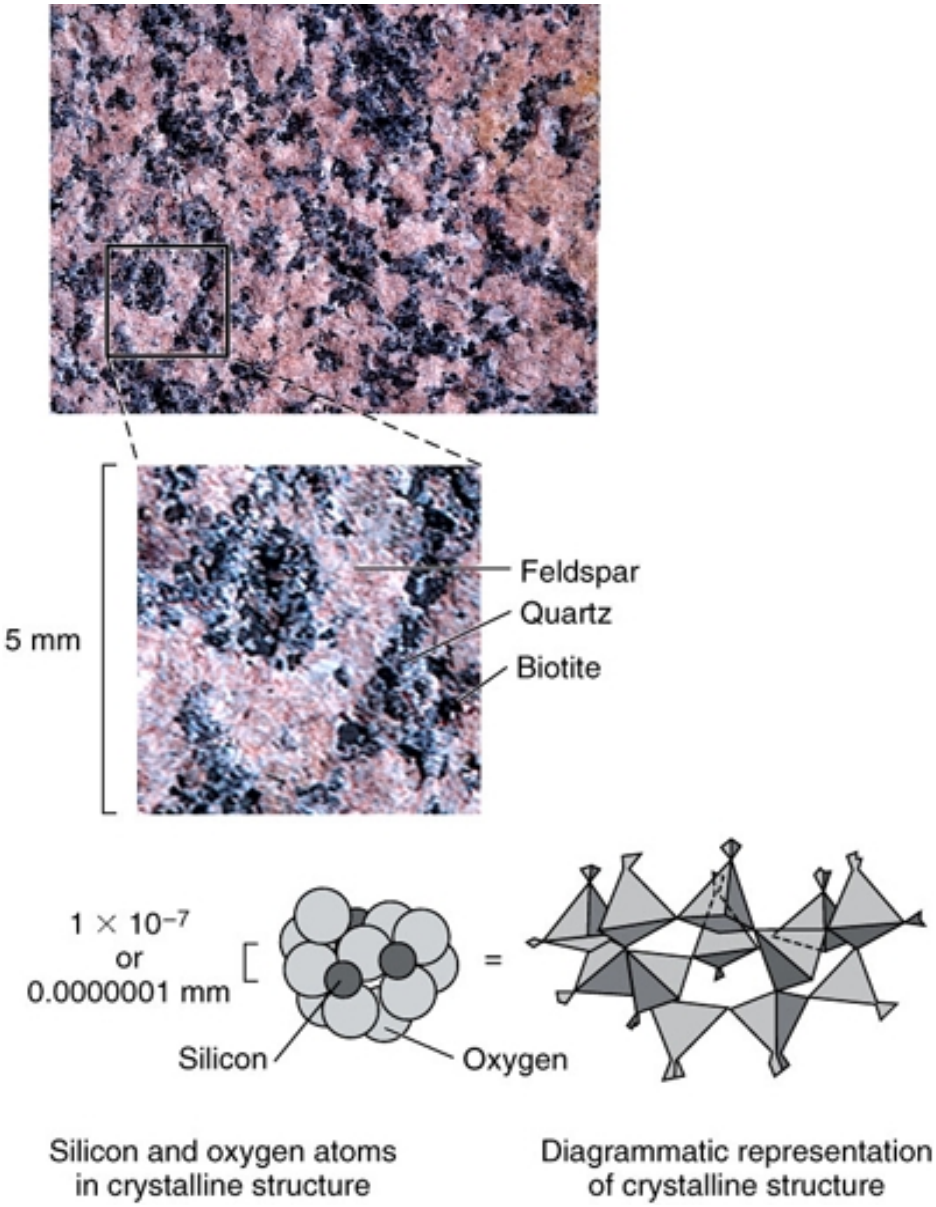
Olivine ($MgSiO_4$)

-Minerals have a chemical formula.

What is a Mineral ?

A *mineral* is:

-naturally formed,
-inorganic substance,
-solid,
-crystalline,
-chemically distinct

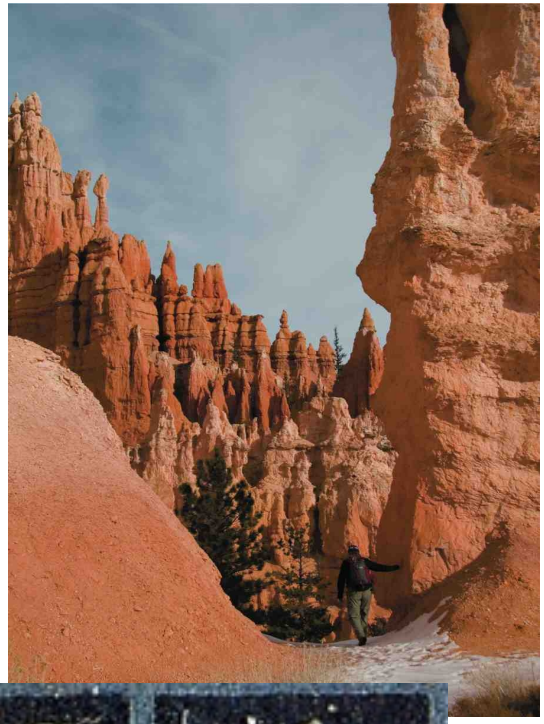


Silicon and oxygen atoms in crystalline structure

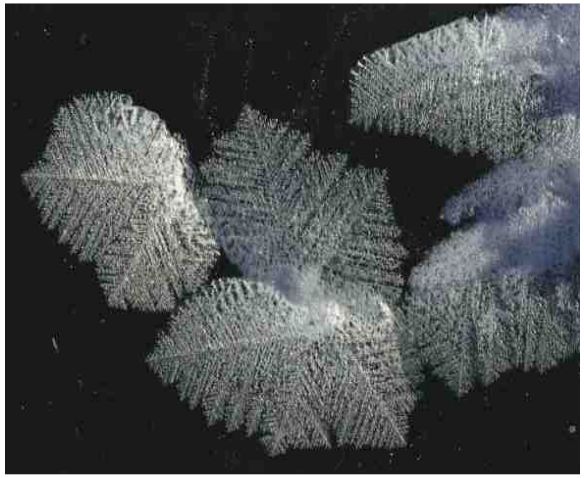
Diagrammatic representation of crystalline structure

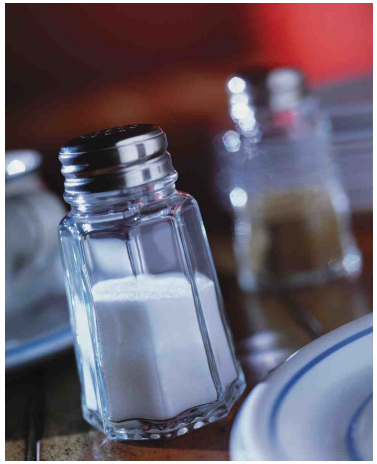
Where do Minerals Form ?

- Geosphere (most minerals)
- Hydrosphere (e.g., halite)
- Biosphere (e.g., calcite)
- Atmosphere (water ice, snow)



foraminifera





Where do Minerals Form ?

- The Naica Mine in Chihuahua, Mexico mines lead, zinc, and silver.

- Miners recently (2000) discovered a underground cave of giant gypsym crystals (4 x 50 ft!).

- These crystals form by hydrothermal fluids which come from deep magma chambers.

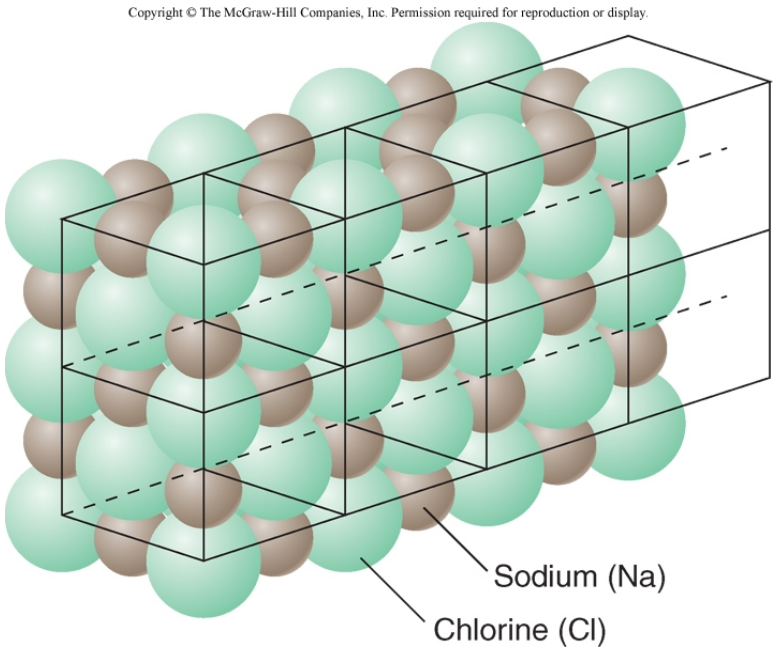
Where do Minerals Form ?

Atoms and Elements

An *element* is a substance that can not be broken down into others by ordinary chemical reactions

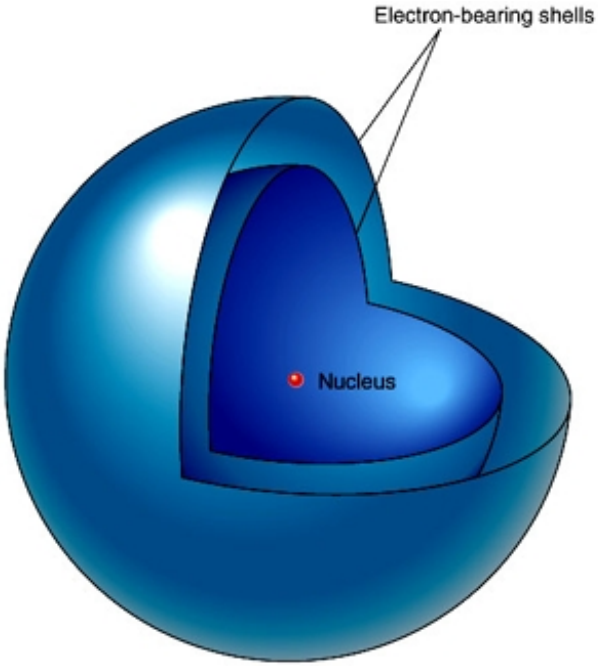
An *atom* is a chemical unit that cannot be broken down by chemical means composed of:

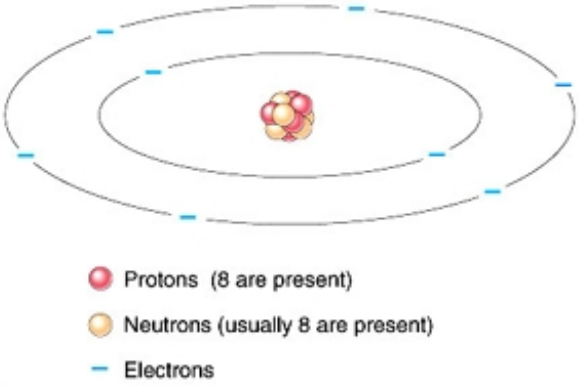
- Protons (positively charged)
- Neutrons (zero net charge)
- Electrons (negatively charged)



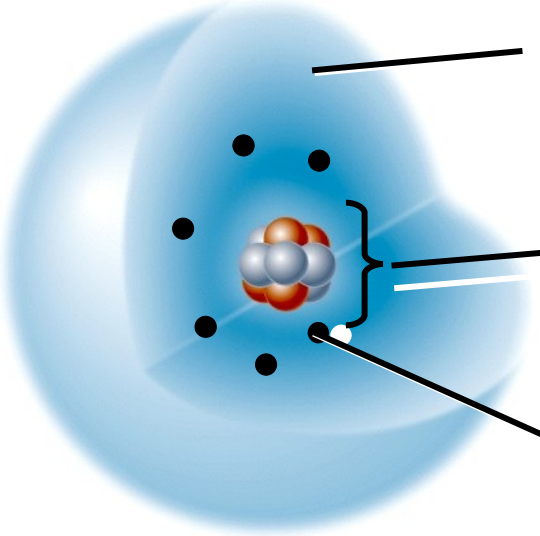
Atomic Structure

- Protons and neutrons form the *nucleus* of an atom
  - Represents tiny fraction of the volume at the center of an atom, but nearly all of the mass
- Electrons orbit the nucleus in discrete *shells* or energy levels
  - Shells represent nearly all of the volume of an atom, but only a tiny fraction of the mass
  - Numbers of electrons and protons are equal in a neutral atom
  - Ordinary chemical reactions involve only outermost shell (valence) electrons





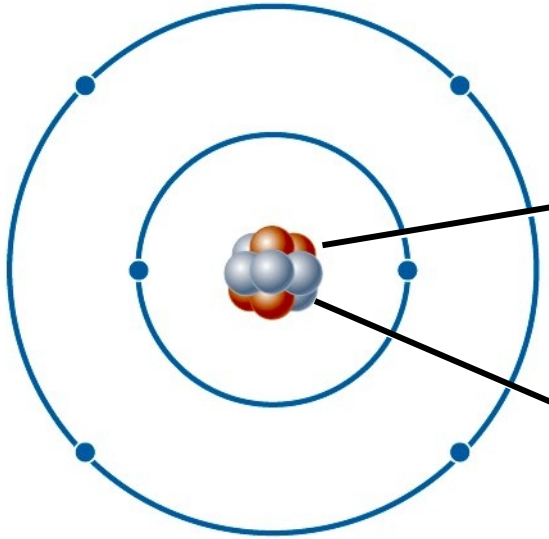
Carbon atom



Electron cloud

Nucleus

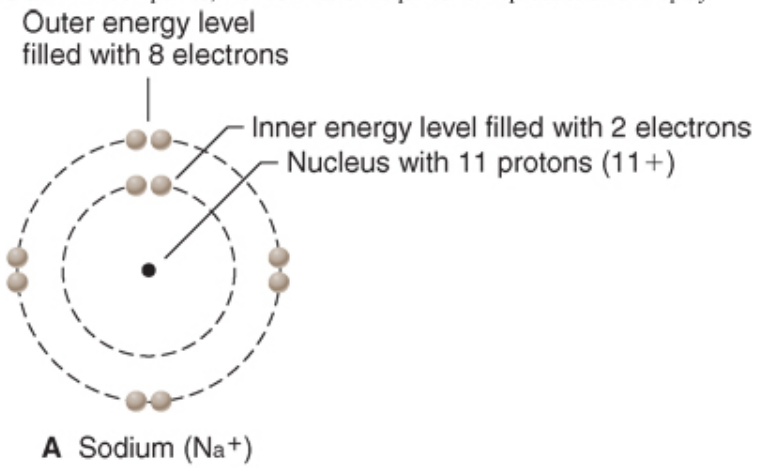
Carbon has 6 electrons (-)...



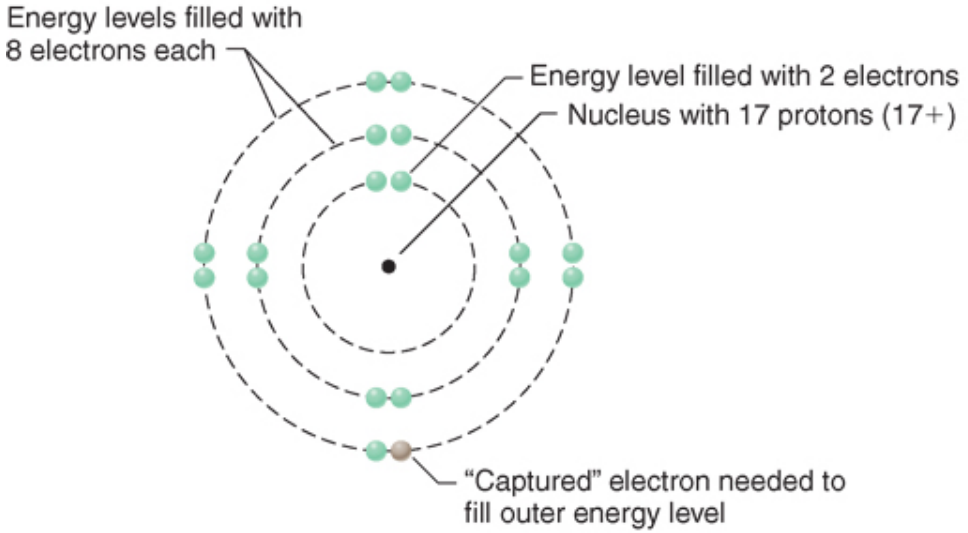
...and a nucleus of 6 protons (+) ...

...and 6 neutrons.

Electrons Organize in Energy Levels



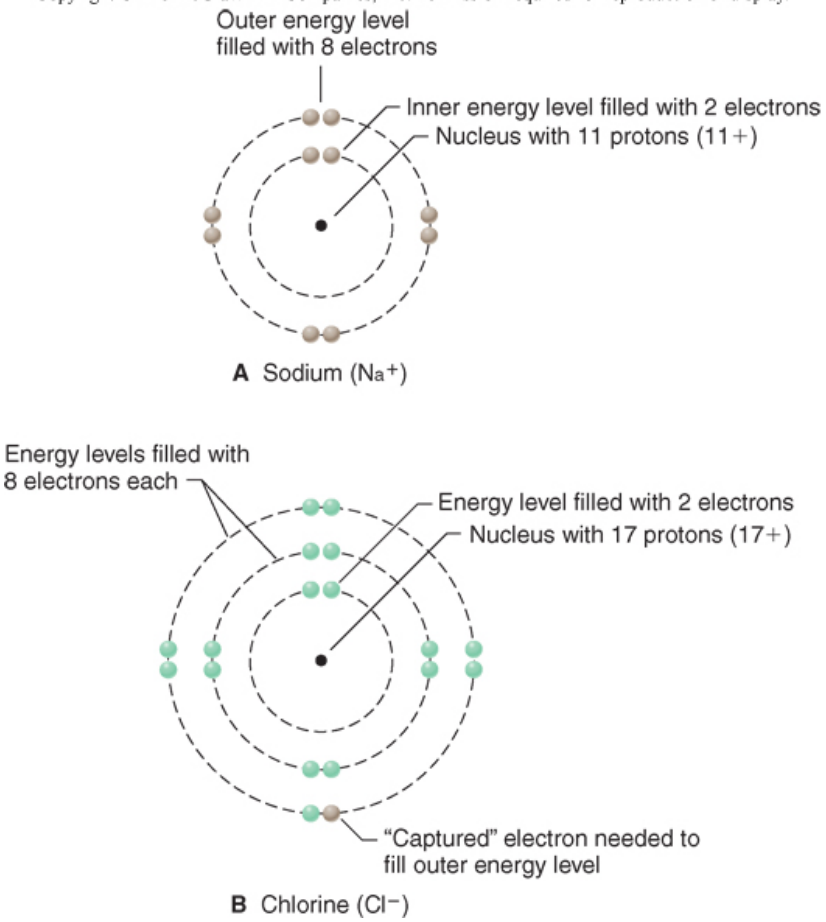
A Sodium (Na^+)



B Chlorine (Cl^-)

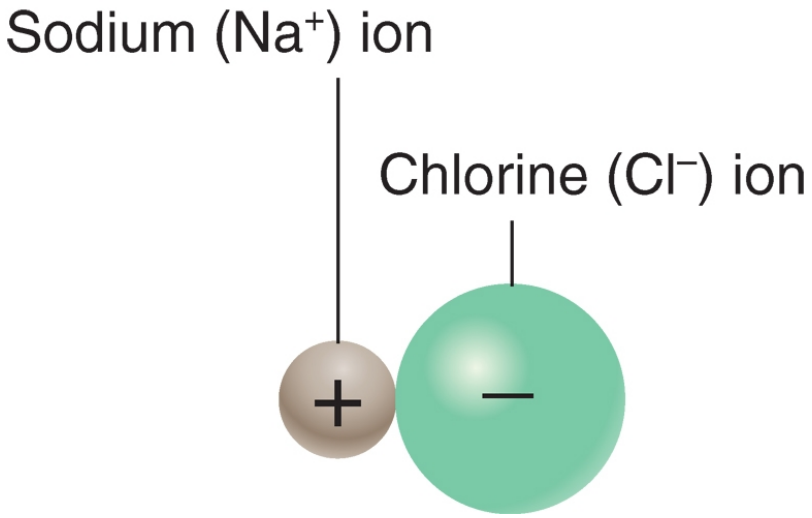
Chemical Bonding

- Chemical *bonding* is controlled by outermost shell (valence) electrons
- Elements will typically be reactive unless their valence shell is full
- Atoms or groups of atoms with unequal numbers of protons and electrons, thus having a non-zero charge, are called *ions.* Positively charged ions are known as *cations*, and negative charges as *anions*.
- Positive and negative ions are attracted to one another and may stick or chemically *bond* together



Chemical Bonding (4 types)

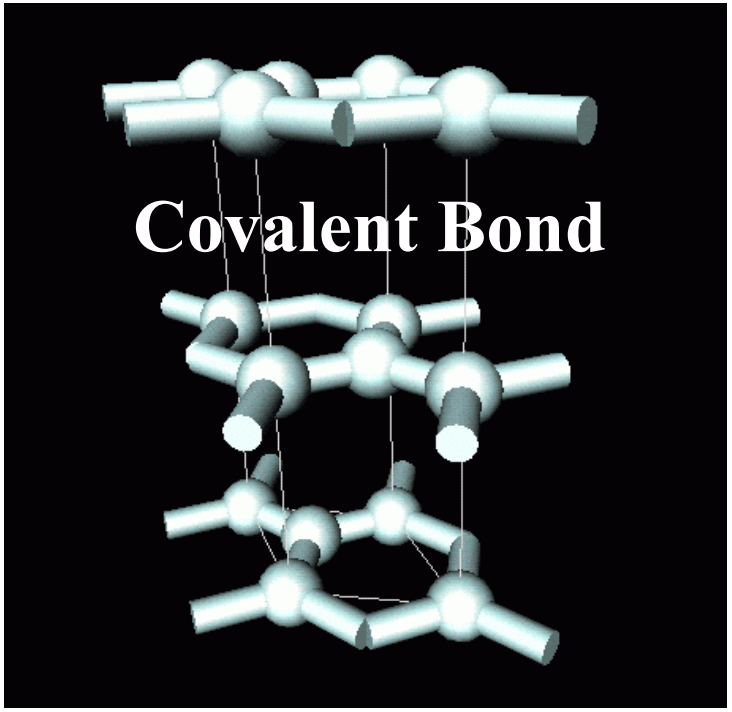
- Ionic bonding *(animation)*
  - Involves *transfer* of valence electrons from one atom to another
- Covalent bonding
  - Involves *sharing* of valence electrons among adjacent atoms
- Metallic bonding
  - Electrons flow freely throughout metals; results in high electrical conductivity



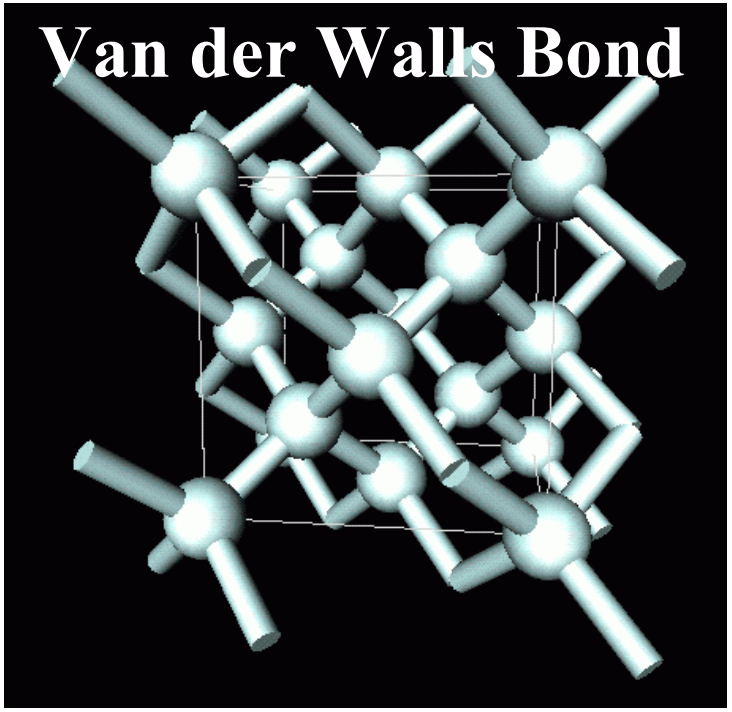
Ionic bonding of NaCl (sodium chloride)

- Van Der Walls bonding
  - Loose bonds in sheet structures (e.g. micas)

Chemical Bonds in Diamonds and Graphite



Graphite

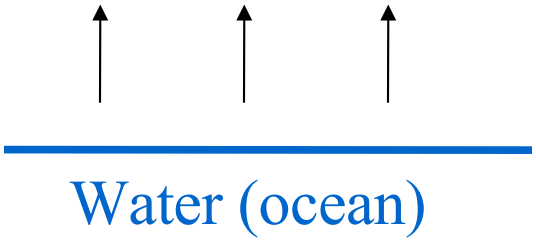


Diamonds

-Diamond and graphite are both made of carbon (C), but why is one the hardest substance on Earth and the other very soft ?

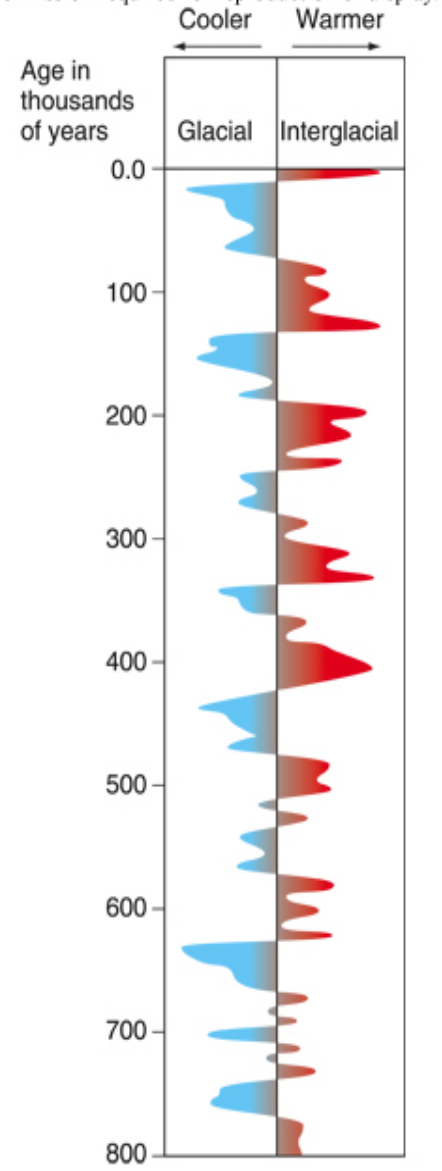
Isotopes

- Atoms of an element with different numbers of neutrons are called *isotopes*
- Isotopes may be either stable or unstable
  - *Stable* isotopes retain all of their protons and neutrons through time
  - Unstable or *radioactive* isotopes spontaneously lose subatomic particles from their nuclei over time
- Stable isotopes can be used to track climate change over time.



^{16}O - light

^{18}O - heavy



Composition of Earth's Crust

- Common elements
  - Nearly 97% of the atoms in Earth's crust are represented by the 8 most common elements
    - O, Si, Al, Fe, Ca, Na, K, Mg
- Common mineral types
  - Most minerals are *silicates* (contain Si and O bonded together)
- Minerals have crystalline structures
  - Regular 3-D arrangement of atoms

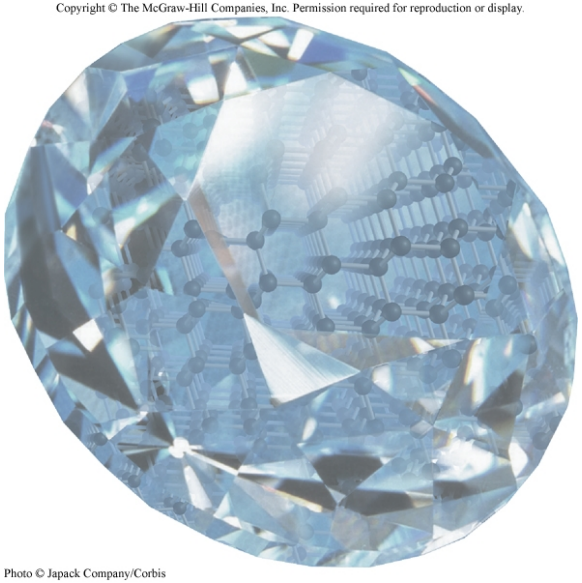


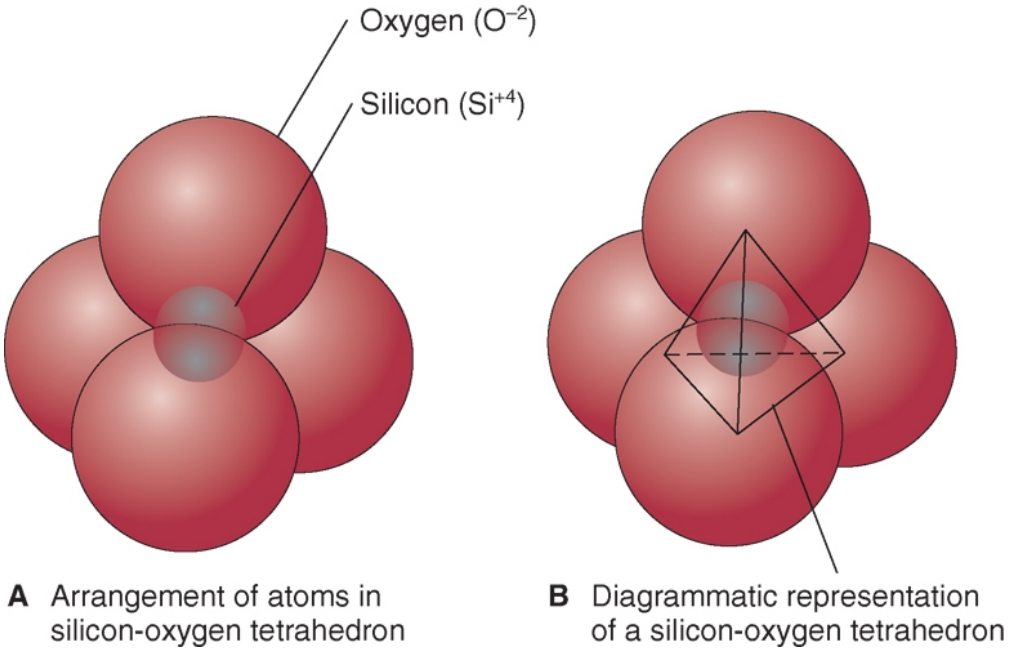
Photo © Japack Company/Corbis

BOX 2.4 ■ TABLE 1

Crustal Abundance of Elements

Element	Symbol	Percentage by Weight	Percentage by Volume	Percentage of Atoms
Oxygen	O	46.6	93.8	60.5
Silicon	Si	27.7	0.9	20.5
Aluminum	Al	8.1	0.8	6.2
Iron	Fe	5.0	0.5	1.9
Calcium	Ca	3.6	1.0	1.9
Sodium	Na	2.8	1.2	2.5
Potassium	K	2.6	1.5	1.8
Magnesium	Mg	2.1	0.3	1.4
All other elements		1.5	—	3.3

Silicate Structures



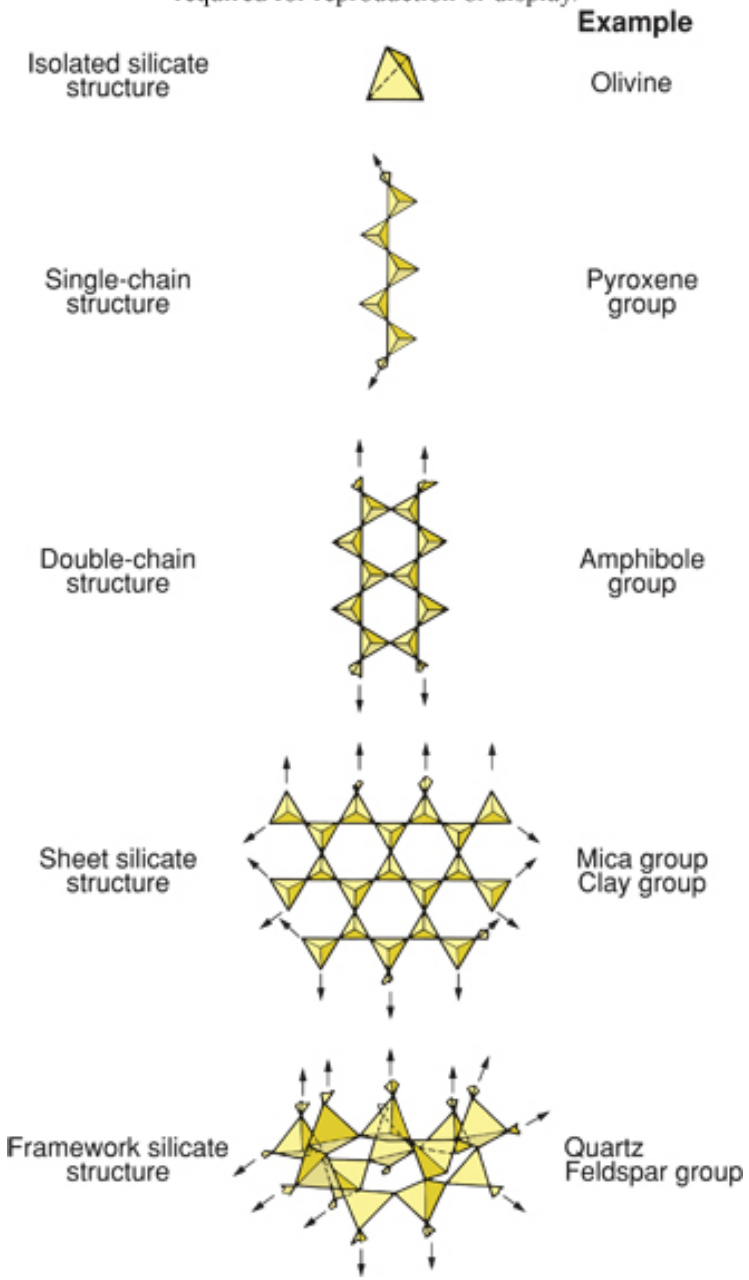
A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron

- The Silicon-Oxygen tetrahedron
  - Strongly bonded silicate ion
    - Basic structure for silicate minerals

Chains, Sheets, and Framework

- Sharing of O atoms in tetrahedra
  - The more shared O atoms per tetrahedron, the more complex the silicate structure
    - Isolated tetrahedra (none shared)
    - Chain silicates (2 shared)
    - Double-chain silicates (alternating 2 and 3 shared)
    - Sheet silicates (3 shared)
    - Framework silicates (4 shared)



Atomic Structures Activity

Non-silicate Minerals

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

Minerals

- A *mineral* must meet the following criteria:
  - Crystalline solid
    - Atoms are arranged in a consistent and orderly geometric pattern
  - Forms through natural geological processes
  - Has a specific chemical composition
    - May include some internal compositional variation, as the solid solution of Ca and Na in plagioclase)

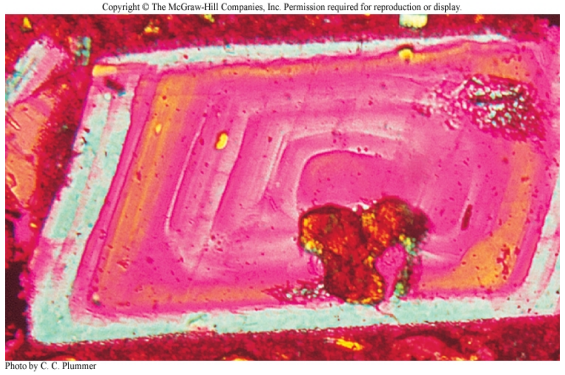


Photo by C. C. Plummer

- Rock-forming minerals
  - Although over 4000 minerals have been identified, only a few hundred are common enough to be generally important to geology (rock-forming minerals)
  - Over 90% of Earth's crust is composed of minerals from only 5 groups (feldspars, pyroxenes, amphiboles, micas, quartz)

Minerals

- Ore minerals
  - Minerals of commercial value
  - Most are non-silicates (primary source of metals)
    - Examples: magnetite and hematite (iron), chalcopyrite (copper), galena (lead), sphalerite (zinc)
  - Must be able to be extracted profitably to be considered current resources
- Gemstones
  - Prized for their beauty and (often) hardness
  - May be commercially useful
    - Diamond, corundum, garnet, and quartz are used as abrasives

Mineral Properties

- *Physical and chemical properties of minerals are closely linked to their atomic structures and compositions*

- Color
  - Visible hue of a mineral
- Streak
  - Color left behind when mineral is scraped on unglazed porcelain
- Luster
  - Manner in which light reflects off surface of a mineral
- Hardness
  - Scratch-resistance
- Crystal form
  - External geometric form

Photo © Parvinder Sethi

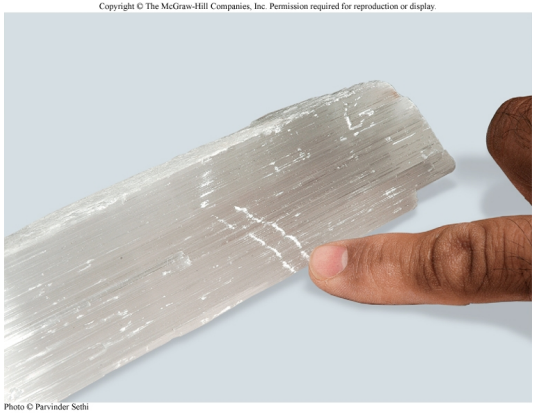
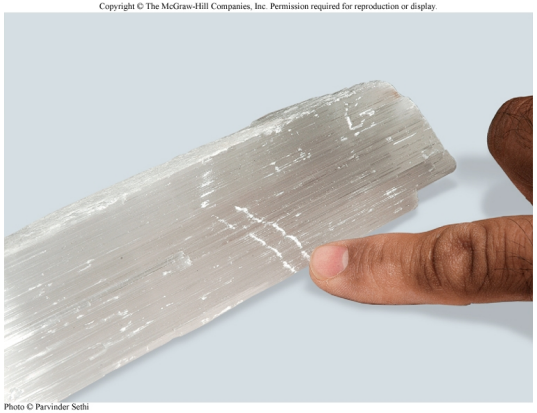


Photo © Parvinder Sethi

Photo © Parvinder Sethi

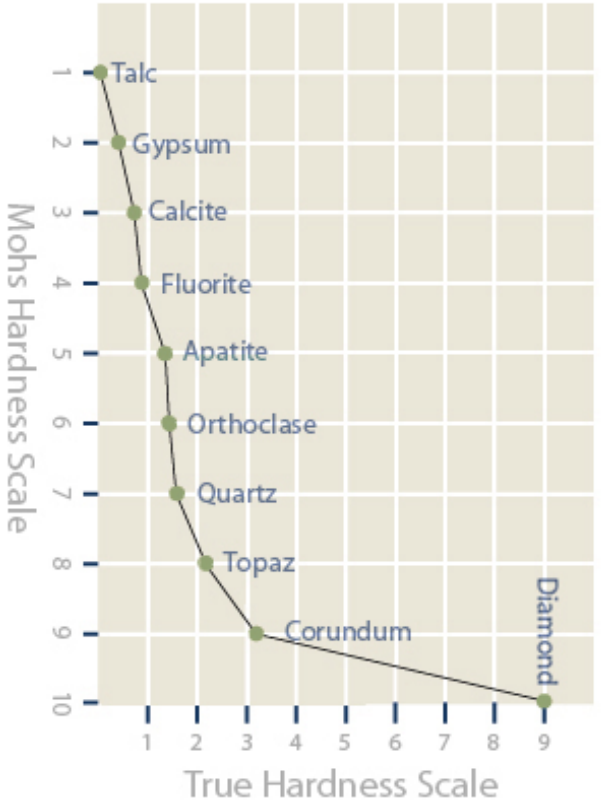
Mohs' Hardness Scale

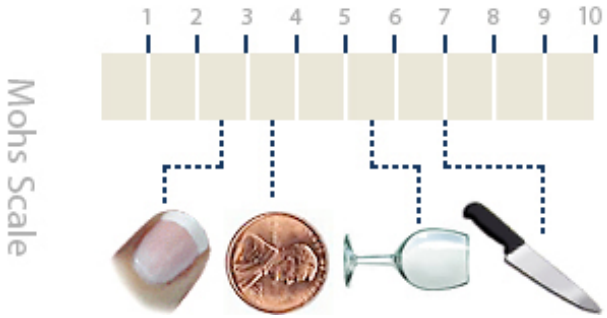


Gypsum

Quartz

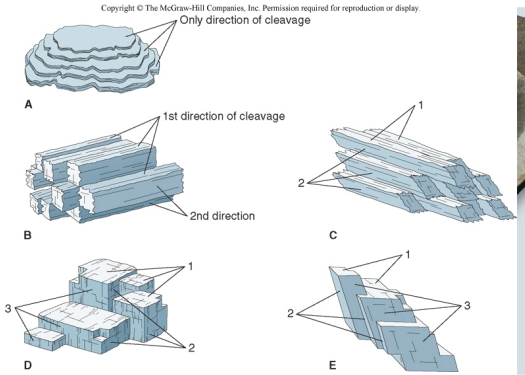
Diamond





Mineral Properties

- Cleavage
  - Breakage along flat planes
- Fracture
  - Irregular breakage
- Specific gravity
  - Density relative to that of water
- Magnetism
  - Attracted to magnet
- Chemical reaction
  - Calcite fizzes in dilute HCl



Magnetite Characteristics

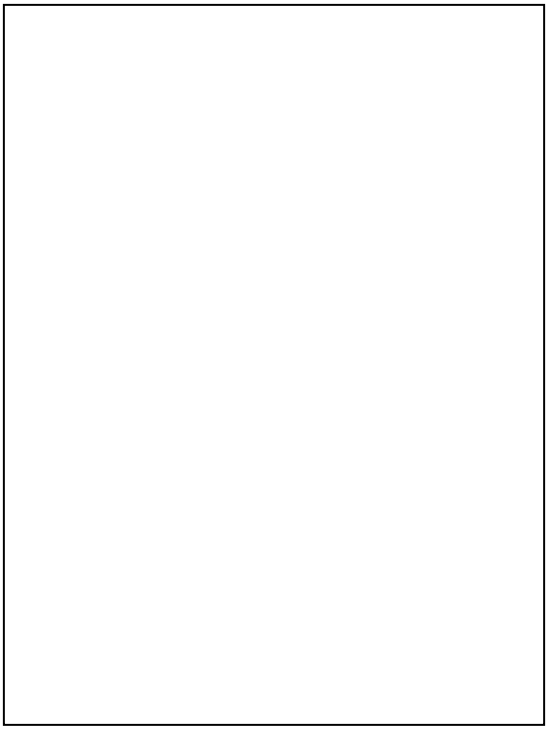
Mineral Characteristics

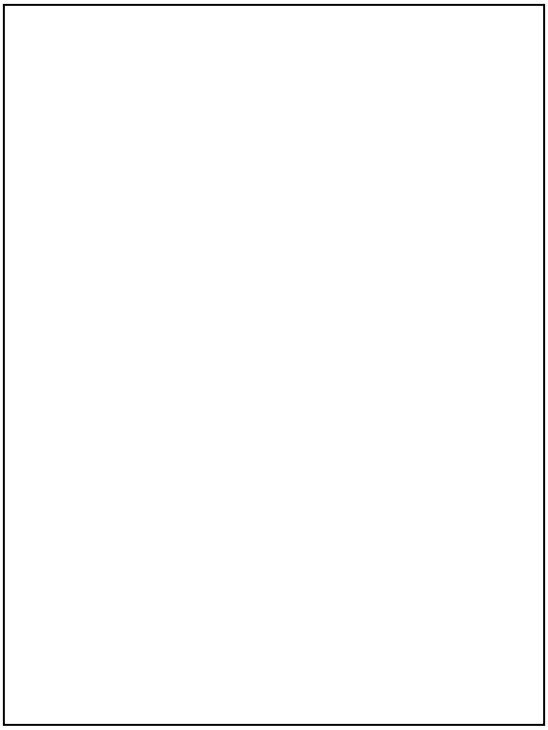
Photo © Parvinder Sethi

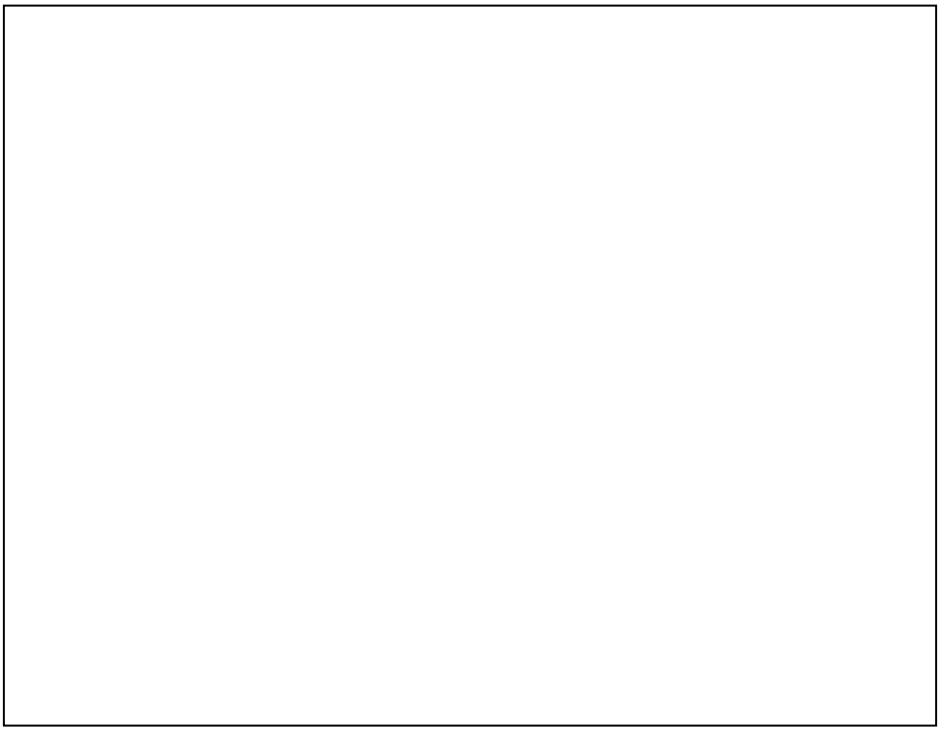
Calcite

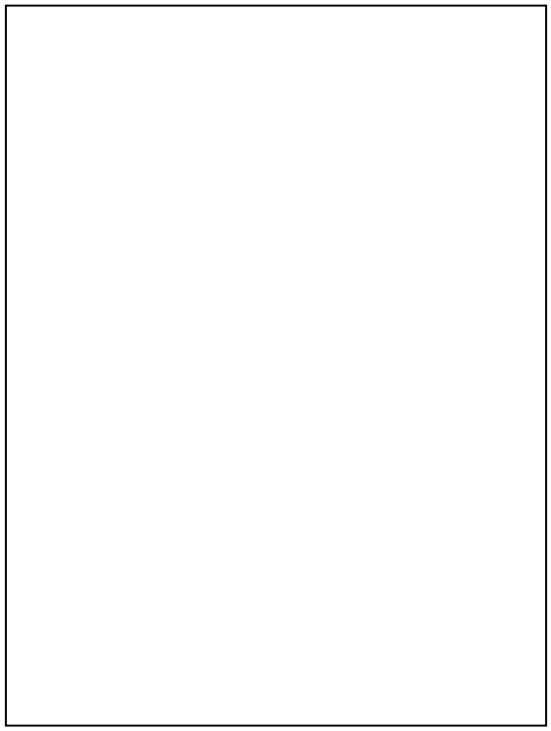
Emerald

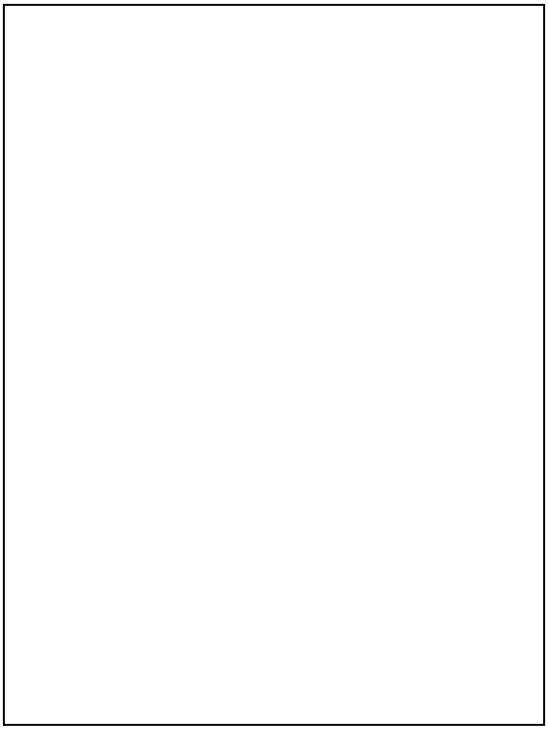
Gold Specs

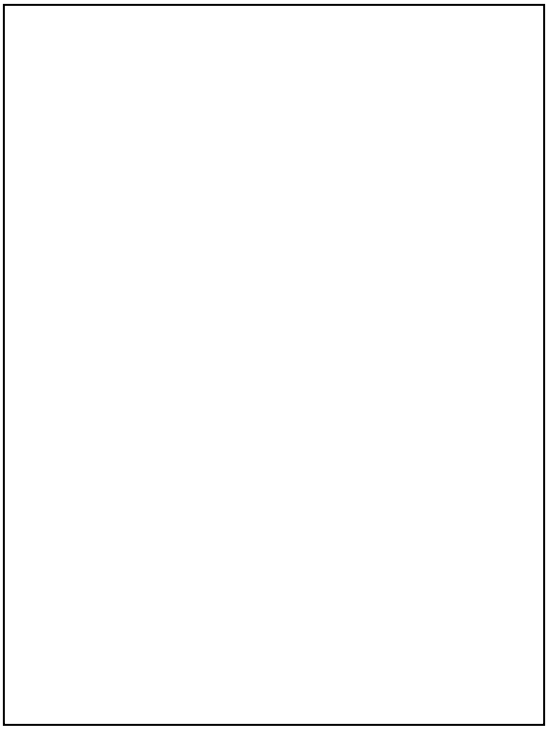


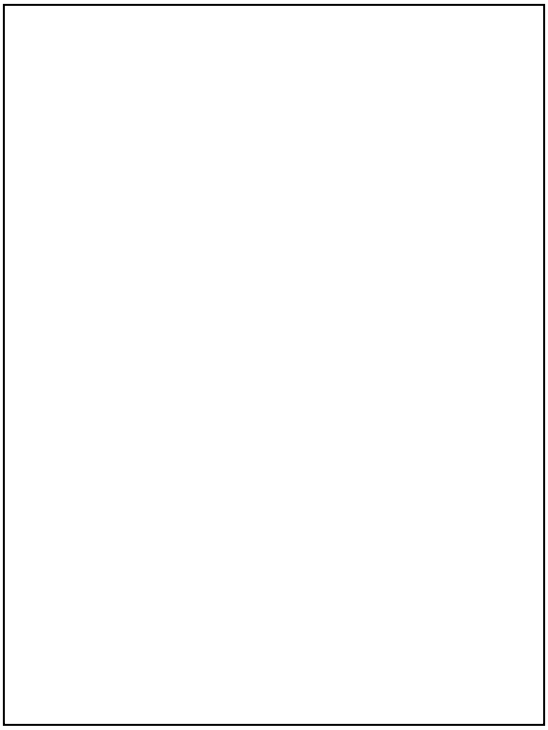


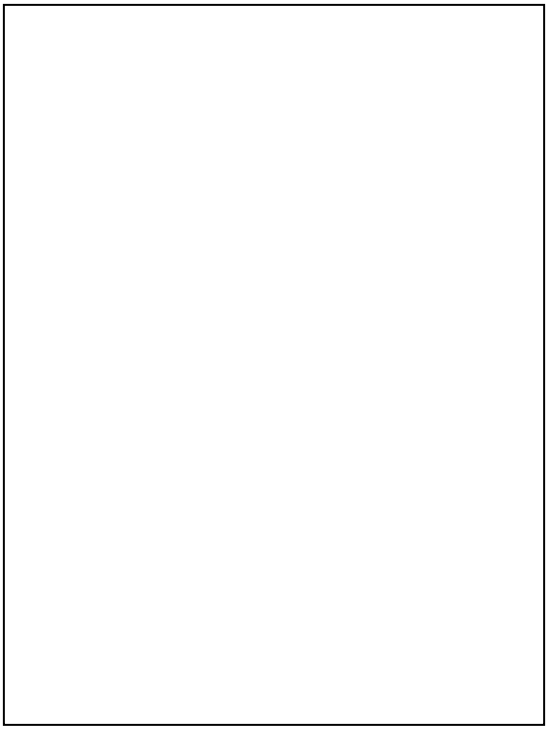


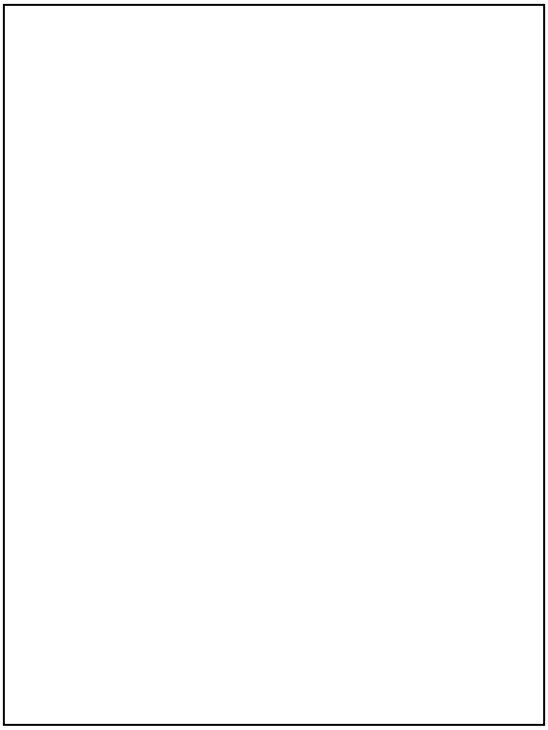




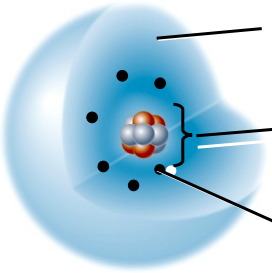








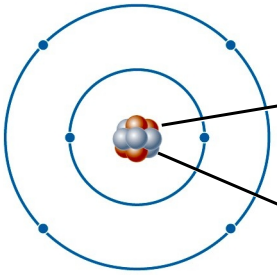
Carbon atom



Electron cloud

Nucleus

Carbon has 6 electrons (-)...



...and a nucleus of 6 protons (+) ...

...and 6 neutrons.