The word **mineral** is used in a variety of ways:

- any valuable material extracted from the Earth like coal, gravel, and even groundwater.
- by nutritionists for elements metabolized by the body
- as anything that isn’t animal or plant

**A mineral** is any naturally occurring inorganic solid that possesses an orderly crystalline structure and a definite chemical composition.

1. *occur naturally* - minerals form by natural geologic processes. Concrete, synthetic diamonds, etc. are excluded.

2. *inorganic* - Organic compounds such as sugar, DNA and solidified tree sap, coal and petroleum are excluded.

3. *solid* - gases and liquids are excluded.

4. *orderly crystalline structure* - atoms are arranged in an orderly repetitive pattern.

5. *definite chemical composition* - the chemical formula of a mineral must be definite but may vary within specified limits.

**examples**: 
- C Diamond
- NaCl Halite
- (Na,Ca)Al(Si,Al)Si2O8 Plagioclase

**Composition and Structure of Minerals**

Atoms are the basic building blocks of minerals — the **Periodic Table of the Elements** describes the >100 elements that are known.
Elements and Compounds

- All minerals are either elements or compounds.
- Not all elements and compounds are minerals.

Na (sodium) = gray metallic clay  
Cl (chlorine) = yellow-green gas  
NaCl (salt) = white crystal (mineral Halite)

A few minerals, such as diamond, graphite, gold, and sulfur are made up entirely of one element.

Most minerals are a combination of two or more elements that are chemically bonded.

The only formulas you need to memorize:

- SiO₂ – Quartz (silicon dioxide)
- CaCO₃ – Calcite (calcium carbonate)

Bonding in Minerals

Ionic bonding
Atoms of the same element have the same number of protons. Atoms of the same element may have different numbers of neutrons.

Atoms of the same element that have different numbers of neutrons are called isotopes.

Example:
• All carbon atoms have have 6 protons. One isotope of carbon has has 6 protons and 6 neutrons in its nucleus and is known as carbon-12 ($^{12}\text{C}$).
• Another well known isotope of carbon is carbon-14 ($^{14}\text{C}$) with 6 protons and 8 neutrons.

Isotopes and Radioactive Decay

The nuclei of many isotopes are unstable and will disintegrate in a process known as radioactive decay. Radioactive decay releases energy and subatomic particles and occurs when the forces that bind the nucleus together are not strong enough to hold it together.

The figure shows the decay of a nucleus in a process known as beta decay. There are many different decay processes where different types of particles are emitted from the nucleus.

Unstable isotopes decay at a steady and predictable rate and are useful for determining the isotopic age of geologic samples.

Over 4,000 minerals have been identified in the scientific literature - Approximately 40 - 50 new ones are discovered every year!

There are relatively few (10-15) common rock-forming minerals.

A rock is any solid mass of mineral, or mineral-like, matter that occurs naturally as part of our planet. One way that rocks are characterized is by their mineral content. For example, the rock granite commonly contains the three minerals:

- quartz
- feldspar
- biotite

Different minerals may be identified by their physical properties (cleavage, hardness, reaction to acid, etc.).
The (microscopic) structure of a mineral is expressed in the macroscopic physical properties of the mineral:

1. **Crystal Form** - symmetry and shape of crystals.
2. **Luster** - how light is reflected on the surface.
3. **Color** - diagnostic for a few minerals.
4. **Streak** - color when mineral is powdered on unglazed tile.
5. **Hardness** - resistance of mineral to abrasion or scratching.
6. **Cleavage** - tendency to break along planes of weak bonds.
7. **Fracture** - minerals that do not exhibit cleavage.
8. **Specific Gravity** - ratio of the weight of a mineral to the weight of an equal volume of water.
9. **Other Properties** - these properties are important for a small number of minerals.
   a. magnetism
   b. double refraction
   c. reaction to acid
   d. taste

**Physical Properties of Minerals**

- **Luster**
  Describes the way that the surface of the mineral reflects light.
  Lusters:
  - Metallic
  - Nonmetallic
    - glassy
    - brilliant
    - dull

- **Color**
  Most minerals can have a wide range of colors due to small amounts of impurities in them such as these examples of quartz.
  - Smokey Quartz
  - Amethyst Quartz
  - Citrine Quartz
  - Rose Quartz
  - Titanium impurities lead to blue Sapphire - a form of Corundum (Al₂O₃)
  - Chromium impurities lead to red RUBY - a form of Corundum (Al₂O₃)
Streak
is the color of a powdered mineral on a streak plate (unglazed porcelain tile).

Hardness
a mineral’s ability to resist being scratched. The Mohs’ hardness scale is not linear!
Mohs hardness scale – unit less 10-point scale with each hardness value represented by a common mineral.

Cleavage
— tendency of minerals to break parallel to crystallographic planes along which chemical bonds are weaker than others.
Fracture
In some crystals, the strength of bonds is approximately equal in all crystallographic directions. Several types of fracture can be described:
- conchoidal – smooth curved surfaces resembling shells
- fibrous – common with asbestos
- hackly – jagged fractures with sharp edges
- irregular or uneven – rough or irregular surfaces

Specific Gravity/Density
The density of any material is its mass/volume. For some minerals, its density is diagnostic - helps to identify it. The specific gravity is similar to density but compares the density of a mineral to the density of water. For example, a mineral with a specific gravity of 3.0 is 3 times more dense than water.
- Quartz (SiO₂) S.G. ~2.6
- Galena (PbS) S.G. ~7.5
- Gold (Au) S.G. ~20

Other Properties
There are many other physical properties that may be diagnostic for some minerals.
- Play of color
- Smell/Taste
- Luminescence

Gold has a specific gravity (density) of 20.

Specific gravity is measured in grams per cubic centimeter OR is just a multiple of how much more something weighs than an equal volume of freshwater.

If a pail of water weighs 2 kg, what does the same size pail of gold weigh?
2 kg X 20 = 40 kg

Magnetism
— results from atomic properties of certain metals in minerals. This property is diagnostic for a few minerals such as magnetite (Fe₃O₄).

Reaction to Acid
Minerals that contain the chemical component carbonate (CO₃²⁻) react to acid by effervescing. The mineral calcite (CaCO₃) effervesces by the reaction:

\[
\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CO}_2 + \text{Ca}^{2+} + 2\text{Cl}^- + \text{H}_2\text{O}
\]

Mineral Groups

Only 8 elements make up the bulk of minerals and represent over 98% of the Earth's crust. Minerals are classified by their chemistry and put into chemical groups.

The two most abundant elements are oxygen and silicon which combine to form the framework for the most common mineral group - the silicates (SiO₄⁴⁻). Other mineral groups include the carbonates (CO₃²⁻), sulfides (S²⁻), oxides (O²⁻) and halides (column VIIA - periodic table).
Silicates

All silicate minerals have the same fundamental building block - the silica tetrahedron. It consists of 4 oxygen (O\(^2-\)) ions surrounding the smaller silicon (Si\(^4+\)) ion. The silica tetrahedron is a complex ion (SiO\(_4\)\(^4-\)) with a charge of -4. Most silicate minerals consist of silica tetrahedra bonded with positively charged ions such as Fe\(^2+\), Ca\(^2+\), Mg\(^2+\), Na\(^+\) and K\(^+\).

Silicates

Silica tetrahedra may link together to form single-chains, double-chains, and sheets by sharing oxygen ions between them.

Common Silicate Minerals

Feldspars are the most abundant minerals - more than 50% of the Earth's crust.

Quartz is the second most abundant (only common mineral made of only SiO\(_2\)).

Rock Forming Minerals

Pyroxene  Amphibole  Mica

Mafic (Dark)

Quartz  – Rock Forming Mineral

Potassium Feldspar  Plagioclase Feldspar

Rock Forming Minerals
**Ferromagnesian (Dark) Silicates**
Tend to be dark colored due to the presence of iron (Fe) and magnesium (Mg), and have a high specific gravity.
- Olivine
- Pyroxenes
- Amphiboles
- Biotite
- Garnet

**Nonferromagnesian (Light) Silicates**
Tend to be light colored and have lower specific gravity than the ferromagnesian minerals.
- Micas (Muscovite, Biotite, Aluminous Mica)
- Feldspars (Plagioclase, Orthoclase, Microcline, K-feldspar)
- Quartz

**Important Nonsilicate Minerals**
Other mineral groups are based on ions other than silica tetrahedron. They are less common than the silicate minerals but are important components of the Earth and have economic uses.

<table>
<thead>
<tr>
<th>Mineral Group</th>
<th>Name</th>
<th>Chemical Formula</th>
<th>Economic Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystals</td>
<td>Tourmaline</td>
<td>Rb₂₃O₂</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Magnetite</td>
<td>Fe₃O₄</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Garnet</td>
<td>Al₂O₃</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Biotite</td>
<td>Ca₂Mg₅Si₃O₁₂</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Garnet</td>
<td>Ca₂Mg₅Si₃O₁₂</td>
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</tr>
<tr>
<td></td>
<td>Muscovite</td>
<td>K₂Al₂(Si₃AlO₁₀)</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>NaAl(Si₃O₁₀)</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Orthoclase</td>
<td>KAl₂(Si₃O₁₀)</td>
<td>One of the most important physical and chemical properties is its ability to induce a magnetic field.</td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
<td>SiO₂</td>
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</table>

**The Naica Mine of Chihuahua, Mexico**
- A working lead-zinc-silver mine in which large voids have been found, containing crystals of selenite (gypsum) as large as 4 feet in diameter and 50 feet long. The chamber holding these crystals is known as the Crystal Cave of Giants, and is approximately 1000 feet down in the limestone host rock of the mine. The crystals were formed by hydrothermal fluids emanating from the magma chambers below. The cavern was discovered while the miners were drilling through the Naica fault, which they were worried would flood the mine. The Naica mine was first discovered by early prospectors in 1794 south of Chihuahua City.

**Diamond**
- Murfreesboro, Arkansas: Diamond Fields

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Crystalline Gold

Tailings – California Gold Country

Asbestos Ore

Asbestos Deposit along a Diabase Sill

New Idria Mine, CA

Cinnabar-Mercury Ore

Mercury Mine Tailings, Panoche Hills, CA
Sulfur Crystal

Sulfur in Volcanic Vent, New Zealand