Module 2: What is a “Chemical Species”?

Submicroscopic Models

Fundamentals of Chemistry Open Course

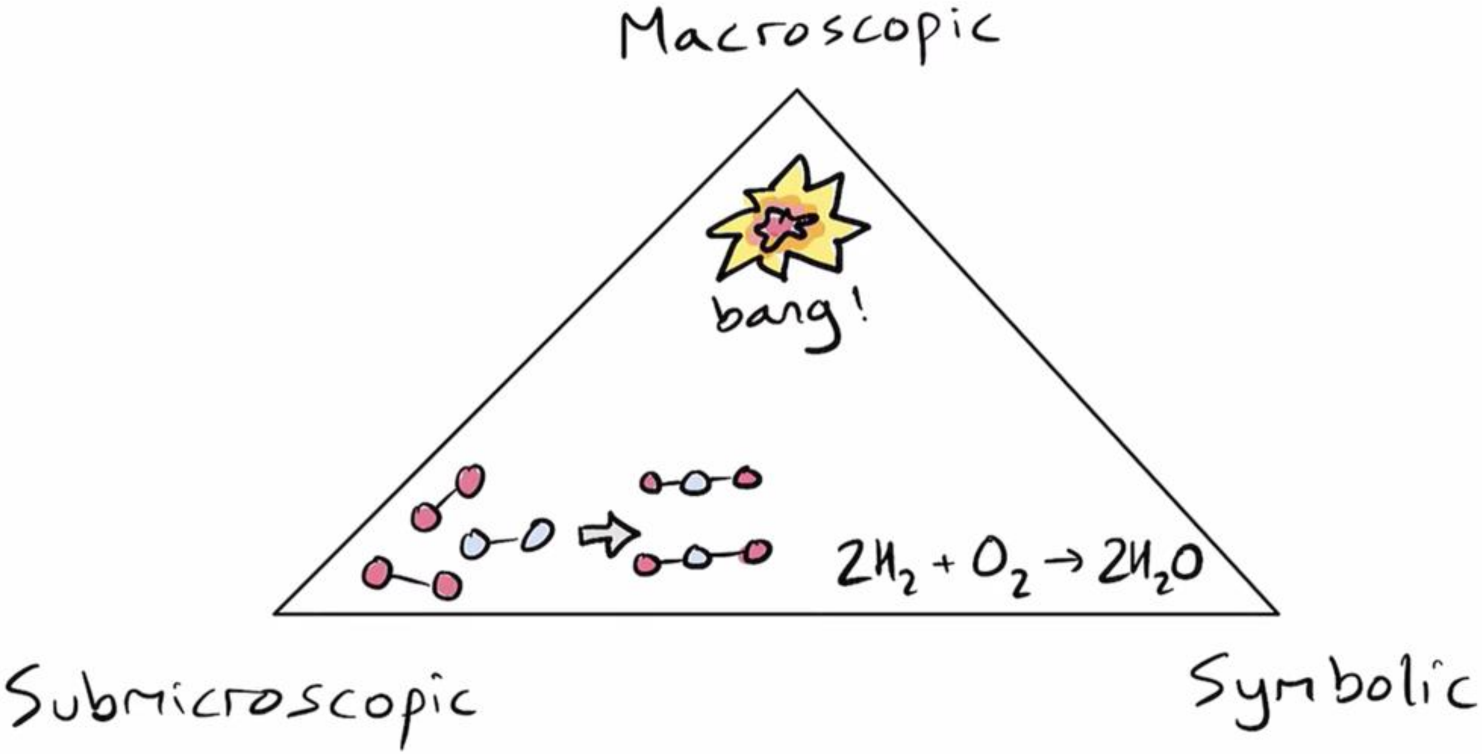
Learning Objectives | Module 2

1. State and apply the laws of chemical combination.
2. State and apply the tenets of the modern atomic theory.
3. Visualize the subatomic particles that constitute the atom using a simple planetary model; count subatomic particles using atomic number (Z) and mass number (M).
4. Represent an atom or ion using an atomic symbol.
5. Represent the number ratios of atoms in a compound using a chemical formula.
6. Visualize and distinguish between submicroscopic models of molecular and ionic compounds.
7. Use the periodic table to efficiently find information about a chemical element.
8. Recognize key collections of elements on the periodic table.
9. Determine the name of a binary ionic compound from the chemical formula and *vice versa*.
10. Determine the name of a simple molecular compound from the chemical formula and *vice versa*.

Johnstone's Triangle: Three Realms of Thought in Chemistry

- We think about chemical substances and reactions at three distinct but related levels or "realms":
  - **Macroscopic:** phenomena large enough for us to experience directly (also known as "bulk" or "in bulk")
  - **Submicroscopic:** atoms and molecules (also known as "the molecular level")
  - **Symbolic:** representations that may refer to either of the other two realms

- We will commonly move between the "realms," connecting different types of knowledge.

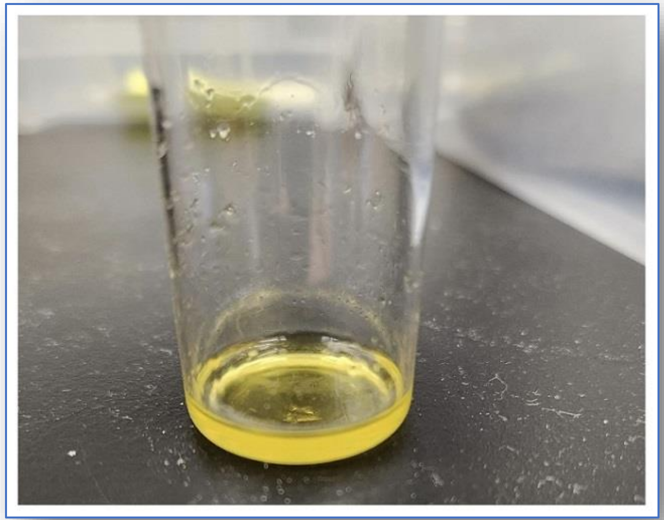


The Macroscopic Level

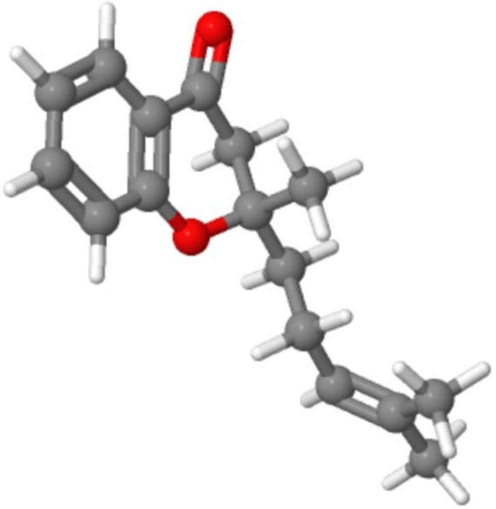
- Direct observations of chemical properties and reactions, such as color and odor
- Measured properties such as mass, amount in moles, temperature, volume, pressure of a gas, etc.
- Intensive bulk properties such as density, molar mass, melting point, boiling point, etc.

2-Methyl-2-(4-methylpent-3-en-1-yl)chroman-4-one

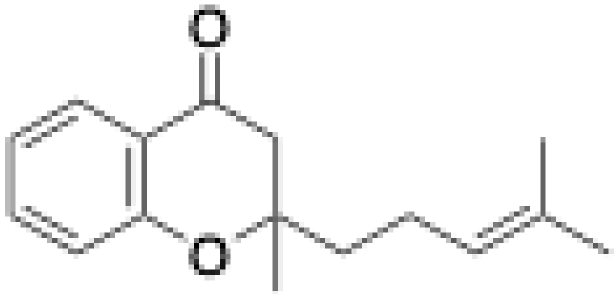
Macroscopic



Submicroscopic



Symbolic



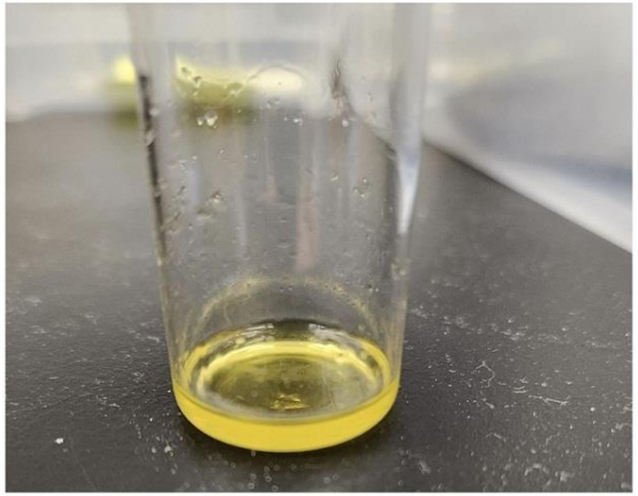
$C_{16}H_{20}O_2$

The Submicroscopic Level

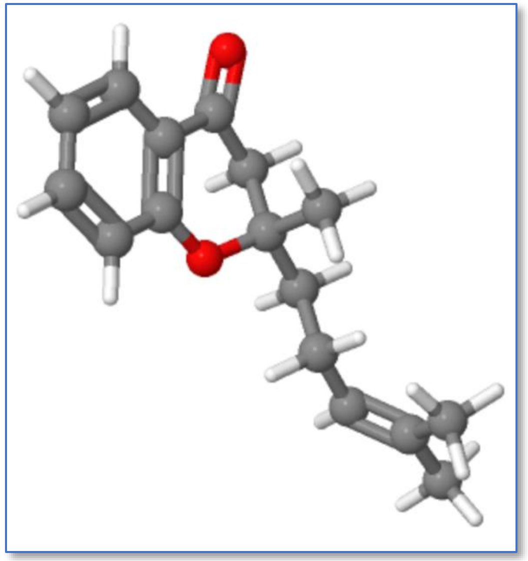
- Not directly observed—the submicroscopic level is based on hypotheses and theories derived from experiments.
- Typically strives for as much physical accuracy as possible (in contrast to the symbolic level)
- Models of atoms and molecules involving small numbers of particles
- Interactions between atoms within molecules (e.g., bonds); interactions between small numbers of molecules

2-Methyl-2-(4-methylpent-3-en-1-yl)chroman-4-one

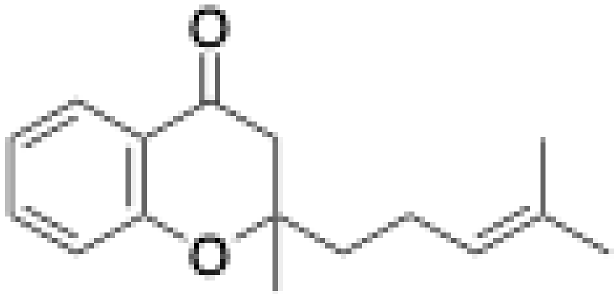
Macroscopic



Submicroscopic



Symbolic



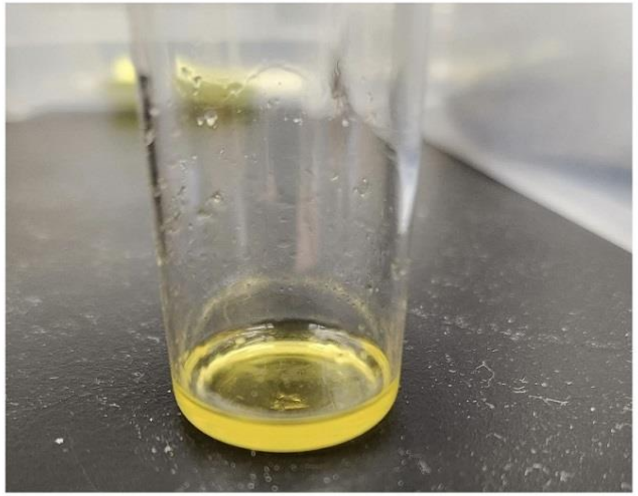
$C_{16}H_{20}O_2$

The Symbolic Level

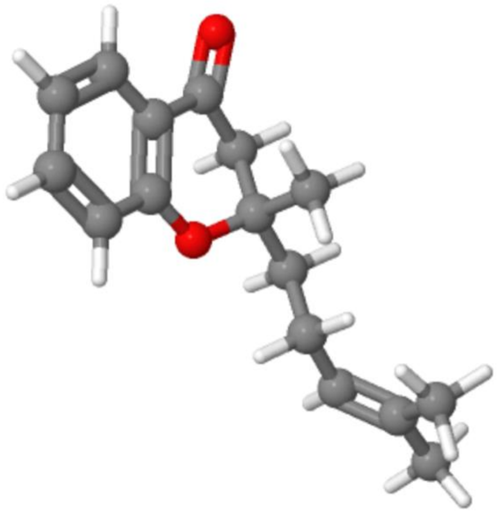
- Textual or graphical **representations** of chemical substances or chemical change
- The goal is usually efficient communication of information, sometimes at the expense of physical accuracy.

2-Methyl-2-(4-methylpent-3-en-1-yl)chroman-4-one

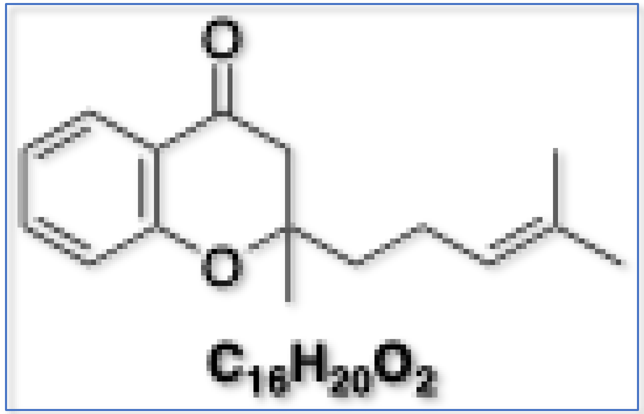
Macroscopic



Submicroscopic



Symbolic



Molecular and Ionic Compounds

- On the submicroscopic level, we distinguish between compounds composed of discrete molecules and those composed of an essentially infinite network of ions or atoms.
    - **Molecular compounds** contain discrete molecules: identical collections of small numbers of atoms bonded together with large distances between them
    - **Ionic compounds** contain an essentially infinite lattice of positive and negatively charged ions
    - **Covalent network solids** contain an essentially infinite lattice of atoms linked by covalent bonds

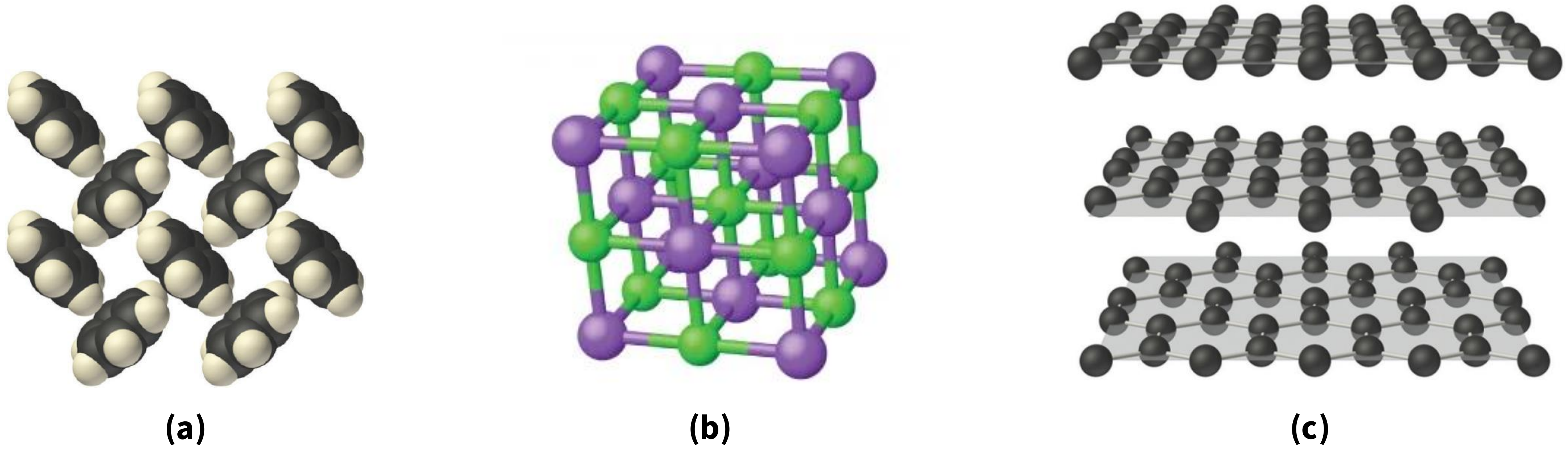


Figure. Submicroscopic models of molecular compounds (a, benzene), ionic compounds (b, sodium chloride), and covalent network solids (c, graphite). Adapted from [Network Covalent Solids and Ionic Solids] on Chemistry LibreTexts.

Submicroscopic Models of the States of Matter

- Chemists are typically concerned with three **states of matter**: gas, liquid, and solid. Solids and liquids are collectively known as **condensed states**.
- **Solids** hold their volume, do not flow, and consist of particles held closely together with little to no free movement.
- **Liquids** also hold their volume but are able to flow; particles in a liquid are held close together but can tumble over one another.
- **Gases** consist of isolated particles separated by large distances. Gases expand freely to fill the volume of the container.

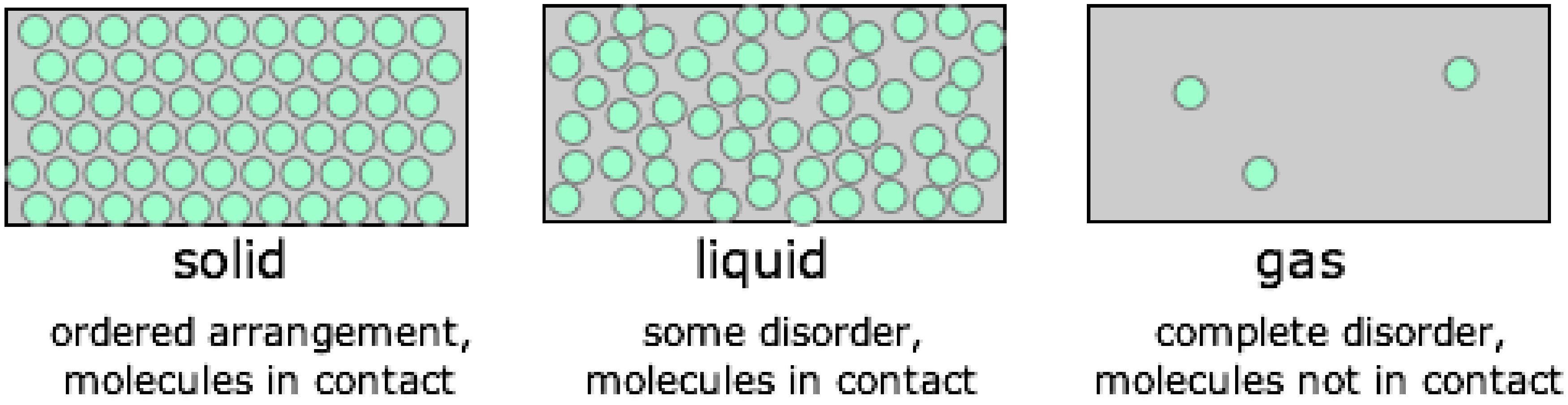


Figure. Submicroscopic models of solid, liquid, and gas. From [Matter Under the Microscope]() on Chemistry LibreTexts.

Phase Designators

- A **phase designator** is an abbreviation in parentheses after a chemical formula that indicates the state or phase of the substance. Phase designators help us use the correct submicroscopic model!
  - Pure solids are denoted with ***(s)***. For example, solid sodium chloride is NaCl(*s*).
  - Pure liquids are denoted with **(ℓ)**. For example, liquid water is $H_2O(\ell)$.
  - Gases are denoted with ***(g)***. For example, gaseous oxygen is $O_2(g)$.
  - Solutes dissolved in water are denoted with ***(aq)***. For example, sodium chloride dissolved in water is NaCl(*aq*).

- Note the same chemical formula may be associated with different phase designators in pure form and in solution!

- Solutions are discussed in more detail in module 3.

Lingering Questions

- Here, we focused on submicroscopic models of pure substances. How do we think about submicroscopic models of mixtures, particularly homogeneous mixtures (**solutions**)?

- How do particles in a substance interact with *each other*? In what ways does our submicroscopic model of a substance affect how we think about interactions *between* particles?

- Chemical bonds are commonly represented as sticks or lines in symbolic and submicroscopic representations. What exactly is a chemical bond? Why do atoms "stick together"?