Module 3: Atoms and Molecules

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1 Overview

1. the **Law of Mass Conservation** says matter can't be created or destroyed
2. **Elements** are the color palette for matter
3. **Compounds** are made of elements that are chemically combined
4. the **Periodic Table** is a thing of rare beauty that will haunt your dreams

2 Mass Conservation

Law 1 (The Law of Conservation of Mass) *Matter cannot be created or destroyed, it can only change forms.*

- this is another conservation law, like the energy conservation law in Module 2
- we can't actually create matter, and we can't actually destroy it, all we can do is convert it from one form to another [1]
- we can convert matter with chemical processes (*e.g.* we can burn wood or wax)
- we can change the state of matter with physical processes (*e.g.* we can freeze water to make ice or evaporate water to make water vapor)
- but we generally can't make more of it, and we can't make less of it

[1] OK, so this isn't *exactly* true: Lavoisier (1743 – 1794) came along when people were still trying to digest Newton (1642 – 1727), they weren't ready for Einstein (1879 – 1955) yet. Let's leave this one here for now, but you should be aware that nuclear reactions really do convert matter into energy.

3 Elements

Definition 1 (Decomposition) *Decomposition is breaking down a substance into two or more other substances.*

Definition 2 (Element) *An element is a substance that cannot be decomposed into a less massive substance.*

- **decomposition** is breaking down a substance into other substances
- many (most) substances can be decomposed, but some cannot
- substances that cannot be decomposed are called **elements** [Wile, 2003, p. 74]
- every physical thing is made up of one or more elements:
  - water is made up of two gasses: Oxygen and Hydrogen
  - sulfuric acid is made up of three gasses: Hydrogen, Sulfur, and Oxygen
  - steel is made up of two solids: Iron and Carbon
  - Iron is made of Iron — it's an element [2]

3.1 The Periodic Table

- each entry in the Periodic Table contains four pieces of information:
  1. the element's **symbol** (*e.g.* H, He, Li, Be, B, C, ...)
  2. the element's **atomic number**
  3. the element's **atomic mass**
  4. the element's location on the chart
- in general terms, the element's symbol acts as a mnemonic, although they don't always work the way we might think (why is lead called "Pb"?)
- the atomic number is unique: it's the defining feature of an element[3]
- we'll get to the atomic mass later
- be aware that not all the elements occur naturally [Wile, 2003, p. 76], there are more elements now than when I was in school(?!)

[2] It's iron all the way down!

[3] On some Periodic Tables, you'll see Hydrogen (H) listed twice, because Hydrogen is weird.

- elements on the *left* of the Periodic Table are metals; elements on the *right* are non-metals, *except Hydrogen (H)*[4]

4 Compounds

Definition 3 (Compound) *A compound is a substance that can be decomposed into elements by chemical means.*

Law 2 (The Law of Definite Proportions) *The proportion of elements in any compound is always the same.*

- there are basically two types of matter: elements and compounds
- a compound is a substance made up of elements (*e.g.* water, steel, sulfuric acid)
- note compounds are made of elements combined *chemically*: bolting a piece of Iron to a piece of Tin doesn't make a compound

5 The Law of Multiple Proportions

Law 3 (The Law of Multiple Proportions) *If two elements combine to form different compounds, the ratio of masses of the* second *element that react with a fixed mass of the* first *element will be a simple, whole-number ratio.*

- this one is easier to understand than it seems:
  - if we have two compounds made up of two elements
  - and if they use the same amount (mass) of one of the elements, then:
  - the amount (mass) of the *other* element in one compound will be a simple ratio of the mass of that same element in the *other* compound
- so if you compare water (H_2O) and hydrogen peroxide (H_2O_2), if you have the same amount of H in each compound (by *mass*), then you'll have twice as much O in the second compound as in the first
- or if you compare water and hydronium (H_3O^+), if you have the same amount of O in each compound, the ratio of H in the two compounds will be $2:3$, a simple, whole-number ratio
- or if you compare hydrogen peroxide and hydroxyl (OH^-), if you have the same amount of O in each compound, the ratio of H in the two compounds will be $1:1$, a simple, whole-number ratio

[4] I told you Hydrogen is weird.

6 Dalton's Atomic Theory

- John Dalton (1766 – 1844) came up with an atomic theory [Wile, 2003, p. 83–85]
    1. all elements are composed of small, indivisible particles called "atoms"
    2. all atoms of the same element have exactly the same properties
    3. atoms of different elements have different properties
    4. compounds are formed when atoms are joined together — since atoms are indivisible, they can only join in simple, whole-number ratios
- as far as it goes, Dalton's Atomic Theory is [mostly] correct
- chemical reactions are just atoms rearranging: they don't create new atoms, nor do they destroy existing atoms
- the total number of atoms stays the same, so the total amount of mass stays the same (see Law 1)
- since atoms are indivisible, they can only combine in consistent ratios (see Law 2)
- since atoms are indivisible, they can only combine in whole-number ratios (see Law 3)
- it turns out atoms aren't actually indivisible: they, too, are made of smaller particles [Wile, 2003, p. 85]
- it turns out atoms of a single element aren't actually identical: there are slight variations in mass between *isotopes* [Wile, 2003, p. 85]

7 Molecules

- compounds are made of *molecules*, which are groups of connected atoms
- just like elements are made of identical atoms, compounds are made of identical molecules

8 Abbreviating and Classifying Compounds

- we write compounds based on the elements that make them up
- the written compounds are called *chemical formulae*
- *e.g.* water is made up of two Hydrogen atoms and one Oxygen atom, so we write it as H_2O

- *e.g.* table salt is made up of one Sodium atom and one Chlorine atom, so we write it as NaCl
- *e.g.* sulfuric acid is written as H_2SO_4, so each molecule contains two Hydrogen atoms, one Sulfur atom, and four Oxygen atoms

9 Ionic and Covalent Compounds

Definition 4 (Iconic Compound) *A compound made of at least one metal and at least one non-metal is an* Iconic Compound

Definition 5 (Covalent Compound) *A compound made solely of non-metal atoms is a* Covalent Compound

9.1 Examples

Example 1 Is H_2O an ionic or covalent compound?

Example 2 Is NaCl an ionic or covalent compound?

Example 3 Is $PbSO_4$ an ionic or covalent compound?

10 Naming Compounds

- to name ionic compounds:
  1. start with the name of the first atom in the compound
  2. take the next atom and replace its ending with the "-ide" suffix
  3. combine those to get a name
- so NaCl is "sodium chloride"
- and PbO is "lead oxide"
- and $PbCl_2$ is "lead chloride"
- naming covalent compounds is a little more complicated, because they can form in more variations...
- to name covalent compounds:
  1. start with the name of the first atom in the molecule
  2. take the next atom and replace its ending with the "-ide" suffix
  3. add the appropriate prefix to each atom in order to indicate count (see Table 1)

Prefix	Count
mono	one
di	two
tri	three
tetra	four
penta	five
hecta	six
hepta	seven
octa	eight
nona	nine
deca	ten

Table 1: Prefixes for Covalent Compound Names

4. you can drop the "mono-" prefix off the first atom
5. combine those to get a name

- so H_2O is "dihydrogen monoxide"
- so CO is "carbon monoxide"
- so CO_2 is "carbon dixide"

Beware that there are many compounds with other names that don't seem to fit our scheme:

- H_2O (dihydrogen monoxide) is also called "water"
- H_2O_2 (dihydrogen dioxide) is also called "hydrogen peroxide"
- OH^- is "hydroxyl"[5]

References

[Wile, 2003] Wile, D. J. L. (2003). *Exploring Creation with Chemistry.* Apologia Educational Ministries, Inc., 2 edition.

[5] We'll spend a lot more time talking about this one later.