Part V

Elements and Atomic Weights

Element ~ **One dictionary defines it as a substance with "a chemical composition that is in a class unto itself here on earth and even in this universe." Another defines it as a substance containing "atoms of only one kind that singly or in combination constitute all matter."**

To put it simply, elements are the basic building blocks of the chemical and physical world, as we know it.

While many of us remember this basic concept from high school chemistry class, details such as the name, abbreviation, and atomic weight[2] of each element are probably a bit fuzzy. This is understandable as there are more than 100 elements recognized by the international scientific community. Fortunately, a list of elements and their international atomic weights can be found in most chemistry books, in some dictionaries, and at a number of on-line web sites.[3] (A good reference source for anyone working in the aquatic sciences is *STANDARD METHODS for the Examination of Water and Wastewater*.) For your convenience however, we've provided a table of international relative atomic weights in this section along with a brief explanation of how relative atomic weights are determined (page 29) and how they are used to calculate the molecular weight of the various chemical compounds found on earth (page 30).

Why do we need to know about elements and their atomic weights?

For starters, many elements, including calcium, magnesium, nitrogen, phosphorus and silicon, are considered to be important nutrients found in aquatic environments. Familiarity with their names and abbreviations is useful from a communications perspective as scientists commonly use abbreviated terminology in their journal articles, graphs, charts, and lectures. For example, when a scientist discusses the effects of "**N**" or "**P**" in a lake system, an educated reader/listener will know that the scientist is referring to the elements nitrogen or phosphorus, respectively.

Secondly, knowledge of an element's atomic weight is required for accuracy when converting from one unit of measure to another. A marine scientist, for instance, might record nutrient concentrations in units of **micromoles per liter** (µM/L) while a freshwater scientist may use **milligrams per liter** (mg/L) or **micrograms per liter** (µg/L). If either scientist wants to combine databases for comparison, conversions would need to be made to standardize the units of measure. To make the conversions, the atomic weight of each element, such as nitrogen or phosphorus, would have to be known. An explanation of how to do these conversions is provided in Section VII on page 35. And remember, if you should encounter any difficulties converting from one unit of measure to another, don't feel bad as this can be a difficult task even for professionals!

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[2] *An element's atomic weight is approximately equal to the number of protons and neutrons found in an atom.*

[3] *Atomic Weights of the Elements. 1999. World Wide Web version prepared by G.P. Moss, originally from a file provided by D.R. Lide.* <http://www.chem.qmw.ac.uk/iupac/AtWt/>

International Relative* Atomic Weights

Element	Symbol	Atomic Weight
Actinium	Ac	227**
Aluminum	Al	26.981538
Americium	Am	243
Antimony	Sb	121.760
Argon	Ar	39.948
Arsenic	As	74.92160
Astatine	At	210
Barium	Ba	137.327
Berkelium	Bk	247
Beryllium	Be	9.012182
Bismuth	Bi	208.98038
Bohrium	Bh	264
Boron	B	10.811
Bromine	Br	79.904
Cadmium	Cd	112.411
Calcium	Ca	40.078
Californium	Cf	251
Carbon	C	12.0107
Cerium	Cc	140.116
Cesium	CS	132.9054
Chlorine	Cl	35.453
Chromium	Cr	51.9961
Cobalt	Co	58.933200
Copper	Cu	63.546
Curium	Cm	247
Dubnium	Db	262
Dyprosium	Dy	162.50
Einsteinium	Es	252
Erbium	Er	167.259
Europium	Eu	151.964
Fermium	Fm	257
Fluorine	F	18.9984032
Francium	Fr	223
Gadolinium	Gd	157.25
Gallium	Ga	69.723
Germanium	Ge	72.64
Gold	An	196.96655
Hafnium	Hf	178.49
Hassium	Hs	277
Helium	He	4.002602
Holmium	Ho	164.93032
Hydrogen	H	1.00794
Indium	In	114.818
Iodine	I	126.90447
Iridium	Ir	192.217
Iron	Fc	55.845
Krypton	Kr	83.80
Lanthanum	La	138.9055

Element	Symbol	Atomic Weight
Lawrencium	Lr	262
Lead	Pb	207.2
Lithium	Li	6.941
Lutetium	Lu	174.967
Magnesium	M	24.3050
Manganese	Mn	54.938049
Meitnerium	Mt	268
Mendelevium	Md	258
Mercury	Hg	200.59
Molybdenum	Mo	95.94
Neodymium	Nd	144.24
Neon	Ne	20.1797
Neptunium	Np	237
Nickel	Ni	58.6934
Niobium	Nb	92.90638
Nitrogen	N	14.0067
Nobelium	No	259
Osmium	Os	190.23
Oxygen	Os	15.9994
Palladium	Pd	106.42
Phosphorus	P	30.973761
Platinum	Pt	195.078
Plutonium	Pu	244
Polonium	Po	209
Potassium	K	39.0983
Praseodymium	Pr	140.90765
Promethium	Pm	145
Protactinium	Pa	231.03588
Radium	Ra	226
Radon	Rn	222
Rhenium	Re	186.207
Rhodium	Rh	102.90550
Rubidium	Rb	85.4678
Ruthenium	Ru	101.07
Rutherfordium	Rf	267
Samarium	Sm	150.36
Scandium	Sc	44.955910
Selenium	Se	78.96
Seaborgium	Sg	266
Silicon	Si	28.0855
Silver	Ag	107.8682
Sodium	Na	22.989770
Strontium	Sr	87.62
Sulfur	S	32.065
Tantalum	Ta	180.9479
Technetium	Tc	98
Tellurium	Te	127.60
Terbium	Tb	158.92534

International Relative[*] Atomic Weights

Element	Symbol	Atomic Weight
Thallium	TI	204.3833
Thorium	Th	232.0381
Thulium	Tm	168.93421
Tin	Sn	118.710
Titanium	Ti	47.867
Tungsten	W	183.84
Ununilium	Uun	281
Ununquadium	Uuq	289
Uranium	U	238.02891
Vanadium	V	50.9415
Xenon	Xe	131.293
Ytterbium	Yh	173.04
Yttrium	Y	88.90585
Zinc	Zn	65.39
Zirconium	Zr	91.224

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[*] Based on the assigned relative atomic mass of $^{12}C=12$.

[**] Relative weights shown here as whole numbers indicate the mass number of the longest-lived isotope of that element.

Note: The atomic weights you may see here and in other publications may vary slightly. This is due to each publisher rounding off the numbers differently. It's also important to note that atomic weight values are periodically re-determined; this may also contribute to minor differences in weights shown.

Relative Atomic Weights

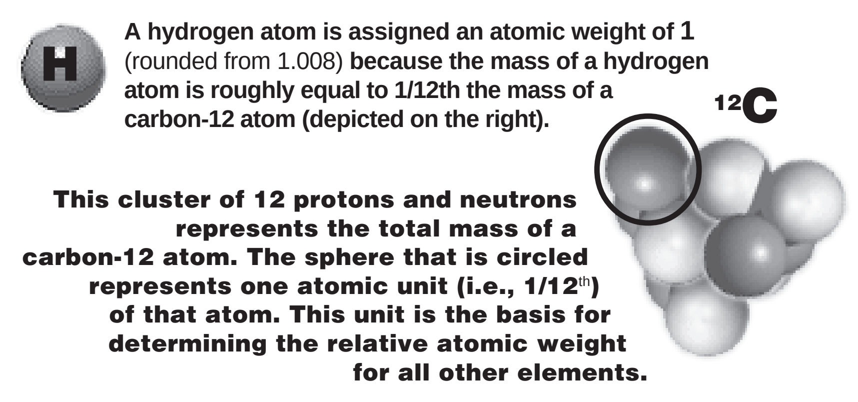
Before the age of nuclear technology, scientists were limited to studying chemical reactions that involved large numbers of atoms at once, as there were no methods for isolating a single atom to determine its weight. However, scientists were able to devise a system for assigning weights to the elements by comparing how heavy a given atom was in relation to other atoms. This is known as the system of relative atomic weights. The following is a brief explanation of how it works.

The current practice is to express the weight of a given element as it relates to the weight of some known standard. In recent years, the accepted standard is a carbon isotope known as **carbon-12** with an assigned weight of 12 atomic mass units.[*] Using only one of these twelve units (i.e., 1/12th), we can assign atomic weights for all the other elements.

In other words, when expressing the atomic weight of an element, we simply need to express the mass of that element relative to the mass of one-twelfth of a carbon-12 atom. These units of weight are referred to as "atomic mass units."

Take hydrogen, for example. The relative atomic weight of hydrogen is expressed as **1.008**. This means that the mass of a hydrogen atom is slightly greater than one-twelfth the mass of a carbon-12 atom.[**] ***See illustration below.***

We can use the element copper (**Cu**) as a second example. Copper has a relative atomic weight of **63.546**. This means that the mass of a copper atom is nearly 64 times that of one carbon-12 atomic unit (i.e., 1/12th).



A hydrogen atom is assigned an atomic weight of 1 (rounded from 1.008) **because the mass of a hydrogen atom is roughly equal to 1/12th the mass of a carbon-12 atom (depicted on the right).**

This cluster of 12 protons and neutrons represents the total mass of a carbon-12 atom. The sphere that is circled represents one atomic unit (i.e., 1/12th) of that atom. This unit is the basis for determining the relative atomic weight for all other elements.

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[*] To further visualize this, imagine 12 individual spheres clustered together as seen in the figure below.

[**] The expressed weight of 1.008 is the ***average*** *weight of naturally occurring hydrogen; the reason it is not exactly 1.000 is that a small fraction of naturally occurring hydrogen atoms have a weight of 2, rather than 1.*

Part VI

Interpreting Water Chemistry Formulas and Calculating Molecular Weights

Now that we've got a better understanding of relative atomic weights (see page 29), **we can begin to consider chemical compounds and learn how to interpret them.**

It's important to be able to interpret such formulas because elements are rarely found alone in nature. More often than not, they combine with other elements to form chemical substances or compounds. For example, let us consider one of the most commonly known compounds — water. The abbreviation alone tells us that a water molecule ($\mathbf{H_20}$) is comprised of two atoms of hydrogen ($\mathbf{H_2}$) and one atom of oxygen (**O**). When combined with one more atom of oxygen, we end up with a compound known as hydrogen peroxide ($\mathbf{H_2O_2}$).

We can find the molecular weight of a chemical compound by totaling up the weight, in atomic mass units, of all the atoms in that given formula.

We use molecular weights to describe how many grams are in one **mole*** of a substance. When dealing with concentrations of chemicals, it's often helpful to know the molecular weight of a specific compound so that we can evaluate how it is interacting with other substances. While you may not have the opportunity to do this in a laboratory, it is still helpful to be able to interpret the language used by the chemists. Learning to calculate the molecular weight of a substance is the first step toward a better understanding of water chemistry. To help you in this endeavor, we've provided several practice exercises below.

A mole is the standard unit of measure used by chemists for communicating quantities of a chemical compound; a mole is also referred to as a* ***gram molecule**. The term "*mole*" is abbreviated as "mol" or "M."*

Step 1

Before we can calculate the molecular weight of a chemical compound, we need to know how many atoms are present for each element.

For the purposes of this exercise, we've chosen three chemical compounds that are commonly associated with water chemistry.

For NaCl *(sodium chloride)* there will be:

- one atom of sodium (**Na**)
- one atom of chlorine (**Cl**)

For $\mathrm{CaC0_3}$ *(calcium carbonate)* there will be:

- one atom of calcium (**Ca**),
- one atom of carbon (**C**)
- three atoms of oxygen (**O**)

For $\mathrm{Fe(OH)_3}$ *(hydrated ferric hydroxide)* there will be:

- one atom of iron (**Fe**),
- three atoms of oxygen (**O**)
- three atoms of hydrogen (**H**)

Note: If a subscript follows an atom abbreviation with no parenthesis, that number tells us how many atoms are present for that element. If parentheses are involved, you must multiply each individual subscript on the inside of the parentheses by the subscript number on the outside.

Step 2

To calculate the molecular weight of a substance or compound, you must first know the atomic weight of each element within the compound.

International Relative Atomic weights can be found in the table on pages 28-29. For your convenience, we've provided atomic weights for the compounds used in this exercise.

NaCl {
Na = 22.989770
Cl = 35.453

$\mathrm{Fe(OH)_3}$ {
Fe = 55.845
O = 15.9994
H = 1.00794

$\mathrm{CaCO_3}$ {
Ca = 40.078
C = 12.0107
O = 15.9994

Step 3

Once you have a relative atomic weight for each element in a compound, multiply the weight of each atom by the number of atoms that are present in the formula, then add the answers.

NaCl

One atom of sodium (Na) = 1 x 22.989770 = **22.989770**
One atom of chlorine (Cl) = 1 x 35.453 = **35.453**

Add these values for the molecular weight:

22.989770 + 35.453 = **58.44277** atomic mass units (amu)

The answer **58.44277** represents the molecular weight for one mole of **NaCl** in atomic mass units (amu).

$\mathrm{CaCO_3}$

One atom of calcium (Ca) = 1 x 40.078 = **40.078**
One atom of carbon (C) = 1 x 12.0107 = **12.0107**
Three atoms of oxygen (O) = 3 x 15.9994 = **47.982**

Add these values for the molecular weight:

40.078 + 12.0107 + 47.982 = **100.0707** atomic mass units (amu)

The answer **100.0707** represents the molecular weight for one mole of **$\mathrm{CaCO_3}$**.

$\mathrm{Fe(OH)_3}$

One atom of iron (Fe) = 1 x 55.845 = **55.845**
Three atoms of oxygen (O) = 3 x 15.9994 = **47.982**
Three atoms of hydrogen (H) = 3 x 1.00794 = **3.02382**

Add these values for the molecular weight:

55.845 + 47.982 + 3.02382 = **106.85082** atomic mass units (amu)

The answer **106.85082** represents the molecular weight for one mole of **$\mathrm{Fe(OH)_3}$**.

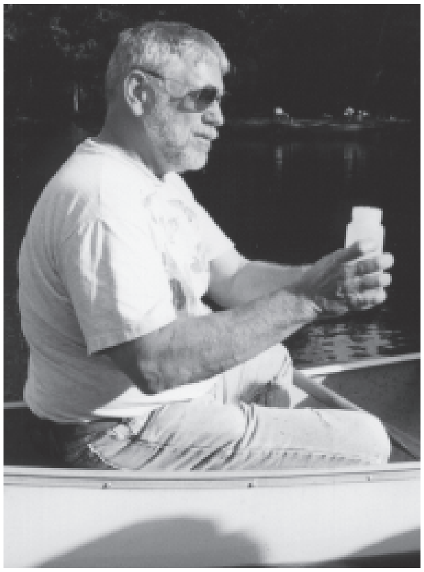
Part VII

Different Ways of Expressing a Chemical Compound

Many elements that are important to lakes are found in more than one chemical form. **Nitrogen** (**N**) is a good example. It can combine with two oxygen atoms to form **nitrites** (expressed by the compound formula **NO_2^{-1}**) or it can combine with three oxygen atoms to form nitrates (**NO_3^{-1}**). Ammonium ions (**NH_4^{+1}**) are formed when one nitrogen atom is combined with four hydrogen atoms. Nitrogen can also be found in various organic molecules produced by living organisms in lakes.[5]

The sum of these various nitrogen compounds is known as **total nitrogen**. We often rely on total measurements because some elements, nitrogen included, tend to continually transfer from one form to another through the metabolism of aquatic organisms, making it difficult to track individual chemical compounds. This is true for phosphorus as well. Florida LAKEWATCH measures total phosphorus concentrations for the same reason. These compounds are commonly measured in concentrations of milligrams per liter (mg/L) or micrograms per liter (µg/L).

There are times however, when we may want to isolate and measure a specific chemical compound. A case in point is the standard that has been set for nitrates in drinking water: In most communities in the United States, the maximum amount of nitrates allowed in drinking water is considered to be **45 mg/L NO_3**. (While occurrences have been rare, it's been found that in small babies, higher nitrate levels can interfere with the ability of the blood to carry oxygen, resulting in a phenomenon known as the *blue baby syndrome*.)



Joe Richard

Because nitrogen compounds are constantly changing within an aquatic environment, some water monitoring programs, including Florida LAKEWATCH, prefer to measure total nitrogen concentrations. Such information helps scientists estimate the potential for biological productivity in a waterbody.

If we made a separate measurement of just the nitrogen contained in the **nitrate** formula mentioned above, we would express the concentration as **10.2 mg/L NO_3-N**. This is known as a **nitrate-nitrogen** formula. An interpretation of this particular formula tells us that there are **10.2 mg** of nitrogen contained within the nitrates in a liter of water. The "**–N**" symbol found in the latter portion of the formula tells us that the number value (**10.2 mg/L**) is describing the weight of nitrogen only contained in that compound.

A similar approach would be used if we were to make a

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[5] *Organic molecules are formed by the actions of living things and/or have a carbon backbone. Methane (CH_4) is an example, although it's important to note that not all methane is formed by living organisms.*

separate measurement of the nitrogen contained in an ammonium compound. The formula would be expressed as **mg/L NH4 -N** and is known as an **ammonium–nitrogen** formula. And if we wanted to measure the weight of nitrogen only as it combines with organic molecules, we would use an **organic-nitrogen** formula expressed as **mg/L organic-N.**

As you can see from the examples above, a nitrate formula is expressed differently than a nitrate-nitrogen formula, even though they both represent measurements of nitrates found in one liter of water.

To convert units of nitrates to units of nitrate-nitrogen we need to multiply by a conversion factor consisting of the atomic weight of nitrogen divided by the combined atomic weights of one nitrogen and three oxygen atoms. An example of this conversion process is provided below.

Note: The same approach can be used for other chemical compounds found in water. For instance, there may be times when one would want to isolate the weight of phosphorus contained in phosphates or the weight of sulfur contained in sulfates, etc.

Converting from nitrates to nitrate – nitrogen

$$45\ \text{mg/L NO}_3 = 45 \times (14^{*} \div (14 + 48^{**})) = \ ?$$

(original nitrate formula)

⬇ ⬇ ⬇

$$45\ \text{mg/L NO}_3 = 45 \times 0.226 = 10.2\ \text{mg/L NO}_3\text{– N}$$

(nitrate-nitrogen formula)

[*] ***14** is the relative atomic weight for **nitrogen** (rounded from 14.00674).*

[**] *The number **48** was attained by multiplying the relative atomic weight of a single oxygen atom (16) by 3, as there are three oxygen atoms in a nitrate molecule.*

The nitrate formula *(top left)* **tells us that there is a total concentration of 45 mg of nitrates in a liter of water. After doing the conversion, the nitrate – nitrogen formula** *(bottom right)* **tells us that out of the 45 mg/L of nitrates, there are 10.2 mg of actual nitrogen within that same liter of water. It should be noted that the nitrate – nitrogen formula is currently being used by most water chemistry labs as the preferred way to express this relationship.**

Part VIII

Using Atomic Weights to Compare Different Measures of Concentration


Amy Richard


Joe Richard

Kelly Schulz (left) processes total phosphorus samples for the Florida LAKEWATCH program at a UF/IFAS water chemistry laboratory. The freshwater total phosphorus concentrations she records into the LAKEWATCH database are expressed as micrograms per liter (µg/L). Erin Bledsoe (right) prepares a Van Dorn sampler before lowering it into marine offshore waters for a sample. Phosphorus and nitrogen concentrations found in saltwater samples are often expressed as micromoles per liter (µM/L). If the two were to be compared, conversions would be needed.

Although most aquatic scientists have adopted the International System (SI) for standardizing scientific units of measure, it doesn't necessarily mean they will use the same units of measure for the same things. For example, scientists who study saltwater systems (i.e., oceanographers, etc.) and those that study freshwater systems (i.e., limnologists) often express their work differently. Oceanographers tend to use the micromole per liter (µM/L) as a unit of measure in their analyses while limnologists tend to use the milligram per liter (mg/L) or microgram per liter (µg/L) units of measure for their studies.

This isn't a problem unless one scientist decides to compare his or her data with those of another, in which case conversions must be made so that one can compare "apples with apples." See the examples on the next page for an explanation on how atomic weights are used to convert from one unit of measure to another.

Converting micromoles per liter (µM/L) to micrograms per liter (µg/L)

To convert a concentration of an element given as **micromoles per liter** (µM/L) to units of **micrograms per liter** (µg/L), you would simply **multiply** the concentration in **micromoles** times the relative atomic weight of the element. For example, to convert a phosphorus concentration of **10 µM P/L** to units of **µg P/L**, you would multiply **10** times the relative atomic weight for phosphorus (**31**)* to get **310 µg/L** of phosphorus. *Notice how the abbreviation for phosphorus (P) is expressed in the equation below.*

10 µM P/L = 10 (micromoles) X **31** (relative atomic weight for phosphorus) = **310 µg P/L**

* *Using the table on page 28 we can see that the relative atomic weight for phosphorus is 31 (rounded from 30.973761).*

Converting micrograms per liter (µg/L) to micromoles per liter (µM/L)

To convert a concentration of an element given as **micrograms per liter** (µg/L) to units of **micromoles per liter** (µM/L), you would **divide** the concentration in micrograms by the relative atomic weight of the element. For example, to convert a nitrogen concentration of **100 µg/L** to units of **µM/L** you would divide **100** by nitrogen's relative atomic weight of **14** to get **7.142 µM/L** of nitrogen. *Notice how the abbreviation for nitrogen (N) is expressed in the equation below.*

100 µg N/L = 100 (micrograms) ÷ **14** (relative atomic weight for nitrogen) = **7.142 µM N/L**

* *Using the table on page 28 we can see that the relative atomic weight for nitrogen is 14 (rounded from 14.0067).*

Speaking in Molecular Terms

The following are terms that you are likely to hear within the water chemistry arena:

Atomic weight is approximately equal to the number of protons and neutrons found in an atom.

Gram atomic weight refers to the weight of an element in units of grams. Along those same lines, if one were to express the weight of an element in units of milligrams, you would then refer to it as the milligram atomic weight.

Micromolar solution refers to the molecular weight of a substance expressed as "micrograms contained in one liter of water" (i.e., one-millionth of a gram molecular weight). For example a micromolar solution of phosphorus contains 31 micrograms (µg) of phosphorus in one liter of water.

Molar solution is one mole dissolved in enough water to make one liter.

Mole is the molecular weight of a substance expressed in grams; also known as a gram molecule. Chemists tend to use moles to describe chemical compounds.

Molecular weight refers to the combined (the sum) atomic weight of all the atoms in a molecule.

Relative atomic weight refers to the relative weight of each element, based on the assigned relative atomic mass of $^{12}C = 12$.

Selected Scientific References

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