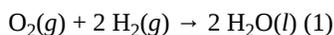


2.5.1: Biology- Water

Two criteria are usually applied to any theory. First, does it agree with facts which are already known? Second, does it predict new relationships and stimulate additional observation and experimentation? Dalton's atomic theory was able to do both of these things. It was especially useful in dealing with data regarding the masses of different elements which were involved in chemical compounds or chemical reactions.

To test a theory, we first use it to make a prediction about the macroscopic world. If the prediction agrees with existing data, the theory passes the test. If it does not, the theory must be discarded or modified. If data are not available, then more research must be done. Eventually the results of new experiments can be compared with the predictions of the theory. One hallmark of a *scientific* theory is that it suggests tests that may falsify the theory. Non-scientific theories do not. For example, Intelligent Design (ID) theory proposes that the world was created by an intelligent designer, but proposes no tests of that claim. It's a theory, but not a *scientific* theory.

Several examples of this process of testing a theory against the facts are afforded by Dalton's work. For example, postulate 3 in [Dalton's Atomic Theory](#) states that atoms are not created, destroyed, or changed in a chemical reaction. Postulate 2 says that atoms of a given element have a characteristic mass: By logical deduction, then, equal numbers of each type of atom must appear on left and right sides of chemical equations such as



and the total mass of reactants must equal the total mass of products. Dalton's atomic theory predicts Lavoisier's experimental law of conservation of mass.

A second prediction of the atomic theory is a bit more complex. A compound is made up of molecules, each of which contains a certain number of each type of atom. No matter how, when, or where a compound is made, its molecules will always be the same. Thus water molecules always have the formula H_2O . No matter how much we have or where the compound came from, there will always be twice as many hydrogen atoms as oxygen atoms. Since each type of atom has a characteristic mass, the mass of one element which combines with a fixed mass of the other should always be the same. In water, for example, if each oxygen atom is 15.873 times as heavy as a hydrogen atom, the ratio of masses would be

$$\frac{\text{mass of 1 O atom}}{\text{mass of 2 H atoms}} = \frac{15.873 \times \text{mass of 1 H atom}}{2 \times \text{mass of 1 H atom}}$$

and cancelling "mass of 1 H atom" in the numerator and denominator we get

$$\frac{15.873}{2} = \frac{7.937}{1}$$

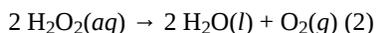
No matter how many water molecules we have, each has the same proportion of oxygen, and so *any* sample of water must have 7.937 times as much oxygen as hydrogen. We have just derived the **law of constant composition**, sometimes called the **law of definite proportions**. When elements combine to form a compound, they always do so in exactly the same ratio of masses. This law had been postulated in 1799 by the French chemist Proust (1754 to 1826) four years before Dalton proposed the atomic theory, and its logical derivation from the theory contributed to the latter's acceptance. The law of constant composition makes the important point that the composition and other properties of a *pure* compound are independent of who prepared it or where it came from. The carbon dioxide found on Mars, for instance, can be expected to have the same composition as that on Earth, while the natural vitamin C extracted and purified from rose hips has exactly the same composition as the synthetic vitamin C prepared by a drug company. Absolute purity is, however, an ideal limit which we can only approach, and the properties of many substances may be affected by the presence of very small quantities of impurities.

A third law of chemical composition may be deduced from the atomic theory. It involves the situation where two elements can combine in more than one way, forming more than one compound. For example, hydrogen and oxygen form another compound, hydrogen peroxide, modeled here:

This is a "Jmol" model. If you place the mouse pointer on the molecule, hold down the left mouse key, and move the mouse, you can rotate the model to get a 3D perspective. The oxygen atoms are red, hydrogen gray.

Hydrogen peroxide is a pale blue liquid that freezes just 0.4°C below 0°, boils at 150.2°C, and is slightly more viscous than water. It is used in 3% water solution as an antiseptic (it's used to disinfect biological safety cabinets) and bleaching agent. Pure hydrogen peroxide is a dangerous oxidizer, used in rocket engines, which burns skin even in 10% water solutions. Surprisingly, is naturally produced in organisms as a byproduct of oxygen metabolism. Nearly all living things possess enzymes known as peroxidases, which very rapidly catalytically decompose low concentrations of hydrogen peroxide to water and oxygen.

From the molecular model of hydrogen peroxide, you can readily see that its chemical formula is H₂O₂. (Since there are two atoms of each kind in the molecule, it would be incorrect to write the formula as HO). Hydrogen peroxide cannot be synthesized directly by the reaction of hydrogen and oxygen, and it decomposes to water and oxygen:



From the formulas H₂O and H₂O₂ we can see that water has only 1 oxygen atom for every 2 hydrogens, while hydrogen peroxide has 2 oxygen atoms for every 2 hydrogens. Thus, for a given number of bromine atoms, hydrogen peroxide will always have twice as many oxygen atoms as water. Again using postulate 2 from [Dalton's Atomic Theory](#), the atoms have characteristic masses, and so a given number of hydrogen atoms corresponds to a fixed mass of hydrogen. Twice as many oxygen atoms correspond to twice the mass of oxygen.

Therefore we can say that for a given mass of hydrogen, hydrogen peroxide will contain twice the mass of oxygen that water will.

✓ Example 2.5.1.1: Mass Ratio

Given that the mass of an oxygen atom is 7.937 times the mass of a hydrogen atom, calculate the mass ratio of oxygen to hydrogen in hydrogen peroxide.

Solution The formula H₂O₂ tells us that there are 2 oxygen atoms and 2 hydrogen atoms in each molecule. Thus the mass ratio is

$$\frac{\text{mass of 2 O atoms}}{\text{mass of 2 H atoms}} = \frac{2 \times 15.873 \times \text{mass of 1 H atom}}{2 \times \text{mass of 1 H atom}}$$

and again cancelling "mass of 1 H atom" in the numerator and denominator we get

$$\frac{2 \times 15.873}{2} = \frac{15.873}{1}$$

Note that the mass of oxygen per unit mass of hydrogen is double that calculated earlier for water.

The reasoning and calculations above illustrate the law of multiple proportions. When two elements form several compounds, the mass ratio in one compound will be a small whole-number multiple of the mass ratio in another. In the case of water and hydrogen peroxide, the mass ratios of mercury to bromine are 7.937 and 15.873, respectively. The second value is a small whole-number multiple of (2 times) the first.

Until the atomic theory was proposed, no one had expected *any* relationship to exist between mass ratios in two or more compounds containing the same elements. Because the theory predicted such relationships, Dalton and other chemists began to look for them. Before long, a great deal of experimental evidence was accumulated to show that the law of multiple proportions was valid. Thus the atomic theory was able to account for previously known facts and laws, and it also *predicted a new law*. In the process of verifying that prediction, Dalton and his contemporaries did many additional quantitative experiments. These led onward to more facts, more laws, and, eventually, new or modified theories. This characteristic of stimulating more research and thought put Dalton's postulates in the distinguished company of other good scientific theories.

From ChemPRIME: [2.4: Testing the Atomic Theory](#)

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