Modeling Lewis Structures with Building Bricks

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Abstract

By combining the concept of valence electrons and the idea of modeling molecules with toy building blocks, a modeling system that mimics Lewis structures was created. The ideas that are central to Lewis structures—paired and unpaired electrons, lone pairs, bonding pairs, the octet rule, single bonds, multiple bonds, formal charge—are all expressed in this modeling system. Further, the actions that the user must perform to make a molecule have a metaphorical meaning in this model, and as such, each action can help the user to better understand the Lewis model of bonding.

Keywords: General Chemistry, Introductory/High School Chemistry, Bonding Theory, Acid-Base Chemistry

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Introduction

The building brick model described herein was inspired by a passage from an article in the September 6, 1999 issue of C&E News,[1] The passage from the C&E News article follows:

> For example, Charles Adolph Wurtz (1817-84) used blocks of various widths to represent the different valencies of carbon. Joseph Loschmidt (1821-95) represented compounds with small circles for hydrogen, large circles for carbon, double circles for oxygen, and overlapping circles marked with |Cb [sic] and ≡ for double and triple bonds. And Friedrich August Kekulé (1829-96) used sausage shaped figures to represent polyvalent atoms, the number of bulges corresponding to the atom's valency.

Building bricks are a logical combination of Wurtz's "blocks of various widths" and Kekulé's "bulges corresponding to the atom's valency". It should be made clear that the building brick model is not suggested as a physical representation of the shape of any molecule; after all, existing model kits perform that function more effectively than rectangular building blocks ever could. Instead, this modeling system is suggested as a physical representation of Lewis structures that stresses the importance of valence electrons, lone pairs, bonding pairs, and the octet rule.

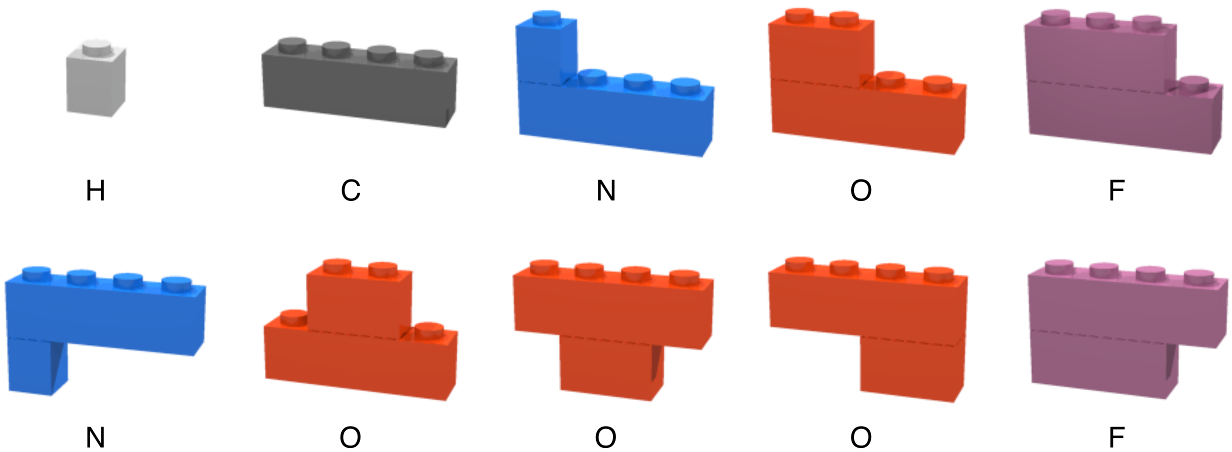
Others have used toy building blocks to aid chemical education. For example, Eric Witzel,[2] and Dean Campbell and Arthur Ellis[3,4] have published ideas for using building blocks in chemical education. Additionally, in their *Science and Technology/Engineering Curriculum Framework*[5] the Massachusetts Department of Education suggests that teachers use LEGO® bricks to model molecules. Witzel models the stoichiometry of reactions using building blocks. Campbell and Ellis use building blocks, very creatively, to model the physical appearance of a variety of objects including molecules, crystals, polymers, and analytical instruments. The brief statement in the Massachusetts curriculum framework only suggests that molecules be modeled by “assigning colors to various atoms”. Although each of these publications suggests using building blocks to model molecules, none bases the models on chemical principles. In contrast, the building brick model presented herein is based on accepted chemical theory.

The building brick modeling system is described in the *Method* section of this paper. In addition to describing the basics of the building brick modeling system, a method for tracking protons in an acid-base reaction is presented. Finally, some mechanical limitations associated with the model are also presented. In the *Discussion* section of this manuscript, several models are interpreted and the analogy used in the building brick model is examined in detail.

Method

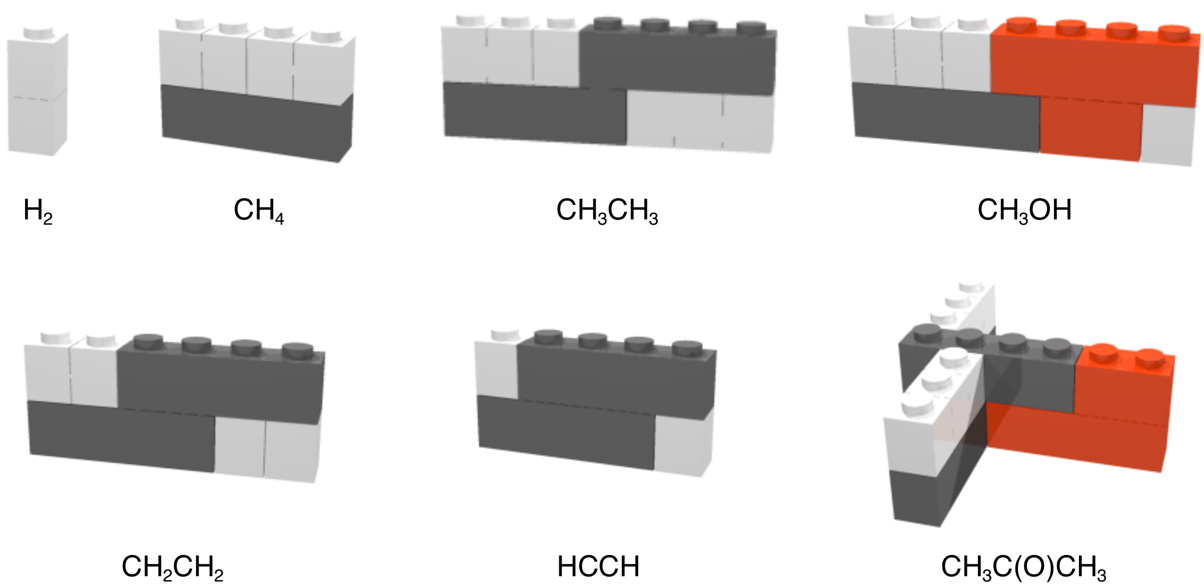
The modeling system starts with a toy building brick. A valence electron is represented by the smallest building brick, a brick that has one stud on its top and one hole in its bottom. Thus, a hydrogen atom can be represented by a one stud by one stud (1x1) brick. Atoms with more valence electrons are represented by larger bricks. For example, a carbon atom is represented by a brick one stud wide and four studs long (1x4). Atoms with more than four valence electrons are constructed by adding a second row of bricks on top of a 1x4 brick. For example, a nitrogen atom can be represented by a 1x1 brick on top of a 1x4 brick. See Figure 1 for brick models of hydrogen, carbon, nitrogen, oxygen, and fluorine atoms. Additionally, it should be noted that under this system there are several different but equivalent ways of representing atoms like nitrogen, oxygen, and fluorine.

Figure 1 A Few Brick Elements



(Top) Hydrogen and four elements from the second period. (Bottom) Alternate representations for some of the elements of the second period.

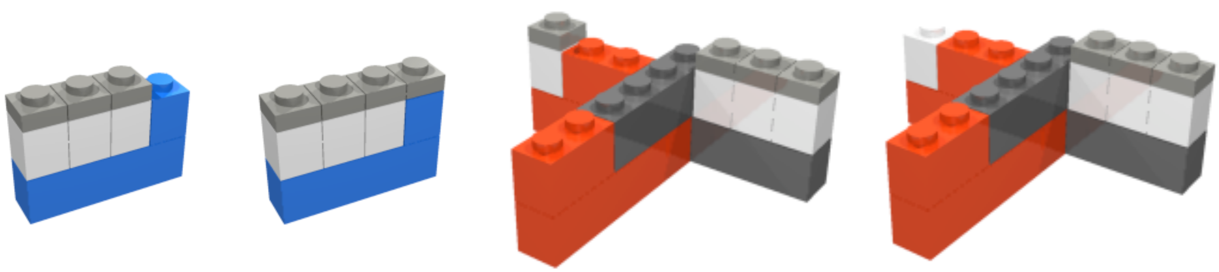
Figure 2 A Few Brick Models



Molecules are created by snapping bricks together. There are three rules. (1) A molecule is two bricks tall. (2) A stable molecule is made by making certain that the molecule is two bricks high across all bricks. (3) No bricks can be added to or removed from an atom unless one wishes to create an ion (under certain circumstances bricks can be moved from atom to atom within a molecule). Thus, anions are formed by adding extra 1x1 bricks (electrons) to elements, cations are formed by removing 1x1 bricks (electrons) from elements, and a hydrogen molecule is made by stacking a white 1x1 brick on top of another white 1x1 brick. Similarly, a methane molecule is made by stacking four white 1x1 bricks on top of a black 1x4 brick. An ethane molecule is made by combining two black 1x4 bricks and six white 1x1 bricks. A selection of molecules is presented in Figure 2. The chlorine atom and the chloride ion are compared in Figure 3.

Figure 3 Chlorine and Chloride

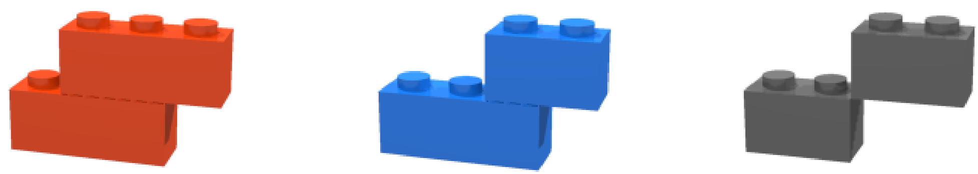
Figure 4 Models of NH_3, NH_4^+, CH_3CO_2H, and $CH_3CO_2^-$ that include the Representations for the Nuclei of the Hydrogen Atoms



To model proton transfers, protons must be included in the model. To prevent the model from becoming unnecessarily complicated, only the proton in the nucleus of the hydrogen atom is modeled. Thus, in the modified model, all extra electrons are modeled as a white 1x1 brick and hydrogen atoms are modeled using a combination of a white 1x1 brick and a dark gray 1x1 plate (plates are thinner than bricks). Models of NH_3, NH_4^+, CH_3CO_2H, and $CH_3CO_2^-$ are presented in Figure 4.

At this point, it is important to note a few important structural limitations to the building brick model. Often 2x2 bricks must be substituted for some of the 1x4 bricks to create rings that contain multiple bonds. For example, benzene can not be made using six black 1x4 bricks and six white 1x1 bricks; however, benzene can be made from three black 2x2 bricks, three black 1x4 bricks, and six white 1x1 bricks. Creating pentavalent and hexavalent atoms also requires special bricks. A 1x5 brick, which doesn't exist in the LEGO® system of building bricks, and a 1x6 brick are required to construct pentavalent and hexavalent atoms respectively. In addition, a substantial modification to the brick elements is required in order to construct rings that contain an odd number elements; it is simply not possible to create a ring containing an odd number of 1x4 bricks.

Figure 5 Atom Forms for Making Rings with an Odd Number of Elements

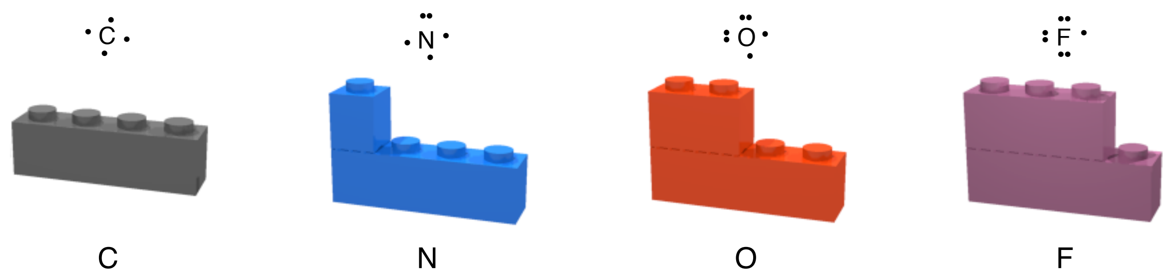


To create odd numbered rings, one of the 1x4 bricks used to make the ring must be broken apart to allow connections to both the top and the bottom of the brick. For example, an oxygen atom can be constructed from two 1x3 bricks stacked one atop the other such that only two studs are used to connect the two 1x3 bricks (see Figure 5). Likewise, a nitrogen atom can be created from a 1x2 brick and a 1x3 brick connected one atop the other. The least successful work around is the solution for the carbon atom. A carbon atom can be created from two 1x2 bricks. However, these two bricks cannot be placed one atop the other; the bricks must be placed adjacent to each other, with one brick in the first row and the other brick in the second row of the molecule. Thus, it is possible to use these alternate forms to create rings that contain an odd number of elements, but the models that are produced with these alternate forms can be difficult to interpret.

Discussion

Several important concepts are demonstrated with the building brick model. The bricks that compose each atom are arranged so that the atoms have the same number of paired and unpaired studs as their Lewis representations have paired and unpaired electrons (see Figure 6). The bricks in a stable molecule have eight studs just as their Lewis representations have eight valence electrons. Additionally, the bricks that form the molecules are arranged so that the molecules have the same number of lone pairs and bonding pairs as their Lewis representations. Finally, formal charges can be determined by tracking the movement of bricks from one part of the molecule to another.

Figure 6 Lewis and Building Brick Representations of Four Elements of the Second Period

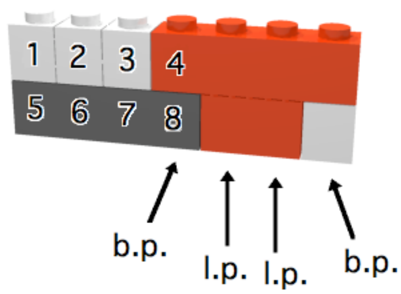


Building brick atoms and Lewis atoms have the same number of paired and unpaired electrons.

Since the building brick model is based on valence electrons, it shouldn't be a surprise that an atom's Lewis structure resembles its building brick structure. For example, a building brick carbon atom has four unpaired electrons; thus, like a Lewis structure of a carbon atom, the building brick carbon atom is best interpreted as a carbon atom that has been hybridized in preparation for bonding. As expected, a building brick nitrogen atom has three unpaired electrons and two paired electrons. A building brick oxygen atom has two unpaired electrons, and two sets of paired electrons. A building brick fluorine atom has one unpaired electron and three sets of paired electrons.

The building brick model of methanol demonstrates some of the details of the Lewis model that are emphasized by this system (see Figure 7). Note that there are three white 1x1 bricks and one stud of a red 1x4 brick on top of the carbon atom (the black 1x4 brick). Considering that each stud represents an electron, one can see that the carbon atom in methanol has an octet of electrons: the four black studs on the black 1x4 brick plus the three white 1x1 bricks plus the stud of the red 1x4 brick that is connected to the top of the black 1x4 brick. The oxygen atom also possesses an octet of electrons: the six red studs from the red 1x4 and 1x2 bricks plus the white 1x1 brick plus the stud of the black 1x4 brick that is connected to the bottom of the red 1x4 brick.

Figure 7 A Closer Look at a Building Brick Model of Methanol

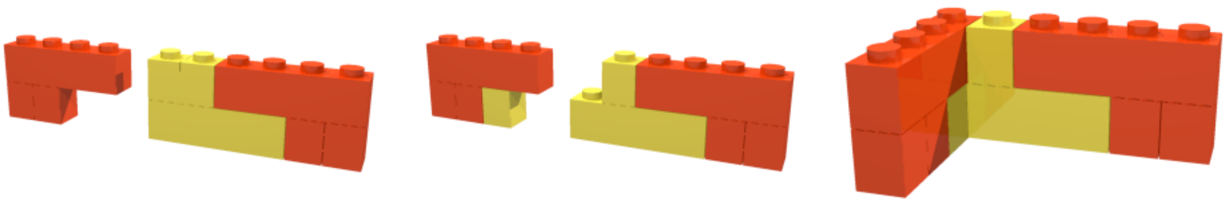


The electrons that form carbon's octet are numbered 1 through 8. The C–O and O–H bonding pairs are indicated with the arrows and the letters "b.p.". The two lone pairs of electrons on the oxygen atom are indicated by the arrows and the letters "l.p.".

Bonds between the atoms are indicated where bricks representing different atoms are snapped together. For example, one stud on the black 1x4 brick is connected underneath one stud on the red 1x4 brick. These two studs represent a pair of electrons. The two studs are physically holding the two bricks together, and symbolically the pair of electrons is holding the two atoms together. Thus, the red stud and the black stud to which the red stud is connected represent a pair of bonding electrons. Similarly, the white 1x1 brick connected to the bottom of the red 1x4 brick represents the O–H bond between the oxygen and hydrogen atoms. The lone pairs on the oxygen atom are represented in the brick model by the red bricks that are stacked one atop the other (see Figure 7).

As demonstrated in Figure 7, single bonds are represented by the connection of one brick to another brick at one stud. Multiple bonds, as seen in the models of ethylene, acetylene, and acetone (see Figure 2), are represented by the connection of one brick to another by two or three studs for double or triple bonds respectively. Again, the physical connections between the pairs of studs mimics the pairs of electrons required to form the bonds.

Figure 8 The Steps in Forming SO_2

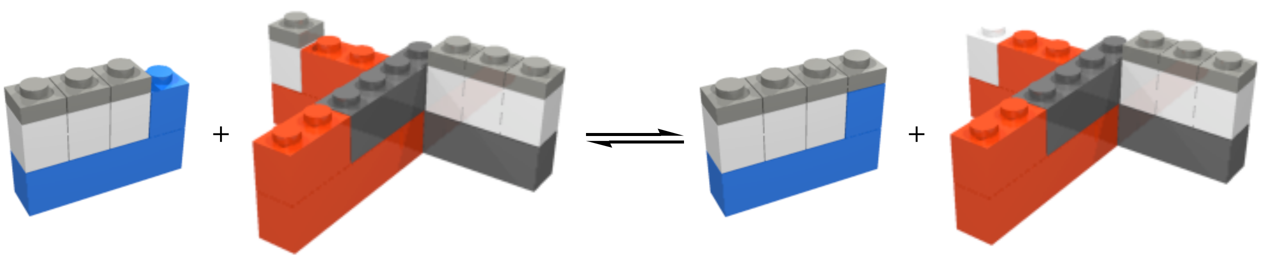


In order to create SO_2 the valency of the central sulfur atom must be expanded and the valency of one of the oxygen atoms must be contracted. To accomplish this, one of sulfur's electrons is transferred to one of the oxygen atoms.

The building brick model also allows the user to expand or contract the valence of a given atom. As an example, consider sulfur dioxide (see Figure 8). Combining one sulfur atom and one oxygen atom so that the oxygen atom has a complete octet also completes the octet of the sulfur atom. Additionally, each atom has satisfied its expected valency, two. To make room for the second oxygen atom, an electron (a 1x1 brick) must be transferred from the sulfur atom to the second oxygen atom. Once the 1x1 brick (electron) has been transferred, there is room to form a bond between the oxygen and sulfur atoms. In this manner, the valence of the second oxygen atom is contracted to one, and the valence of the sulfur atom is expanded to three. It is also interesting to note that the formal charges of the sulfur and oxygen atoms are indicated by the movement of the 1x1 brick. Because the oxygen atom acquired an electron (1x1 brick) and the sulfur atom lost an electron (1x1 brick), the formal charges on the oxygen and sulfur atoms are negative one (one extra 1x1 brick) and positive one (one missing 1x1 brick) respectively.

As was stated previously, a modified version of the building brick model can model proton transfers. In this variation, a proton is moved by disconnecting a gray plate from a heteroatom–hydrogen atom bonding pair and transferring it to a lone pair on another heteroatom. The reaction of ammonia with acetic acid is offered as an example in Figure 9. In the reaction of ammonia with acetic acid, the gray plate is removed from the white 1x1 brick atop the red oxygen brick on the acetic acid molecule and transferred to the open spot atop the blue 1x1 brick on the ammonia molecule. The movement of the gray plate nicely mimics an actual proton transfer.

Figure 9 The Reaction of NH_3 with CH_3CO_2H



$$NH_3 + CH_3CO_2H \rightleftharpoons NH_4^+ + CH_3CO_2^-$$

This simple model reinforces several important aspects of acid base chemistry. First, the difference between a hydrogen atom transfer and a proton transfer is made clear; it is easy to see that the electron is left behind when the proton is transferred. Secondly, the importance of lone pairs also becomes evident when models of ammonia (Figures 4 and 9) and methane (Figure 2) are compared. There isn't any room for another proton on the methane model, but there is room for one proton on an ammonia molecule. The obvious conclusion is that lone pairs are required for a molecule to behave as a base. Lastly, the charges on the molecules can also be calculated by examining the models. For example, the NH_3 model is made from three gray plates and three white 1x1 bricks. Since the number of gray plates (protons) and white 1x1 bricks (electrons) is the same, the molecule is neutral. Thus, if the number of gray plates is the same as the number of white 1x1 bricks the molecule is neutral. An excess of gray plates indicates a positive charge. An excess of white bricks indicates a negative charge.

Conclusion

By modeling each valence electron as a stud on a building brick, a physical representation of Lewis structures can be created. In this model, bonding pairs and lone pairs are modeled effectively. More importantly, an atom's valence arises unambiguously from the number of valence electrons it possesses, and expanding and contracting an atom's valence also follows from actions on the atom's valence electrons. Additionally, the action of expanding or contracting an atom's valence also allows the user to understand formal charge. Thus, students can use this model to understand Lewis structures, one of the basic models for understanding covalent bonding.

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