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Vegetables for building molecular models

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ABSTRACT: An exciting classroom activity involving the construction of molecular models and building hybrid orbitals is presented in this paper. Basic molecular geometries were built by connecting different types of vegetables using bamboo skewers. Vegetable of different shapes were used to describe the hybridization of atomic orbitals. This exercise is suitable for high school and undergraduate chemistry students. The activity helps students to apply Valence Shell Electron Pair Repulsion (VSEPR) theory to envisage the basic shapes of molecules and to conceptualize the hybridization of the atomic orbitals.

Key words/phrases: Electron domain geometry, Hybridization of atomic orbitals, Molecular geometry

INTRODUCTION

Molecular geometries and bonding theories play a critically important role in determining physical and chemical properties of substances. Three dimensional molecular models illustrating molecular geometries are powerful teaching tools for high school and undergraduate chemistry courses. Nevertheless, visualizing the molecular geometries and understanding the formations of σ and π bonds often challenges the introductory chemistry students. Space-filling models are more realistic, while ball-and-stick models explicitly show the molecular geometry. Educators continue to exercise a variety of innovative approaches to illustrate molecular geometries based on the VSEPR (valence shell electron pair repulsion) theory. These approaches include models made of Styrofoam spheres (Gillespie, 1974; Birk and Foster 1989; Mattson, 1994), balloons (Roberts and Traynham, 1976), plywood (Chapman, 1978), magnets (Shaw and Shaw, 1991; Dabke and Gebeyehu, 2010), snap hooks & latex tubing (Parker, 1997), cotton balls (Kundell, 1992), paper (Eggleton et al., 1990), and pipe cleaners (He et al., 1990). Similarly, a variety of materials (Kenney, 1992; Fowles, 1955; Brumlik, 1961; Martins, 1964; Walker, 1965; Fountain, 1979; Stubblefield, 1984; Emerson, 1988; Hernandez et al, 1996; Samoshin, 1998) (like paper-mache, putty, polystyrene, soda bottles, beakers, etc.) have been used to illustrate the hybridization of atomic orbitals. This paper presents easy-to-construct molecular models made out of vegetables and bamboo skewers. Vegetable models can come handy in situations where commercial molecular models are not readily available. Students can try these environmentally friendly models as hands-on activity in a kitchen as well as in a classroom. Positioning the vegetables in view of keeping the electron domains farthest away from each other is the key feature of this activity. Unlike rigid molecular models, there are no pre-drilled holes in the 'atoms' made of vegetables. Students can easily change the geometries simply by inserting the bamboo skewers at different positions in a fruit or vegetable in order to obtain the 'least crowded' structure.

The main purpose of this paper is to illustrate the molecular shapes by using vegetables that are always available around us. The construction of models using vegetables does not require any special expertise. Vegetables (peppers, chilies, lemons, limes, strawberries, and eggplants) are connected using bamboo skewers to depict the molecular geometries.

Teaching Goals

- To demonstrate the basic shapes of molecules
- To compare the electron domain and molecular geometries of molecules
- To visualize the hybridization of atomic orbitals

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MATERIALS

Two dozen lemons or limes, one dozen green chilies, two dozen peppers of two different colors, one dozen eggplants (small size & round shape), one dozen strawberries, four dozen bamboo skewers (6-inch or longer), and pliers. Use lemon or lime for the central atom, green chilies for a single bond, orange peppers for a double bond, red peppers for the nonbonding electron domains, eggplants and strawberries for hybridization models.

Constructing Molecular Models

Photographs of all molecular models built are shown on Table 1 and 2. The construction of the different molecular geometries is explained below.

Molecular Geometries:

Linear Geometry: Firmly hold a lemon and insert a 6-inch bamboo skewer through its center. At least 1-inch length of the skewer should protrude on either side of the lemon. Connect two orange-colored peppers on two ends of the bamboo skewer. As shown in Table 1, the arrangement represents linear electron domain geometry around the central atom (lemon). Applying the VSEPR theory, a carbon atom has two bonding electron domains in CO_2. The electron domains (peppers) are positioned at 180^{O} angle showing the 'best' structure in view of keeping the two bonding electron domains farthest away from each other. This results in linear geometry for CO_2. Since there are no nonbonding electron domains attached to the central atom (carbon) in CO_2, the electron domain and molecular geometry are identical. We used lemons or limes to represent the central atom in the structures presented in Table 1. Atoms other than the central atom are not shown in the structure. However more explicit structures can be made by using other fruits (cherries for example) to represent the atoms connected to the central atom.

Trigonal Planar Geometry: Insert three bamboo skewers from three sides of a lemon at approximate angle of 120^{o}. Attach three green chilies to the above mentioned bamboo skewers. Cut off the extra length of bamboo skewers. This arrangement represents trigonal planar electron domain and molecular geometry in BF_3 (Table 1). Three bonding electron domains on the boron atom are 'best' positioned in a trigonal planar mode.
The electron domain geometry of NO_2^- anion is also trigonal planar. However, the nitrogen atom is covalently connected to two oxygen atoms with one single bond and one double bond. Represent these bonding electron domains by attaching a green chili and an orange pepper to the central atom (Table 1). Use a red pepper to represent the nonbonding electron domain. The molecular geometry does not include the nonbonding electron domain. Remove the red pepper and cut off the protruding bamboo skewer to represent the bent molecular geometry in NO_2^- ion.

Other Geometries: Further as shown in Table 1, arrange vegetables in similar manner to represent tetrahedral, trigonal-pyramidal, trigonal-bipyramidal, seesaw, T-shaped, octahedral, square pyramidal, and square planar geometries. Remove the red pepper (representing the nonbonding electron domains, if any) for a changeover from electron domain geometry to molecular geometry. Use corks and pieces of bamboo skewers to hold the structures without any external support.

Hybrid Orbitals:

The building of models for hybrid orbitals is shown on Table 2. For sp^3 hybridization, insert four bamboo skewers in a lemon in a tetrahedral fashion. Attach four eggplants to the inserted bamboo skewers. As shown in Table 2, connect four strawberries to the protruding ends of the four bamboo skewers. The strawberries represent four hydrogen atoms. The arrangement depicts sp3 hybridization of the orbitals on the carbon in tetrahedral electron geometry in methane. As shown in Table 2, construct the models for sp^2 and sp hybridizations.

CONCLUSIONS

A simple and inexpensive way of building models of molecular geometries and orbital hybridization using vegetables has been described. This activity helps students comprehend the bonding theories in an enjoyable way. A variety of locally available fruits and vegetables of different shapes and colors like cherries, oranges, pears, potatoes, and okra can be used to depict the molecular geometries. Furthermore, these vegetables can be used for constructing the models for sp^3d and sp^3d^2 hybridizations as well as for the bonding networks in benzene. Students can perform this activity at home or school, individually or in groups, exchange the models between different groups, and elucidate their geometries to each other. A document camera can be used for a larger class. The edible nature of these models is the most attractive feature of this activity!

Table 1. Vegetable Arrangements Showing Electron Domain- and Molecular Geometries.

Number of Electron Domains	Bonding Electron Domains	Nonbonding Electron Domains	Electron Domain Geometry	Molecular Geometry	Example
2	2	0	Linear 		CO_2, CS_2
3	3	0	Trigonal Planar 		BF_3
3	2	1	Trigonal Planar 	Bent 	NO_2^-
4	4	0	Tetrahedral 		CH_4, CCl_4
4	3	1	Tetrahedral 	Trigonal pyramidal 	NH_3

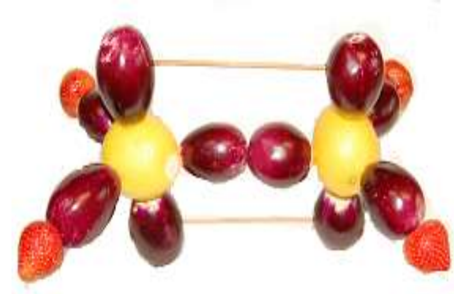
4	2	2	Tetrahedral 	Bent 	H_2O
5	5	0	Trigonal bipyramidal 		PCl_5
5	4	1	Trigonal bipyramidal 	Seesaw 	SF_4
5	3	2	Trigonal bipyramidal 	T-shaped 	ClF_3
5	2	3	Trigonal bipyramidal 	Linear 	XeF_2

6	6	0	Octahedral		SF_6
					
6	5	1	Octahedral	Square pyramidal	BrF_5
					
6	4	2	Octahedral	Square planar	XeF_4
					

Table 2. Vegetable Arrangements Showing hybridization

Description	Graphic Illustration
sp^3 hybridization of the orbitals on the carbon in CH_4: Eggplants represent four *sp*^{3} hybridized orbitals. One lemon and four strawberries represent carbon and hydrogen atoms respectively. The four electron pairs around carbon can be visualized as four *sp*^{3} hybrid orbitals in a tetrahedral arrangement. These hybrid orbitals overlap with *1s* orbitals on hydrogen atoms and form C-H σ bonds.	*sp*^{3} 

sp^2



sp^2 hybridization of the orbitals on carbons in C_2H_4: Lemons represent the carbon atoms. Horizontally positioned eggplants represent *sp^2* hybrid orbitals. Vertically positioned eggplants represent unhybridized*2p* orbitals on carbon atoms. Strawberries represent the hydrogen atoms.

Bonding around two carbons in C_2H_4 can be visualized as three *sp^2* hybridized orbitals and one unhybridized*2p* orbitals on each carbon atom. Two *sp^2* hybrid orbitals linearly overlap to form a C-C σ bond. Four *sp^2* hybrid orbitals on carbon atoms overlap with *1s* orbitals on each hydrogen atom to form four C-H σ bonds. Two unhybridized*2p* orbitals (one on each carbon) laterally overlap to form a π bond. A pair of bamboo skewers connecting vertically positioned eggplants represents a πbond between two carbon atoms.

sp

sp hybridization of the orbitals on the carbon in C_2H_2: Lemons represent carbon atoms. The four linearly positioned four eggplants in the horizontal plane represent *sp* hybrid orbitals on two carbon atoms. Other mutually perpendicular eggplants represent unhybridized*2p* orbitals on carbon atoms. Strawberries represent the hydrogen atoms.

Bonding around two carbons in C_2H_2 can be visualized as two hybridized orbitals and two unhybridized*2p* orbitals on each carbon atom. Two *sp* hybrid orbitals linearly overlap to form a C-C σ-bond. Two *sp* hybrid orbitals on carbon atoms (one on each carbon) overlap with *1s* orbitals on each hydrogen atom to form two C-H σ-bonds. Four unhybridized *2p* orbitals (two on each of the carbon atoms) laterally overlap to form two C-C π bonds. Two pairs of bamboo skewers represent these π bonds.

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