Using Magnets, Paper Clips, and Ball Bearings to Explore Molecular Geometries

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The molecular geometries and type of bonding play a major role in determining physical and chemical properties of substances. The valence-shell electron-pair repulsion model (VSEPR model) provides a simple way of predicting the molecular geometries. The VSEPR model gives an account of valence shell electrons of all atoms contributing to the structure. In particular, the VSEPR model illustrates the bonding and nonbonding electron domains around the central atom. The bonding and nonbonding electrons experience repulsion and tend to position themselves far apart from each other. There has been a continuing interest in demonstrating the molecular geometries based on VSEPR using different types of models (Kauffman 1975; Chapman 1978; Davies 1991; Shaw and Shaw 1991; Hervas and Silverman 1991). For example, three-dimensional models have been used to explain the exact shapes of the molecules using bar magnets and Styrofoam spheres (Kauffman 1975).

The particularly challenging part in demonstrating the VSEPR models is to show the "best" arrangement of bonding and nonbonding electrons around the central atom that minimizes the repulsion among the electron pairs. Rigid molecular models do not facilitate quick and easy interchangeable geometries. In this article, we present a versatile use of magnets (as electron domains) and a ball bearing (as a central atom).

Magnetic models do not involve a sphere with drilled holes or sockets to attach a bond at a fixed position. Magnets simply stick to a metal ball bearing and can be positioned in any desired direction. The use of a magnetic model facilitates swift interchangeable geometries. The geometries can be changed by simply moving the magnets around the central ball bearing. Students can readily compare a variety of shapes and decide the most suitable shape of a molecule or an ion in view of trying to "get electron domains out of each other's way." In addition to the main advantage mentioned above, magnetic models offer several other practical advantages compared with the other models. The advantages include the following:

1. Magnets can be easily added or removed to compare the electron domain geometry and molecular geometry.
2. Magnets of different colors can be used to distinguish between bonding and nonbonding electron domains as well as between different bond orders.

FIGURE 1

Possible arrangements of four electron domains around the central atom.

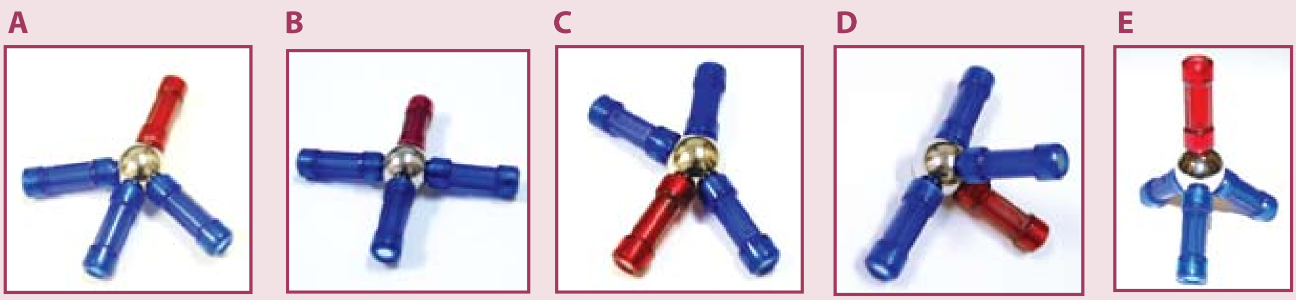
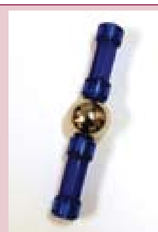


TABLE 1

Electronic and molecular geometries with examples.

Number of electron domains	Bonding electron domains	Nonbonding electron domains	Electron domain geometry	Molecular geometry	Example
2	2	0	Linear 	Linear 	CO_2, CS_2
3	2	1	Trigonal planar 	Bent 	NO_2^-
4	2	2	Tetrahedral 	Bent 	H_2O
5	2	3	Trigonal bipyramidal 	Linear 	XeF_2
6	6	0	Octahedral 	Octahedral 	SF_6
6	4	2	Octahedral 	Square planar 	XeF_4

Note. Instructions for students were as follows: Use a ball bearing to show the central atom. Use magnets of a variety of colors to represent different bond orders and nonbonding electrons. In the table, green magnets show a double bond, blue magnets show a single bond, and red magnets show the nonbonding pairs of electrons.

3. The nonbonding electron domains exert greater repulsive forces on adjacent bonding electron domains and tend to compress the bond angles. The repulsive forces of nonbonding electron domains (two domains in water, one in ammonia, and none in methane) can be effectively shown by comparing the bond angles at the central atom in a tetrahedral electron domain geometry.

Materials

- Construction toy magnets of a variety of colors
- Steel ball bearings
- Colored paper clips

Building the models

Figure 1 presents an arrangement of bonding and nonbonding electron domains in ammonia (NH_3). An ammonia molecule has four electron domains. Three electron domains are bonding (blue magnets) and one is nonbonding (red magnet). These electron domains can be positioned around the central nitrogen atom (a ball bearing) in a number of ways (see Figure 1 A–E). However, only one particular arrangement is the most suitable that minimizes the repulsion between bonding and nonbonding electron domains as well as repulsion within the bonding electron domains (tetrahedral geometry,

TABLE 2

Geometries of inorganic compounds.

Name of the compound	Description	Molecular geometry
trans-Co(*en*)$_2$Cl$_2$ (*en* is ethylene diamine)	Two *en* ligands (green magnets and paper clips) and two chlorides (yellow magnets) are connected to the central cobalt atom in a *trans* position in an octahedral geometry. *trans*-Co(*en*)$_2$Cl$_2$ is a green-colored complex.	
cis-Co(*en*)$_2$Cl$_2$	Two *en* ligands (violet magnets and paper clips) and two chlorides (yellow magnets) are connected to the central cobalt atom in a *cis* position in an octahedral geometry. *cis*-Co(*en*)$_2$Cl$_2$ is a violet-colored complex.	
CoCl(*dppe*)$_2$ *dppe* is diphenylphosphino)-ethane	Two *dppe* ligands (green magnets and paper clips) and a chloride (yellow magnet) are connected to the central cobalt atom in a trigonal bipyramidal geometry. CoCl(*dppe*)$_2$ is a green-colored complex.	
CoCl(*dppe*)$_2$	Two *dppe* ligands (red magnets and paper clips) and a chloride (yellow magnet) are connected to the central cobalt atom in a square pyramidal geometry. CoCl(*dppe*)$_2$ is a red-colored complex.	
$[Br_4Ta\ (\mu\text{-}N)TaBr_4]^{3-}$ (μ-N is nitrido bridging ligand)	A bridging nitrido ligand (a smaller ball bearing and two blue magnets) is connected to two tantalum atoms (larger ball bearings). Four bromides (red magnets) and a nitrido ligand form a trigonal bipyramidal geometry around each tantalum atom.	

Note. Instructions for students were as follows: Use a ball bearing to show the central atom. Use magnets and paper clips of a variety of colors to represent different ligands or to represent actual colors of the complexes.

Figure 1E). Students compared several other arrangements (not shown in Figure 1) and arrived at the conclusion that the tetrahedral geometry is the best electron domain geometry for ammonia.

Table 1 presents the electronic and molecular geometries of molecules consisting of two to six electron domains. Molecular geometry can be visualized by simply removing the nonbonding electron domain (red magnet) from the electron domain geometry. If no nonbonding electron domain is present, the electron domain and molecular geometry are exactly identical.

Table 2 illustrates the shapes of several inorganic complexes. In addition to using magnets and ball bearings for bonding atoms, we used paper clips to show bridging ligands. As an example, we present the geometry of *trans*-$Co(en)_2Cl_2$. In this geometry, two pairs of nitrogens (green magnets) are coordinately bonded to the central cobalt atom (a ball bearing). Ethylene (green paper clips) connect the adjacent nitrogen atoms. Chlorides (yellow magnets) are placed in *trans* position in an octahedral geometry around the central cobalt atom. *cis*-$Co(en)_2Cl_2$ geometry can be readily made by rearranging the magnets and the paper clips. We used green and violet magnets for ethylenediamine ligands to represent the respective colors of the *trans*- and *cis*- isomers. This method can be diversified to illustrate the geometries of *facial* and *meridional* isomers as well as the geometries of complexes containing bridging ligands.

The magnetic models presented in this paper have been tested in our general chemistry and upper level chemistry classes. We used the magnetic models for a hands-on activity in the general chemistry laboratory. The activity presented in this paper fulfilled the main objective. We received encouraging feedback from the students. We used a document camera to project the magnetic models for a class of over 70 students. An epoxy can be used to permanently bond the magnets, ball bearings, and paper clips if needed. ■

References

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