## Section 4.2: Three-Dimensional Structure

### Mini Investigation: Balloon Model of Electron Repulsion, page 210

Answers may vary. Sample answers:

**A.** The two balloons tied together orient themselves in a straight line, as far from one another as possible.

**B.** The three balloons tied together orient themselves in the triangular arrangement called trigonal planar.

**C.** The four balloons tied together orient themselves in a tetrahedral arrangement.

**D.** Yes, the balloons are good models of valence shell electron-pair repulsions. The balloons move as far apart as possible in the same way that electrons in valence shell orbitals move as far apart as possible.

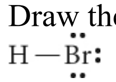
**E.** In any of the modes, if I pushed the balloons together and let go, the balloons would quickly move back to their original orientation.

**F.** If one balloon in 4 balloons tied together was a lone pair, the three-dimensional structure would be a trigonal pyramid. If 2 balloons in the 4 were lone pairs, the three-dimensional structure would be a trigonal planar.

### Tutorial 1 Practice, page 212

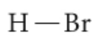
**1. (a)** Geometry of HBr predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



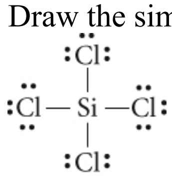
**Step 2.** The hydrogen bromide molecule has 1 pair of bonding electrons. The only possible structure is linear.

**Step 3.** Draw the three-dimensional structure.



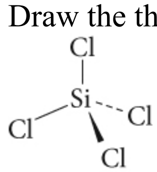
**(b)** Geometry of $SiCl_4$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



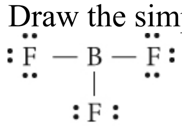
**Step 2.** The silicon tetrachloride molecule has 4 pairs of bonding electrons around the central atom. There are no lone electron pairs on the silicon atom. The best arrangement of the 4 bonding electron pairs around the central atom to minimize electron-pair repulsion is a tetrahedral structure.

**Step 3.** Draw the three-dimensional structure.



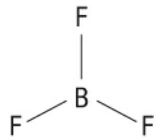
**(c)** Geometry of $BF_3$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



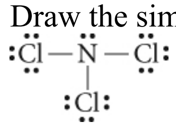
**Step 2.** The boron trifluoride molecule has 3 pairs of bonding electrons around the central atom. There are no lone electron pairs on the boron atom. The best arrangement of the 3 bonding electron pairs around the central atom to minimize electron-pair repulsion is a trigonal planar structure.

**Step 3.** Draw the three-dimensional structure.



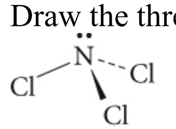
**(d)** Geometry of $NCl_3$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



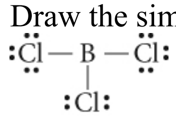
**Step 2.** The nitrogen trichloride molecule has 3 pairs of bonding electrons around the central atom. There is 1 lone electron pair on the nitrogen atom. The best arrangement of the 4 electron pairs (3 bonding and 1 lone pair) around the central atom to minimize electron-pair repulsion is a trigonal pyramidal structure.

**Step 3.** Draw the three-dimensional structure.



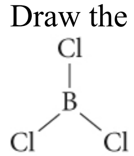
**2. (a)** Geometry of $BCl_3$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



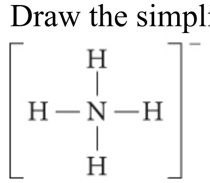
**Step 2.** The boron trichloride molecule has 3 pairs of bonding electrons around the central atom. There are no lone electron pairs on the boron atom. The best arrangement of the 3 bonding electron pairs around the central atom to minimize electron-pair repulsion is a trigonal planar structure.

**Step 3.** Draw the three-dimensional structure.



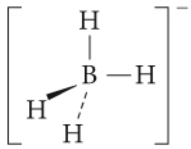
**(b)** Geometry of $BH_4^-$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



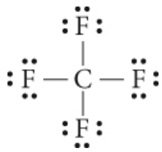
**Step 2.** The tetrahydroborate ion has 4 pairs of bonding electrons around the central atom. There are no lone electron pairs on the boron atom. The best arrangement of the 4 bonding electron pairs around the central atom to minimize electron-pair repulsion is a tetrahedral structure.

**Step 3.** Draw the three-dimensional structure.



**(c)** Geometry of $CF_4$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.

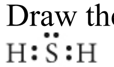


**Step 2.** The tetrafluoromethane molecule has 4 pairs of bonding electrons around the central atom. There are no lone electron pairs on the boron atom. The best arrangement of the 4 bonding electron pairs around the central atom to minimize electron-pair repulsion is a tetrahedral structure.

**Step 3.** Draw the three-dimensional structure.

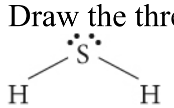
**(d)** Geometry of $H_2S$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure.



**Step 2.** The hydrogen sulfide molecule has 2 pairs of bonding electrons around the central atom. There are 2 lone electron pairs on the sulfur atom. The best arrangement of the 4 electron pairs (2 bonding and 2 lone pairs) around the central atom to minimize electron-pair repulsion is a bent structure.

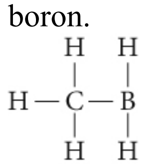
**Step 3.** Draw the three-dimensional structure.



## Tutorial 2 Practice, page 214

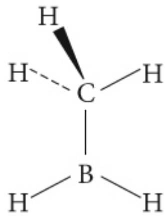
**1. (a)** Geometry of $CH_3BH_2$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. There are two central atoms, carbon and boron.



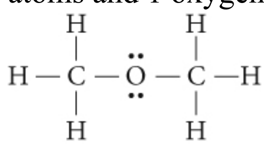
**Step 2.** The methylborane molecule has 4 pairs of bonding electrons around the central carbon atom and 3 pairs of bonding electrons around the central boron atom. There are no lone electron pairs on either central atom. To minimize electron-pair repulsion, the best arrangement of the 4 bonding electron pairs around the carbon atom is a tetrahedral structure, and the best arrangement of the 3 bonding electron pairs around the boron atom is a trigonal planar structure.

**Step 3.** Draw the three-dimensional structure.



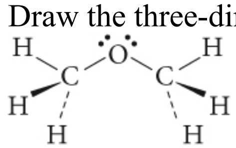
**(b)** Geometry of $CH_3OCH_3$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. There are three central atoms, 2 carbon atoms and 1 oxygen atom.



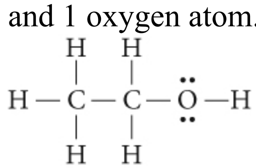
**Step 2.** The methoxymethane molecule has 4 pairs of bonding electrons around each central carbon atom. There are 2 pairs of bonding electrons around the oxygen atom, and it has 2 lone pairs. To minimize electron-pair repulsion, the best arrangement of the 4 bonding electron pairs around each carbon atom is a tetrahedral structure. The best arrangement of the 4 electron pairs (2 bonding pairs and 2 lone pairs) around the oxygen atom is a bent structure.

**Step 3.** Draw the three-dimensional structure.



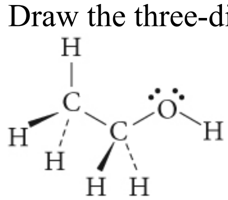
**(c)** Geometry of $CH_3CH_2OH$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. There are 3 central atoms, 2 carbon atoms and 1 oxygen atom.



**Step 2.** The ethanol molecule has 4 pairs of bonding electrons around each central carbon atom. There are 2 pairs of bonding electrons around the oxygen atom, and it has 2 lone pairs. To minimize electron-pair repulsion, the best arrangement of the 4 bonding electron pairs around each carbon atom is a tetrahedral structure. The best arrangement of the 4 electron pairs (2 bonding pairs and 2 lone pairs) around the oxygen atom is a bent structure.

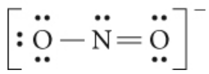
**Step 3.** Draw the three-dimensional structure.



## Tutorial 3 Practice, page 215

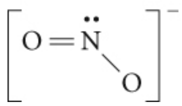
**1.** Geometry of $NO_2^-$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. Nitrogen is the central atom.



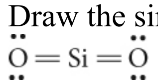
**Step 2.** The nitrite ion has 3 groups of electrons (a single bond, a double bond, and 1 lone pair) around the central nitrogen atom. To minimize electron-pair repulsion, the best arrangement of the 3 electron groups around the nitrogen atom is a bent structure.

**Step 3.** Draw the three-dimensional structure.



**2. (a)** Geometry of $SiO_2$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. The central atom is silicon.



**Step 2.** The silicon dioxide molecule has 2 double bonds and no lone electron pairs around the central atom. To minimize electron-pair repulsion, the best arrangement of the 2 groups of electrons around the silicon atom is a linear structure.

**Step 3.** Draw the three-dimensional structure.

$O=Si=O$

**(b)** Geometry of HCN predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. The central atom is carbon.

$H-C\equiv N:$

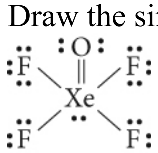
**Step 2.** The hydrogen cyanide molecule has 2 groups of electrons (a single bond and a triple bond) around the central carbon atom, and no lone pairs. To minimize electron-pair repulsion, the best arrangement of the 2 groups of electrons around the carbon atom is a linear structure.

**Step 3.** Draw the three-dimensional structure.

$H-C\equiv N$

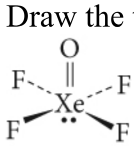
**(c)** Geometry of $XeOF_4$ predicted using VSEPR theory:

**Step 1.** Draw the simplified Lewis structure. The central atom is Xe.



**Step 2.** The xenon oxytetrafluoride molecule has 6 groups of electrons around the central xenon atom (4 single bonds, 1 double bond, and 1lone pair). To minimize electron-pair repulsion, the best arrangement of the 6 groups of electrons around the xenon atom is a square pyramidal structure**.**

**Step 3.** Draw the three-dimensional structure.

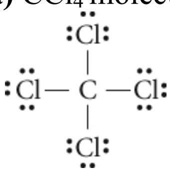


## Section 4.2 Questions, page 216

**1.** The words that make up the initialism "VSEPR"—valence shell electron-pair repulsion —describe the concept of the theory very well. The main concept of the theory is that pairs of electrons, both bonding and non-bonding, will repel one another and maximize the distance between themselves around an atom. This can be used to predict geometric structures for most molecules and ionic substances that contain non-metallic elements. There are some exceptions in which the VSEPR theory does not accurately describe the structure of a pure substance.

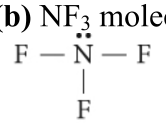
**2.** Prediction of the three-dimensional structure and bond angles:

**(a)** $CCl_4$ molecule:



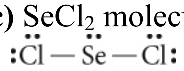
The central atom has 4 bonding pairs and no lone pairs, so $CCl_4$ has a tetrahedral structure. The bond angles are 109.5º.

**(b)** $NF_3$ molecule:



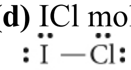
The central atom has 4 pairs of electrons (3 bonding pairs and 1 lone pair), so $NF_3$ has a trigonal pyramidal structure. The bond angles are 107º.

**(c)** $SeCl_2$ molecule:



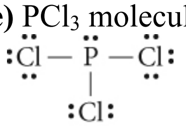
The central atom has 4 pairs of electrons (2 bonding pairs and 2 lone pairs), so $SeCl_2$ has a bent or V-shaped structure. The bond angles are 104.5º.

**(d)** ICl molecule:



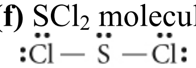
There is 1 bonding pair between the iodine and chlorine atoms, so ICl has a linear structure. The bond angles are 180 º.

**(e)** $PCl_3$ molecule:



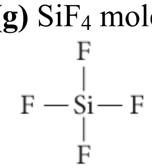
The central atom has 4 pairs of electrons (3 bonding pairs and 1 lone pair), so $PCl_3$ has a trigonal pyramidal structure. The bond angles are 107º.

**(f)** $SCl_2$ molecule:



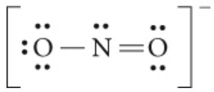
The central atom has 4 pairs of electrons (2 bonding pairs and 2 lone pairs), so $SCl_2$ has a bent or V-shaped structure. The bond angles are 104.5º.

**(g)** $SiF_4$ molecule:

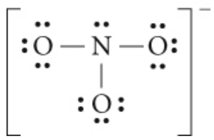


The central atom has 4 bonding pairs and no lone pairs, so $SiF_4$ has a tetrahedral structure. The bond angles are 109.5º.

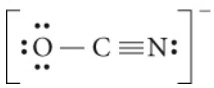
**3.** Prediction of the three-dimensional structure and bond angles:
**(a)** $NO_2^-$ ion:



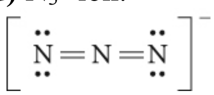
The central atom has 3 electron groups (1 single bond, 1 double bond, and 1 lone pair), so $NO_2^-$ has a bent or V-shaped structure. The bond angle is 120º.
**(b)** $NO_3^-$ ion:



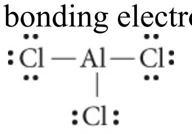
The central atom has 3 bonding electron pairs and no lone pairs, so $NO_3^-$ has a trigonal planar structure. The bond angles are 120º.
**(c)** $OCN^-$ ion:



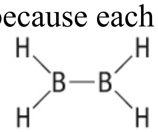
The central atom has 2 groups of electrons (1 single bond, and 1 triple bond) and no lone pairs, so $OCN^-$ has a linear structure. The bond angles are 180º.
**(d)** $N_3^-$ ion:



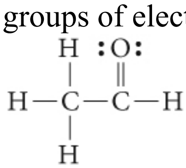
The central atom has 2 groups of electrons (2 double bonds) and no lone pairs, so $N_3^-$ has a linear structure. The bond angles are 180º.
**4.** Molecules such as ICl and HBr are linear. You can tell because only 2 atoms participate in the bonding and there are no unpaired electrons, so the molecule has a linear shape.
**5. (a)** The $AlCl_3$ molecule has a trigonal planar structure, because the central atom has 3 bonding electron pairs and no lone pairs:



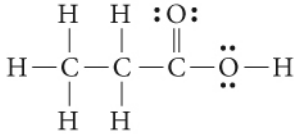
**(b)** Both of the boron atoms in $B_2H_4$ have a trigonal planar arrangement of atoms, because each boron atom has 3 bonding electron pairs and no lone pairs.



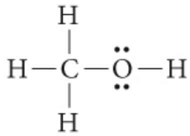
**(c)** In the $CH_3COH$ molecule, the carbon atom in COH is trigonal planar, because it has 3 groups of electrons (1 double bond and 2 single bonds) and no lone pairs.



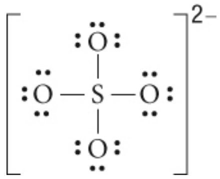
**(d)** In the $CH_3CH_2COOH$ molecule, the carbon atom in COO is trigonal planar, because it has 3 groups of electrons (1 double bond and 2 single bonds) and no lone pairs.



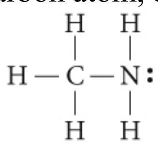
**6. (a)** In the $CH_3OH$ molecule, the arrangement of atoms around the carbon atom is tetrahedral, because there are 4 bonding pairs of electrons and no lone pairs.



**(b)** The $SO_4^{2-}$ ion has a tetrahedral arrangement of atoms around the central sulfur atom, because there are 4 bonding pairs of electrons and no lone pairs.



**(c)** The $CH_3NH_2$ molecule has a tetrahedral arrangement of atoms around the central carbon atom, because there are 4 bonding pairs of electrons and no lone pairs.

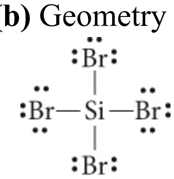


**7. (a)** Geometry of $BeI_2$ predicted using VSEPR theory, and drawing of structure:

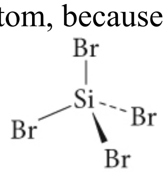
I—Be—I

The central atom has 2 bonding pairs of electrons and no lone pairs, so $BeI_2$ has a linear structure, as shown above.

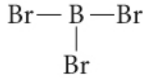
**(b)** Geometry of $SiBr_4$ predicted using VSEPR theory, and drawing of structure:



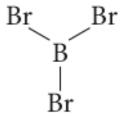
The $SiBr_4$ molecule has a tetrahedral arrangement of atoms around the central carbon atom, because there are 4 bonding pairs of electrons and no lone pairs.



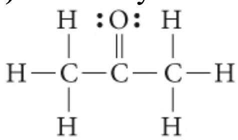
**(c)** Geometry of $BBr_3$ predicted using VSEPR theory, and drawing of structure:



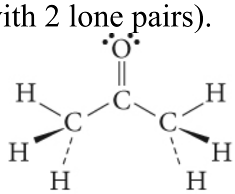
The $BBr_3$ molecule has a trigonal planar arrangement of atoms around the central boron atom, because there are 3 bonding pairs of electrons and no lone pairs.



**(d)** Geometry of $CH_3COCH_3$ predicted using VSEPR theory, and drawing of structure:

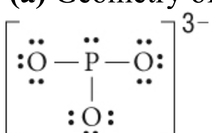


In the $CH_3COCH_3$ molecule, the two carbon atoms bonded to the central carbon have a tetrahedral arrangement of atoms, because there are 4 bonding pairs of electrons and no lone pairs. The central carbon has a trigonal planar arrangement of atoms, because there are 3 groups of electrons around the C atom (2 single bonds, and 1 double bond along with 2 lone pairs).

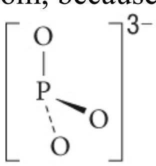


**(e)** Geometry of $CH_2H_4$ predicted using VSEPR theory, and drawing of structure:

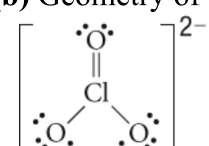
**8. (a)** Geometry of $PO_3^{3-}$ predicted using VSEPR theory, and drawing of structure:



The $PO_3^{3-}$ ion has a trigonal pyramidal arrangement of atoms around the central boron atom, because there are 3 bonding pairs of electrons on the boron atom and 1 lone pair.

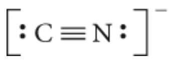


**(b)** Geometry of $CO_3^{2-}$ predicted using VSEPR theory, and drawing of structure:



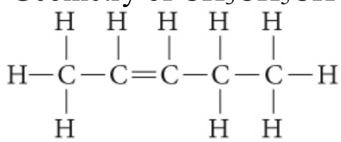
The $CO_3^{2-}$ ion has a trigonal planar arrangement of atoms around the central carbon atom, because there are 3 groups of electrons around the carbon atom (2 single bonds and 1 double bond) and no lone pairs, as shown above.

**(c)** Geometry of $CN^-$ predicted using VSEPR theory, and drawing of structure:



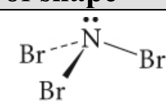
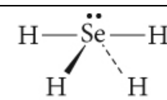
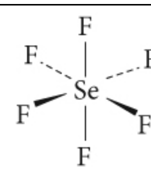
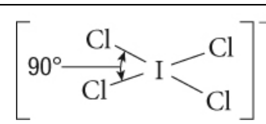
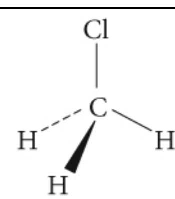
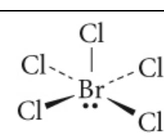
The $CN^-$ ion has only two atoms, so the only possibility is a linear structure.

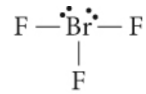
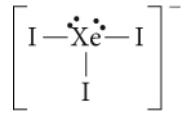
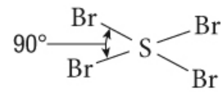
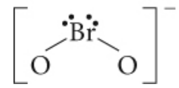
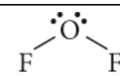
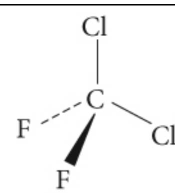
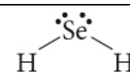
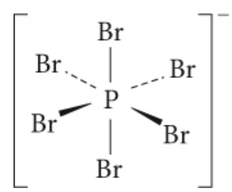
**9.** Geometry of $CH_3CH_5CH{=}CH_2CH_3$ predicted using VSEPR theory:



This molecule will have tetrahedral geometry around the first, fourth, and fifth carbons, because each of these carbons has 4 bonding pairs and no lone pairs. It will have trigonal planar geometry around the second and third carbons, because each of these carbon atoms has 3 groups of surrounding electrons (2 single bonds and 1 double bond).

**10.**

| Compound | Number of pairs of electrons on central atom | Number of lone pairs | Name of shape | Diagram of shape |
|---|---|---|---|---|
| $NBr_3$ | 4 | 1 | trigonal pyramidal |  |
| $CS_2$ | 4 (2 double bonds) | 0 | linear | S — C — S |
| $SeH_4$ | 5 | 1 | seesaw |  |
| $SeF_6$ | 6 | 0 | octahedral |  |
| $ICl_4^-$ | 6 | 2 | square planar |  |
| ICl | 4 | 3 | linear | I — Cl |
| $CH_3Cl$ | 4 | 0 | tetrahedral |  |
| $BrCl_5$ | 6 | 1 | square pyramidal |  |

| | | | | |
|---|---|---|---|---|
| $BrF_3$ | 5 | 2 | T-shaped |  |
| $XeI_3^-$ | 6 | 3 | T-shaped |  |
| $SBr_4$ | 6 | 2 | square planar |  |
| $BrO_2^-$ | 4 | 2 | bent |  |
| $OF_2$ | 4 | 2 | bent |  |
| $CF_2Cl_2$ | 4 | 0 | tetrahedral |  |
| $H_2Se$ | 4 | 2 | bent |  |
| $PBr_6^-$ | 6 | 0 | octahedral |  |