# Symmetry

Names: _____

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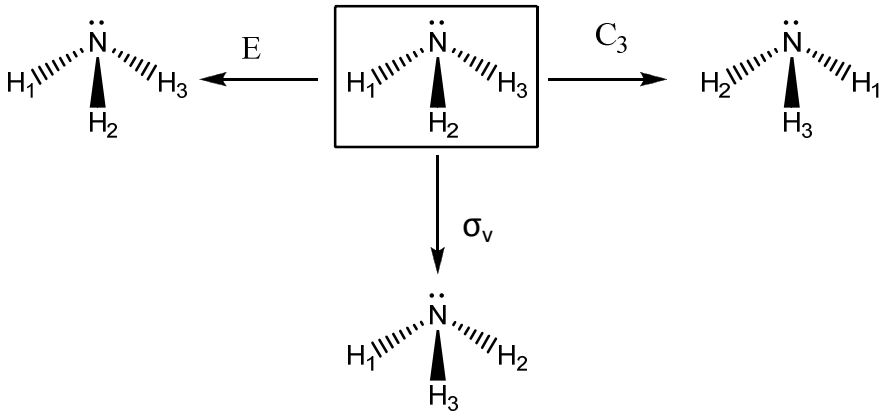
**Model 1: Ammonia**

In groups, consider the three dimensional ammonia molecule in the box below. You may find it useful to use a model kit to build one or more molecules. (Hint: It will be easier to see changes in position of atoms if all H atoms are not the same color.) For each question you must agree on the answer before moving to the next question.




**Critical Thinking Questions**

1. How does the ammonia molecule in the box change when 'E' is applied?

2. How does the ammonia molecule in the box change when '$C_3$' is applied? (Hint: What does the 3 tell us?)

3. How does the ammonia molecule in the box change when '$\sigma_v$' is applied?

4. When a '$\sigma_v$' is applied to the molecule, the structure of the molecule before '$\sigma_v$' is identical to the structure of the molecule after '$\sigma_v$'. Draw the other two possible results when '$\sigma_v$' is applied to the ammonia molecule in the box. The '$\sigma_v$' is also called a 'mirror plane'. How many such mirror planes are there in ammonia? (Hint: Use a model kit to help you see changes in the positions of atoms.)

5. Draw the Lewis structure for $NH_2Cl$ and label each hydrogen atom with a different subscript similar to the ammonia molecule above.

    a. If an 'E' can be applied, draw the $NH_2Cl$ molecule.

    b. If a '$C_3$' can be applied, draw the $NH_2Cl$ molecule.

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    c. If a '$\sigma_v$' can be applied, draw the $NH_2Cl$ molecule.

**Information**

**All molecules can be described in terms of symmetry.** Here are several different statements to describe what is meant by 'symmetry operation'.

A symmetry operation is a movement of a body such that after the movement has been carried out every point of the body looks like it is in its original position.

If you close your eyes when the symmetry operation is performed, and, if you cannot tell that the operation has occurred after you open your eyes, then it was a valid symmetry operation.

"A symmetry element is a geometrical entity such as a line, plane or point that can be used to carry out a symmetry operation." (Cotton, 1971).

In order for the operation to be considered symmetrical, the position and orientation of the atoms relative to one another within the molecule must be the same after the operation as it was before the operation.

**Critical Thinking Questions**

6. Identity Symmetry Operation:
    a. Define the identity symmetry operation, 'E'. (Everyone in the group must agree.)

    b. Will all molecules have the identity symmetry operation, 'E'? Explain.

7. Rotation symmetry operation:
    a. Define the rotation symmetry operation, '$C_3$'.

    b. Will all molecules have the rotation symmetry operation, '$C_3$'? Explain.

c. What does the 3 in '$C_3$' tell us about the rotation symmetry operation?

8. Reflection symmetry operation:

   a. Define the reflection symmetry operation, '$\sigma_v$'.

   b. Will all the molecules have the reflection symmetry operation, '$\sigma_v$'? Explain.

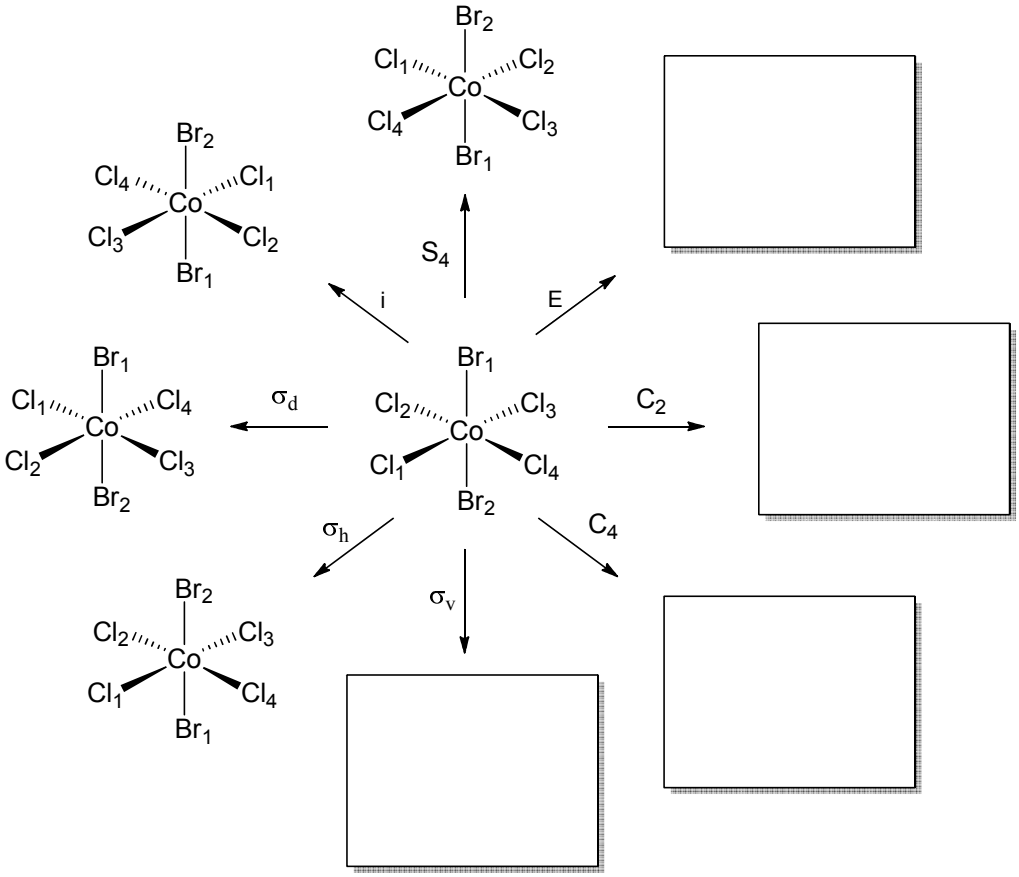
9. Given your definition of a $C_3$ symmetry operation, would you answer question 5b any differently now? If yes, how?

**References**

Cotton, Albert F. *Chemical Applications of Group Theory*, 2nd Ed. John Wiley & Sons: New York, 1971.

**Model 2: *trans*-dibromotetrachlorocobaltate(3-)**

Consider the three-dimensional structure for *trans*-dibromotetrachlorocobaltate(3-).




**Critical Thinking Questions**

10. Fill in the boxes in the model.

11. Rotation symmetry operations:

    a. How does a '$C_2$' differ from a '$C_4$'?

    b. What does a '$C_n$' symmetry operation involve?

c. A principle rotation axis is the rotation axis with the highest n value.

i. What is the principle rotation axis for Model 1?

ii. What is the principle rotation axis for Model 2?

12. How does the starting orientation change when '$\sigma_h$' is applied?

13. Reflection symmetry operation, '$\sigma_h$':

a. Define the reflection symmetry operation, '$\sigma_h$'.

b. Will all molecules have the '$\sigma_h$' reflection symmetry operation? Explain.

14. How does the central molecule change when '$\sigma_d$' is applied?

15. Reflection symmetry operation, '$\sigma_d$':

    a. Define the reflection symmetry operation, '$\sigma_d$' .

    b. Will all molecules have the '$\sigma_d$' reflection symmetry operation? Explain.

16. What is the difference between a '$\sigma_v$' and a '$\sigma_d$'?

17. How does the central molecule change when 'i' is applied?

18. Inversion symmetry operation, 'i':

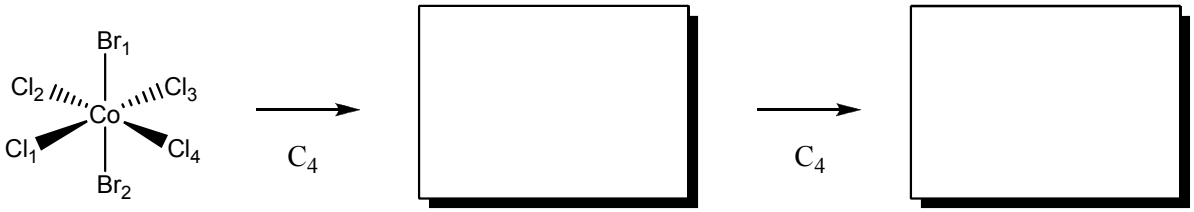
    a. Define the inversion symmetry operation, 'i'.

    b. Will all molecules have the inversion symmetry operation, 'i'? Explain.

19. How does the starting orientation change when '$S_4$' is applied?

20. Some symmetry operations are equivalent to a combination of symmetry operations.

    a. Fill in the boxes below.




    How can you get from the initial structure orientation to the final structure orientation using only one symmetry operation?

    b. Looking back at Model 1 and Model 2, which two symmetry operations can lead to the improper rotation symmetry operation, '$S_4$'?

21. Improper rotation symmetry operation, '$S_n$':

    a. Define the improper rotation symmetry operation, '$S_n$'.

    b. Will all molecules have the improper rotation symmetry operation, '$S_n$'? Explain.

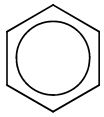
# Symmetry

Names: _____

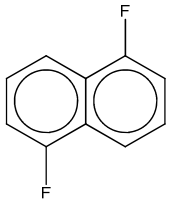
**Exercise Questions**

1. Find the highest order rotational axis for the following molecules.

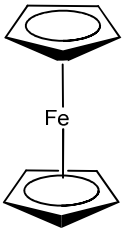
   a. Benzene



   b. 1,5-difluoronaphthalene



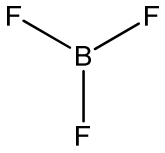

   c. Eclipsed ferrocene



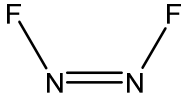

   d. Methane, $CH_4$

2. Determine how many planes of reflection are in each of the following molecules. Show the location and label each reflection plane.

a.

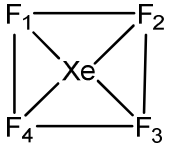



b.

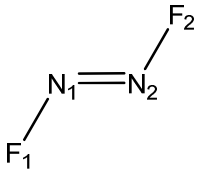



3. Show the center of inversion on the following molecules with a dot. Draw what the orientation after the inversion will look like.

a.




b.




4. Fill in the following boxes.