

## FOCUS QUESTION

What are the symmetry allowed products of the Cope Rearrangement?

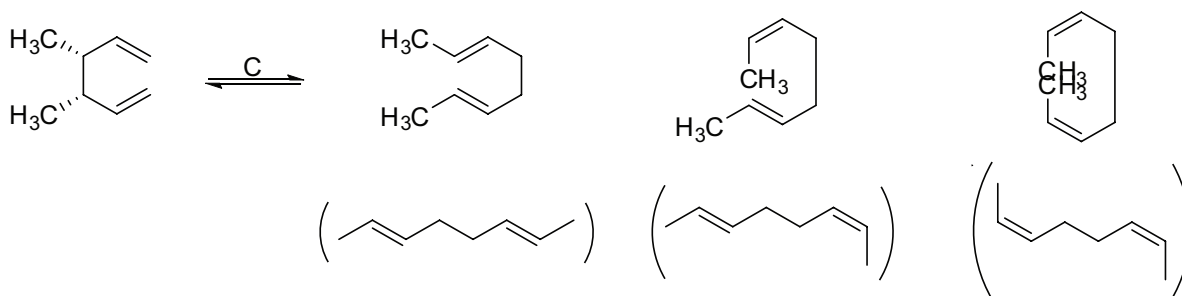
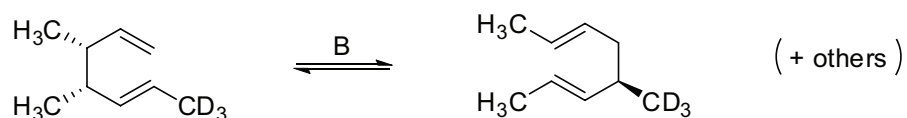
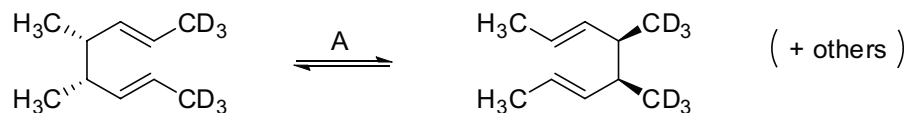
## REVIEW

Before starting to investigate the stereochemistry of Cope rearrangements, a review will be helpful.

- a. A thermodynamically controlled reaction is one in which the product distribution depends on the energy of which of the following?
  - i. the transition state
  - ii. the products
  
- b. A kinetically controlled reaction is one in which the product distribution depends on the energy of which of the following?
  - i. the transition state
  - ii. the products
  
- c. Compared to those with fewer substituents, alkenes that are highly substituted are
  - i. lower in energy
  - ii. higher in energy
  
- d. Compared to trans alkenes, cis alkenes are generally
  - i. lower in energy
  - ii. higher in energy

## MODEL 1

### Substituents in Cope Rearrangements

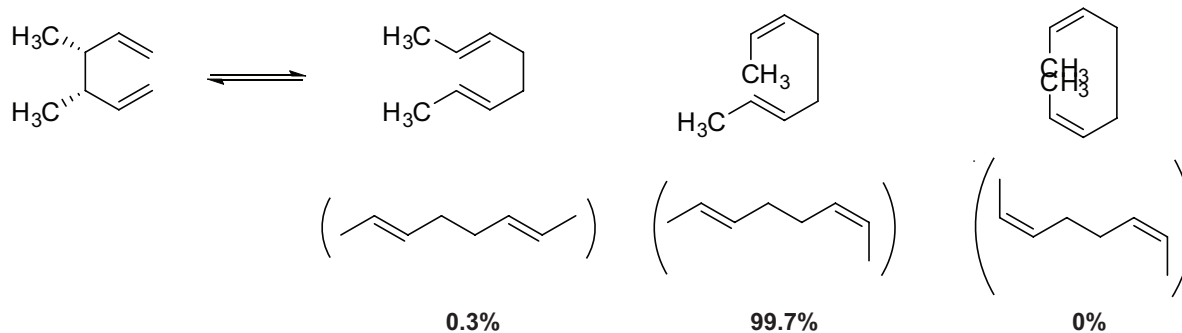


Do questions 1-6 on your own. When everyone in your group is finished all six questions, compare answers and come to a consensus.

1. In reaction A, label each reacting  $\sigma$  bond as rotating in a *conrotatory* or *disrotatory* fashion.
2. Is the product shown an allowed product?
3. In reaction B, label each reacting  $\sigma$  bond as rotating in a *conrotatory* or *disrotatory* fashion.
4. Is the product shown an allowed product?
5. In reaction C, label each reacting  $\sigma$  bond as rotating in a *conrotatory* or *disrotatory* fashion.
6. Cross out any product in reaction C that is symmetry forbidden.
7. In each reaction, circle all non-hydrogen substituents located on the carbons involved in the reacting  $\sigma$  bonds that are rotating.
8. For what type of reactants do the symmetry rules for Cope Rearrangements not have to be considered? Why?

**MODEL 2****The Doering-Roth Experiment**

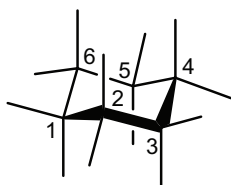
Even within the symmetry allowed products of the Cope Rearrangement there is differing stereochemistry. In order to probe the stereochemistry of the transition state, Doering and Roth conducted the following reaction. The product ratios from their experiment are shown.



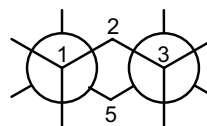
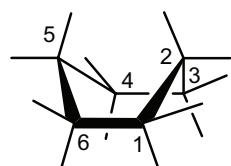
9. Circle the product that is lowest in energy and explain your reasoning.
  
10. Does the product distribution correlate with the energies of the products?
  
11. Given the information in Model 2, do you expect this reaction to be kinetically controlled or thermodynamically controlled? Why?

## REVIEW

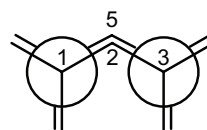
## Cyclohexane Conformations



chair conformation

Newman projection of  
chair conformation

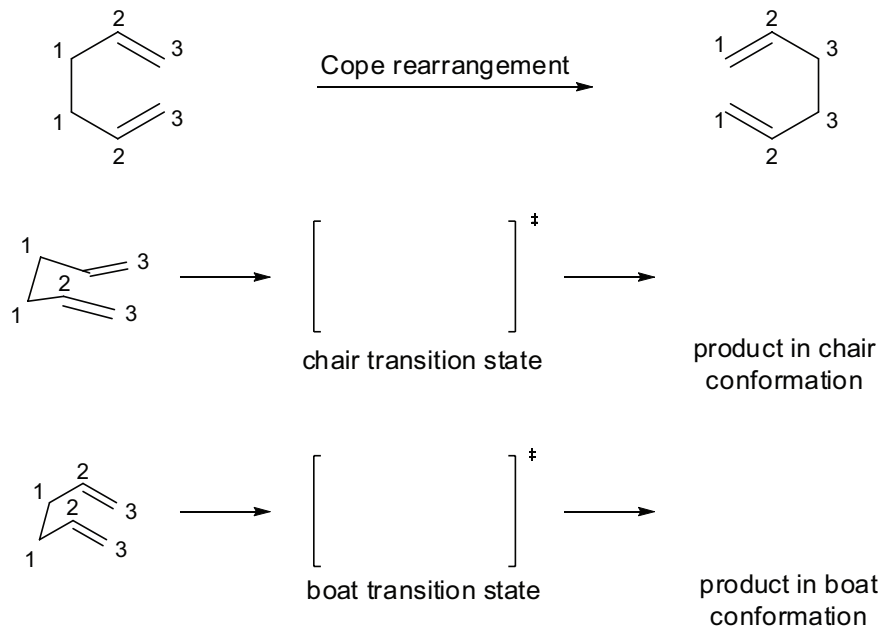
boat conformation

Newman projection of  
boat conformation

12. Are the substituents in the chair conformation staggered or eclipsed?
13. Are the substituents on the 1, 3, 4, and 6 carbons in the boat conformation staggered or eclipsed?
14. Which is lower in energy: cyclohexane in a chair conformation or cyclohexane in a boat conformation?
15. Label each substituent position on the chair cyclohexane as *axial* or *equatorial*.
16. Label each substituent position on the Newman projection of the chair conformation as *axial* or *equatorial*.
17. Four of the six carbons in the boat conformation are equivalent. Which ones are these?
18. The substituents on carbons 1, 3, 4, and 6 in the boat conformation occupy positions similar to either the axial or the equatorial positions in the chair conformation. Label these substituents in the Newman projection of the boat conformation as *axial-like* or *equatorial-like*.
19. In the boat conformation, label the substituents on carbons 1, 3, 4, and 6 as *axial-like* or *equatorial-like*.
20. A chair conformation of a cyclohexane is lower in energy when a large substituent is in which position, axial or equatorial? Explain.
21. Would your answer to question 20 be the same for a boat conformation? Explain.

**MODEL 3****Transition States**

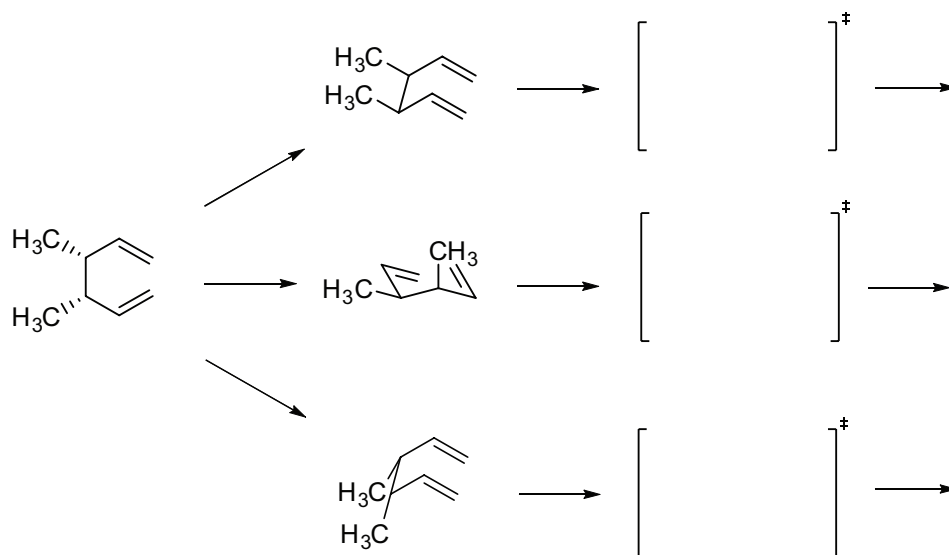
Because Cope reactions go through cyclic transition states (as all pericyclic reactions do), we can investigate the transition state to see if it is chair-like or boat-like.



22. Draw curved arrows to show the electron flow in the Cope rearrangement above.
23. Draw the product of the Cope rearrangement in the chair conformation in the appropriate spot.
24. Draw the product of the Cope rearrangement in the boat conformation.
25. What is the relationship between these products?
  
26. In the transition states, each bond that is breaking should be drawn as a dotted line; each bond that is forming should also be drawn as a dotted line. Draw both the chair transition state and the boat transition state.

**MODEL 4****Comparing Transition States<sup>1</sup>**

While for unsubstituted 1,5-hexadiene both the boat and chair transition states lead to the same product, this is not true for substituted 1,5-hexadienes. The Cope rearrangement of one stereoisomer of 3,4-dimethyl-1,5-hexadiene is considered below.

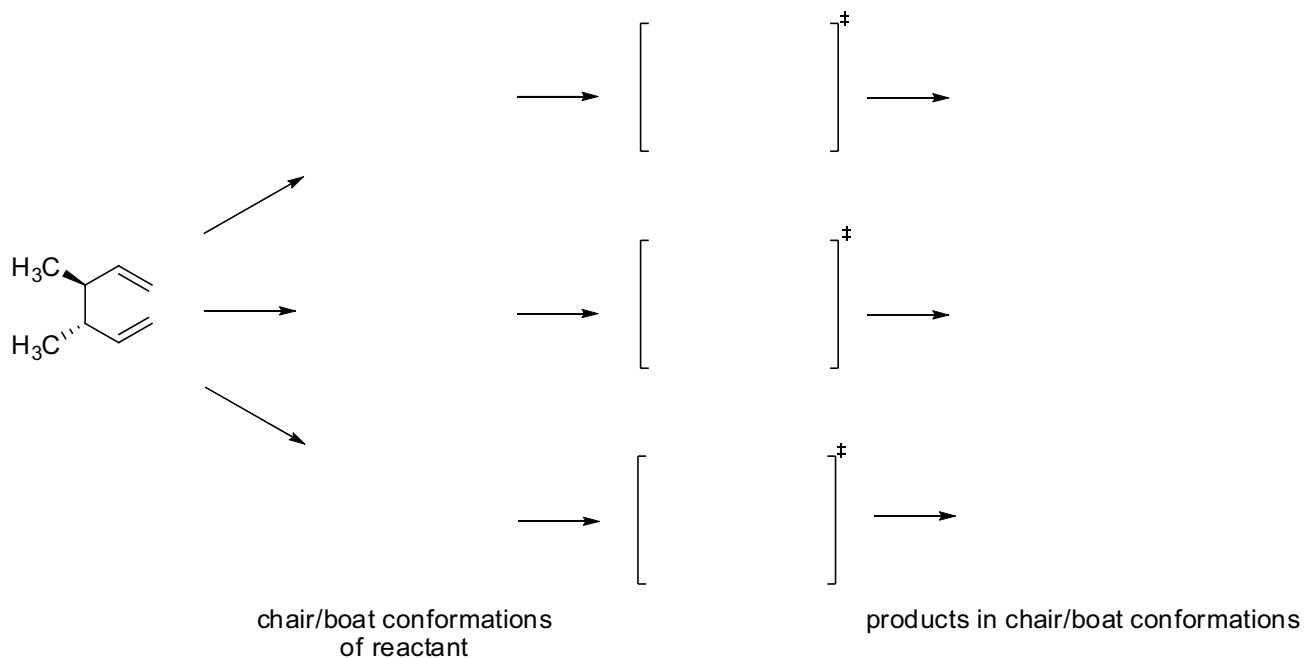


26. As shown above, there are two possible boat conformations of the reactant but only one chair conformation. Why is this so? Hint: try to draw a different chair conformation.
27. Draw the product of each conformation.
28. Put the correct stereochemical labels on both double bonds in each product (*cis*, *trans*, or *neither*). If needed, refer back to the Newman projections of the chair and boat conformations.
29. Draw the transition state for each conformation.
30. Rank the transition states in order of increasing energy (1 = lowest energy).
31. Does the product distribution in Model 2 correlate with your answer to question 30? If so, how?
32. Does your answer to question 31 agree with your answer to question 11?
33. Does your answer to the questions about this model support the idea that the Cope rearrangement goes through a chair-like transition state? Explain your reasoning.

<sup>1</sup> Diagram based on one in Anslyn, E. V.; Dougherty, D. A., *Modern Physical Organic Chemistry*; University Science Books: Sausalito, 2006; p. 917.

**MODEL 5****Second Part of the Doering-Roth Experiment<sup>1</sup>**

Doering and Roth also investigated the Cope products of a different isomer of 3,4-dimethyl-1,5-hexadiene.



34. There are two different chair conformations and one boat conformation that the compound in Model 5 can adopt. Draw all three of them.
35. Explain why there are not two different boat conformations of the compound in Model 5.
36. Draw the transition state and product from each conformation of the reactant.
37. Put the correct stereochemical labels (*cis*, *trans*, or *neither*) on both double bonds in each product.
38. Draw out each product so that it is flat (like the products in Model 2).
39. Rank the transition states in order of increasing energy (1 = lowest energy).
40. Which product will be formed in the highest yield? Which in the lowest? Explain your reasoning.
41. When Doering and Roth did the reaction in Model 5, the product distribution was as follows: *trans-trans*, 90%; *cis-cis*, 10%; *cis-trans*, <1%. Do these results confirm your prediction from question 40?

**SUMMARY**

Based on what you learned in CA 7A and in this activity, describe how to predict the products of a Cope Rearrangement. This explanation should enable a student who was absent for these two activities to predict these products.