

Chem 220 - Organic Chemistry

Problem Set 7, Solution Set

Chapter 8, Reactions of Alkenes

Due: Monday, November 2, 2009

Ozone

In 1840, [Christian Friedrich Schönbein](#) (1799-1868) discovered ozone (Gr.: odorant), the sharp odor produced by electrical discharges. Seven years later (1847) he observed that ozone oxidizes organic compounds but not to their ultimate products of oxidation, carbon dioxide and water. [Two years prior, he had spilled nitric and sulfuric acid on his Frau's apron in her kitchen. The apron, made of cotton, combusted and thus was discovered gun cotton, nitrocellulose. Schönbein also observed that hydrogen peroxide (Threnard; 1818) is oxidized to oxygen gas in the presence of hemoglobin.] In the period 1903-1916, [Carl Dietrich Harries](#) (1866-1923), an assistant to both Hofmann (of the eponymous elimination and rearrangement) and Fischer (of projection and carbohydrate fame) at Berlin, published some 80 papers on the reactions of ozone with organic compounds. His interest was stimulated by the reaction of ozone with rubber, a process that causes rubber to become hard and brittle. These studies led to the analytical and synthetic uses of ozone. From 1904-1916 he was a professor at Kiel. Disenchanted with academic life, he became Director of Research for Siemens and Halske, the German company co-founded by the electrical pioneer, Werner von Siemens, his father-in-law. Not surprisingly, Siemens went into the business of producing ozone generators. The studies of [Rudolf Criegee](#) (1902-1975; [Karlsruhe](#)) produced a unified mechanism for the [process of ozonolysis](#).

[M. Rubin, Bull. Hist. Chem., 2001, 26, 40.](#)

[M. Rubin, Helv. Chem. Acta, 2003, 86, 930.](#)

Reading assignments:

- The alkene module in [ORGO](#).
- [Ozonolysis](#) module.

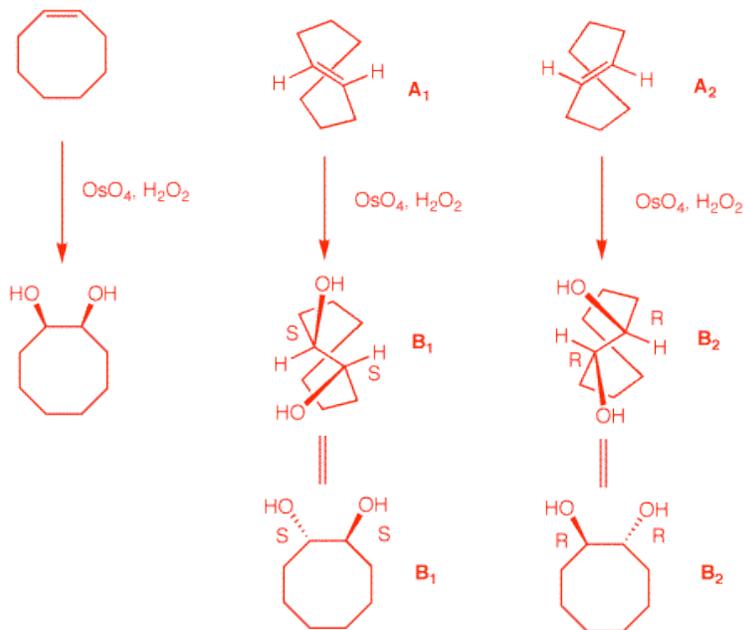
How do I approach solving problems like #1---5? [Here](#) is a step-by-step analysis of a typical problem.

1. An optically active compound **A** (C_8H_{14}) reacts with catalytic OsO_4 and stoichiometric H_2O_2 to form (*R,R*)-diol **B**. Ozonolysis and dimethyl sulfide reduction of **A** forms $OHC(CH_2)_6CHO$. What are the structures of **A** and **B**? Explain.



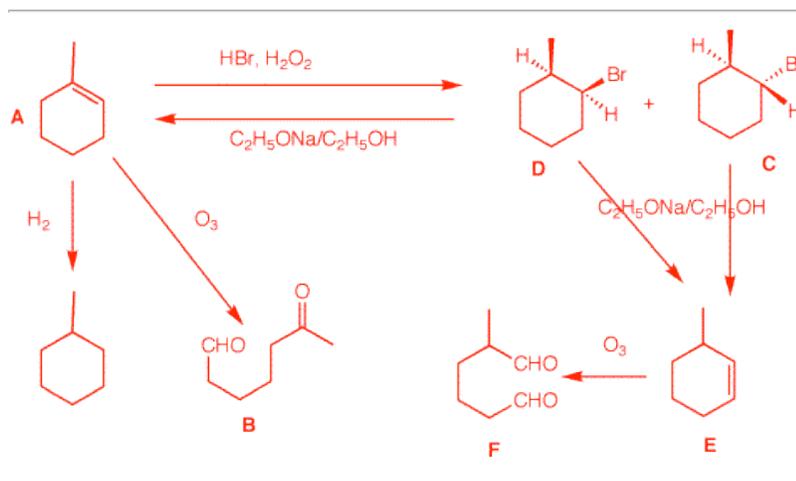
Vladimir Vasilovich
Markovnikov
(1838-1904)

The formula of **A** indicates 2 degrees of unsaturation (DU's). That **A** reacts with OsO_4 and O_3 indicates at least one double bond. The dialdehyde product of ozonolysis indicates the alkene was 1,2-disubstituted and contained in a ring. The ring and double bond account for the 2 DU's. Deconstructing the dialdehyde to the alkene whence it came, leads to *cis*- or *trans*-cyclooctene for **A**. That **A** forms a chiral (*R,R*)-diol **B** means that **A** is also chiral. **A** must be an enantiomer of *trans*-cyclooctene, which is resolvable. *Cis*-cyclooctene, which is achiral, would lead to an achiral 1,2-*cis*-diol. See diagram on the right. The two enantiomers of **A**, **A**₁ and **A**₂, cannot interconvert because the double bond cannot pass through the ring. This also means that only one face of the double bond is exposed to *syn*-hydroxylation. *Syn* addition to a *trans*-double bond gives hydroxyl groups that are *trans* on the ring. Clearly, **B**₂ is **B** and **A**₂ is **A**.

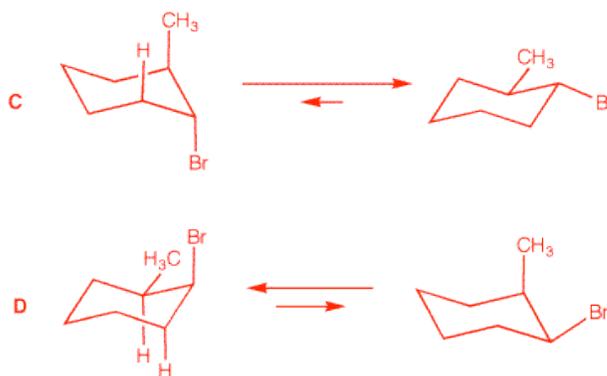


2. Compound **A**, C_7H_{12} , [[Degree of Unsaturation?](#)] affords a *single* ketoaldehyde **B** upon ozonolysis and dimethyl sulfide reduction. Hydrogenation of **A** gives methylcyclohexane. Treatment of **A** with HBr in the presence of *peroxide* gives two stereoisomeric bromides, **C** and **D**. Compound **C** reacts with $\text{C}_2\text{H}_5\text{ONa}/\text{C}_2\text{H}_5\text{OH}$ to give **E** while under the same conditions, compound **D** gives mainly **A** and some of compound **E**. Ozonolysis of **E** gives a single dialdehyde **F**. What are the structures of **A-F**? Explain and illustrate. Pay attention to stereochemistry.

$DU = 2$. The reaction with O_3 suggests an alkene and hydrogenation gives methylcyclohexane. The double bond must be trisubstituted because there is a **single** keto aldehyde formed. **A** must be 1-methyl-1-cyclohexene.



Peroxide and HBr produces bromine radicals that add to the less substituted end of the double bond of **A**. **C** and **D** are cis and trans 2-methyl-1-bromocyclohexane. But which one is which? The base treatment to give E_2 elimination gives the answer.



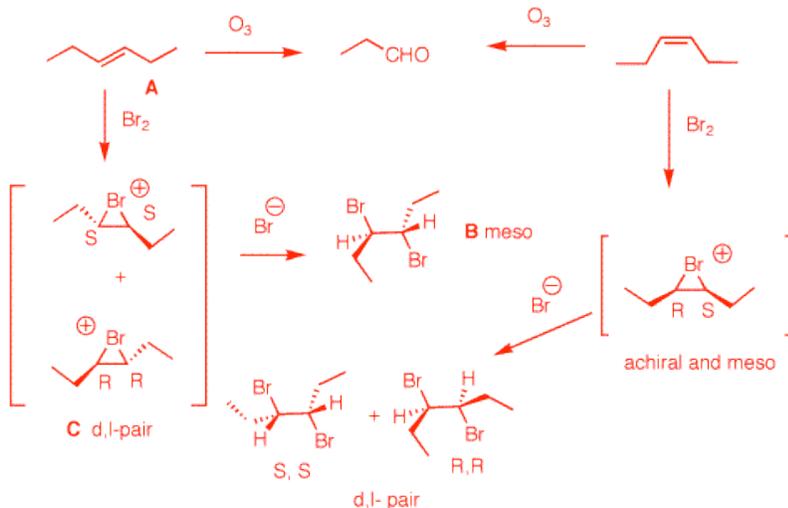
For E_2 elimination to occur, the cyclohexane ring must be in a conformation having the bromine axial. The less stable conformation of trans isomer **C** has the bromine and one β -hydrogen axial. This loss of HBr affords alkene **E**. On the other hand, the more stable conformation of the cis-isomer **D** has an axial bromine and two axial hydrogens.

With small bases such as ethoxide, the Saytzeff rule applies, more of the more substituted alkene **A** and less of **E**.

3. Compound **A** reacts with Br_2 in CCl_4 to give **B**.

The intermediate in this reaction (**C**) is a racemic species. Ozonolysis of **A** affords only propanal (propionaldehyde). What are the structures **A-C**? Explain and illustrate. Pay attention to stereochemistry.

Since ozonolysis of **A** gives only propionaldehyde ($\text{CH}_3\text{CH}_2\text{CHO}$), **A** is either (*E*)- or (*Z*)-3-hexene. A bromonium ion is the intermediate in the bromination of alkenes. The bromonium ion from (*E*)-3-hexene forms a racemic mixture (*d,l*-pair) of intermediates. The intermediate from (*Z*)-3-hexene is achiral and meso. Anti addition of bromine to (*E*)-3-hexene leads to meso-3,4-dibromohexene. Anti addition of bromine to (*Z*)-3-hexene leads to *d,l*-3,4-



dibromohexene.

4. Optically active terpene

A reacts with 2 molar equivalents of hydrogen to produce diastereomers **B** and **C**, both of which are optically inactive.

Compound **B** has a smaller heat of combustion than **C**.

Ozonolysis and dimethyl sulfide reduction of **A** affords pyruvaldehyde **D** ($C_3H_4O_2$, [Google it](#)) and (*S*)-

isopropylsuccinaldehyde

E ($OHCCH(i-$

Pr) CH_2CHO ; tartaric acid

= 2,3-dihydroxysuccinic

acid). What are the

structures **A-E**? What are

the sign and value of the

optical rotation of **A**

(Review [PS4](#))? Explain. **A**

terpene has ten carbons.

This info distinguishes the

structure from some

multiple of C_{10} . There are

*only two ways to piece **D***

*and **E** back together -- **A**₁*

*or **A**₂. Two equivalents of*

hydrogen convert the

diene to a pair of

*cyclohexanes. Only **B**₁*

*and **C**₁ are optically*

inactive (plane of

*symmetry); **B**₂ and **C**₂ are*

*optically active. [Note: **B**₁*

*and **B**₂ have the lower*

heat of combustion over

their respective

diastereomers because

they have a more negative

heat of formation (more

*stable)]. Summary: **A** =*

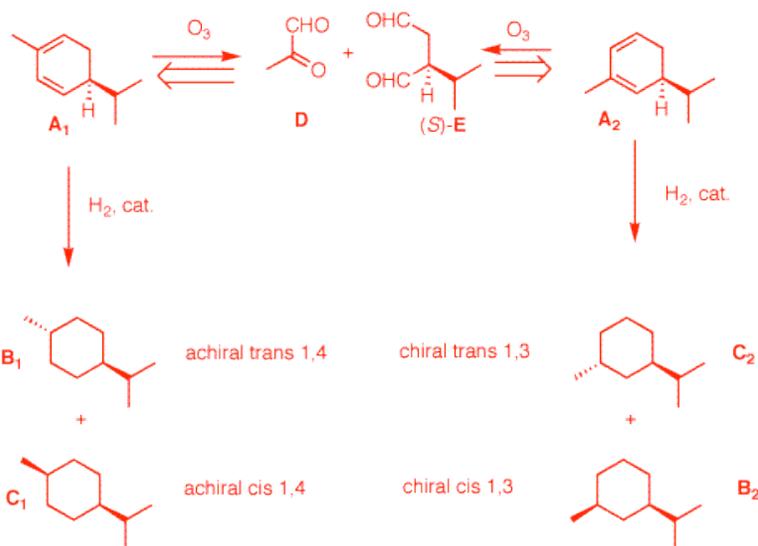
***A**₁; **B** = **B**₁; **C** = **C**₁.*

*From PS4, #6, **A** is (*S*)- α -*

Phellandrene ($[\alpha]_D =$

+86°). Based upon [PS4](#),

*[#7](#), it could be (*S*)- α -*



Phellandrene ($[\alpha]_D = +217^\circ$)

5. Compound **A** ($C_{10}H_{20}$) undergoes ozonolysis to produce a **single, optically active** compound (*R*)-**B**. The reaction of compound **A** with ethereal OsO_4 or aqueous $KMnO_4$ provides a **single, optically active** compound **C**. What are the structures of **A-C**? Show their stereochemistry. Show your reasoning.

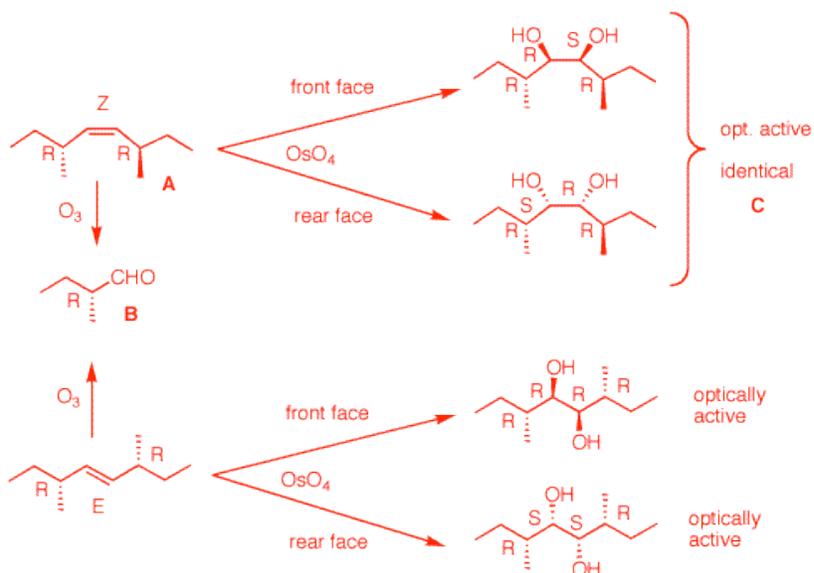
*Compound A has 1 DU. A is an alkene because of its reactions. Since only a single, optically active compound (*R*)-**B** is formed upon*

*ozonolysis, **B** must be C_5 and have a center of asymmetry. There is only one solution: (*R*)- $CH_3CH_2CH(CH_3)CHO$.*

*All that remains is to determine the geometry of the double bond. We have an arrangement of a 1,2-disubstituted double bond flanked by two asymmetric centers of the (*R*)-configuration. When dihydroxylation occurs, there will be two chiral hydroxyl centers flanked by the two (*R*) centers, or *R-X-X-R*, where *X* is a hydroxyl center.*

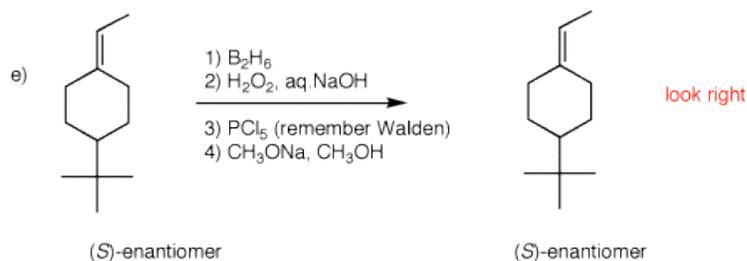
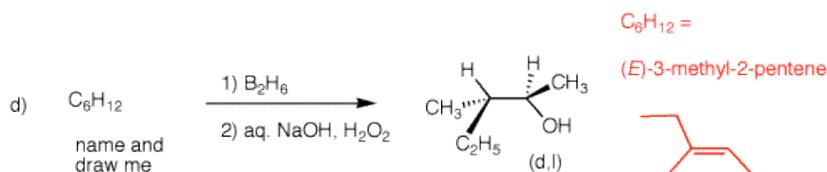
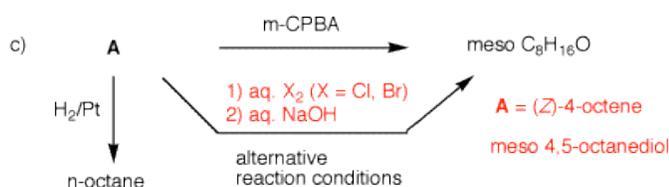
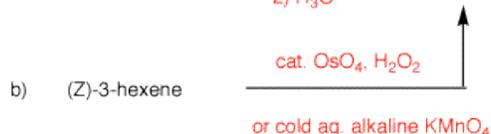
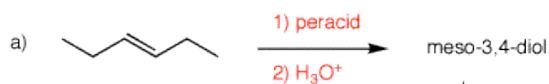
*Imagine that the double bond is (*Z*). Then syn addition of the two hydroxyls will give *R-R-S-R* and *R-S-R-R*, which are identical and optically active.*

Imagine that the double



bond is (E). Then syn addition of the two hydroxyls will give two compounds: R-R-R-R and R-S-S-R. Both compounds are optically active. Therefore, the double bond is (Z). To assist you, think about syn addition to (E)- and (Z)-2-butene.

6. Provide the products, reagents, and/or reagents as required in each of the following problems. Explanations are required for all.



a) We have no direct way to add two hydroxyl groups anti to a double bond. Syn epoxidation followed by acid catalyzed, S_N2 opening of the epoxide is a solution.

b) Straight forward syn-epoxidation.

c) A is a normal chain (hydrogenation data). A is C₈H₁₆ because epoxidation with peracid (no inversions) adds one oxygen atom syn. Since C₈H₁₆O is meso, A must be (Z)-4-octene. The alternative reaction sequence has two inversion (S_N2) reactions.

d) C₆H₁₂ is an alkene from the reaction conditions. The hydroboration sequence adds water to an alkene in an anti-Markovnikov sense. The alkene must be trisubstituted. It appears from the structure of the alcohol that the elements of water have been added trans, which means the alkene is not (Z)-3-methyl-2-pentene but rather (E)-3-methyl-2-pentene.

e) This alkene can be optically active. See PS4, #5b. The tert-butyl group is the highest priority; the hydrogen the lowest. The methyl on the double bond has priority over the hydrogen on the double bond. This may seem like a futile synthesis because you are converting the starting material into itself. Well, it is. But it is a good stereochemical exercise. Hydroboration adds water anti-Markovnikov in a syn manner. There are two possible stereoisomers; water added either cis or trans to the tert-butyl group. The hydroxyl groups can be converted to chlorides with S_N2 inversion (See PS5 Solution Set for a mechanism). Now E₂ elimination of HCl in an anti manner returns the starting enantiomer. Had a tosylate of the alcohol been used as a leaving group, the (R)-enantiomer would have formed upon

elimination because tosylate formation does not involve a change in stereochemistry.

