

1.3: ELECTROPHILIC ADDITIONS TO CONJUGATED DIENES- ALLYLIC CARBOCATIONS

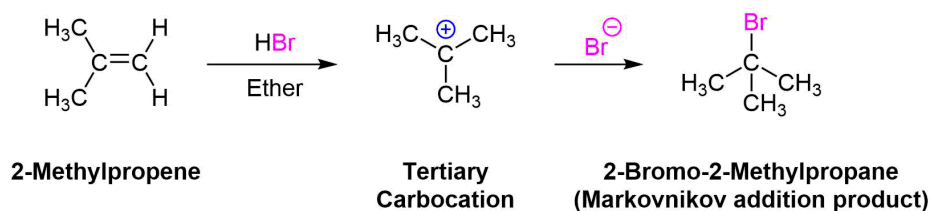
OBJECTIVES

After completing this section, you should be able to

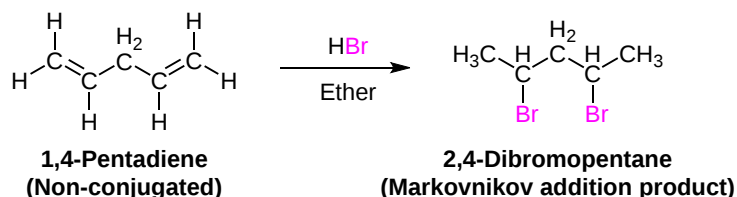
1. write an equation for the addition of one or two-mole equivalents of a halogen or a hydrogen halide to a non-conjugated diene.
2. Write an equation for the addition of one or two-mole equivalents of a halogen or a hydrogen halide to a conjugated diene.
3. Write the mechanism for the addition of one mole equivalent of hydrogen halide to a conjugated diene, and hence account for the formation of 1,2- and 1,4-addition products.
4. Explain the stability of allylic carbocations in terms of resonance.
5. Draw the resonance contributors for a given allylic carbocation.
6. Predict the products formed from the reaction of a given conjugated diene with one-mole equivalent of halogen or hydrogen halide.
7. Predict which of the possible 1,2- and 1,4-addition products is likely to predominate when one-mole equivalent of a hydrogen halide is reacted with a given conjugated diene.
8. Use the concept of carbocation stability to explain the ratio of the products obtained when a given conjugated diene is reacted with one mole equivalent of hydrogen halide.

In Organic Chemistry I [Section 7.7](#), we saw that electrophilic addition to a simple alkene would follow Markovnikov's rule. Markovnikov's rule states that for the electrophilic addition of HX, the carbocation intermediate forms on the double bond carbon with the greatest number of alkyl substituents. Because the stability of carbocation intermediates depends on hyperconjugation, the stability increases as it number of alkyl groups increases (primary < secondary < tertiary), this regioselectivity is provided by preferably forming a more stable carbocation intermediate during the reaction.

During the electrophilic addition of HBr to 2-methylpropene, the more stable tertiary carbocation intermediate is preferably formed which yields the Markovnikov addition product 2-bromo-2-methylpropane. Formation of 1-bromo-2-methylpropane does not occur because it would require the formation of a less stable primary carbocation intermediate.



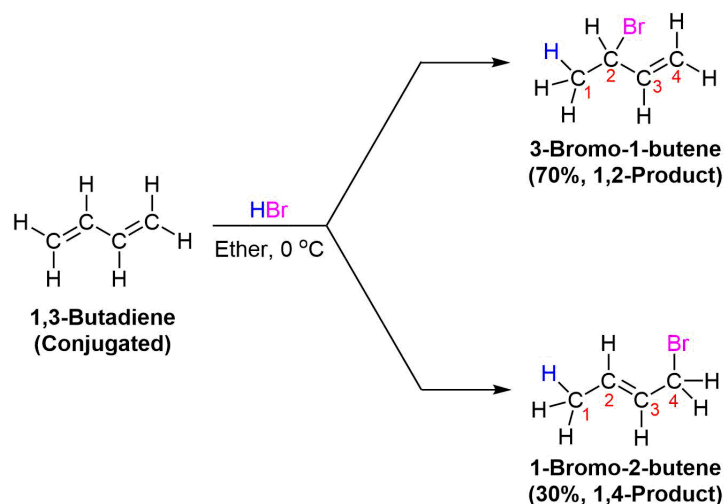
When an electrophilic addition is performed on a non-conjugated diene, the double bonds react in much the same manner as individual alkenes. During the addition of two equivalents of HBr to 1,4-pentadiene, a non-conjugated diene, Markovnikov's rule is still followed producing 2,4-dibromopentane as the product.



Conjugated dienes also undergo electrophilic addition reactions readily, but mixtures of products are invariably obtained. The addition of HBr to 1,3-butadiene, for instance, yields a mixture of two products, constitutional isomers (not counting cis-trans isomers). 3-Bromo-1-butene is the typical Markovnikov product of 1,2-addition to a double bond, but 1-bromo-2-butene seems unusual. The double bond in this product has moved to a position between carbons 2 and 3, and HBr has added to carbons 1 and 4, a result described as 1,4-addition.

NOTE

The numbers (1, 2, and 4) refer to which of the four carbons making up the conjugated diene the H and Br are bonded to in the products and are not related nor used for the compound's IUPAC nomenclature.

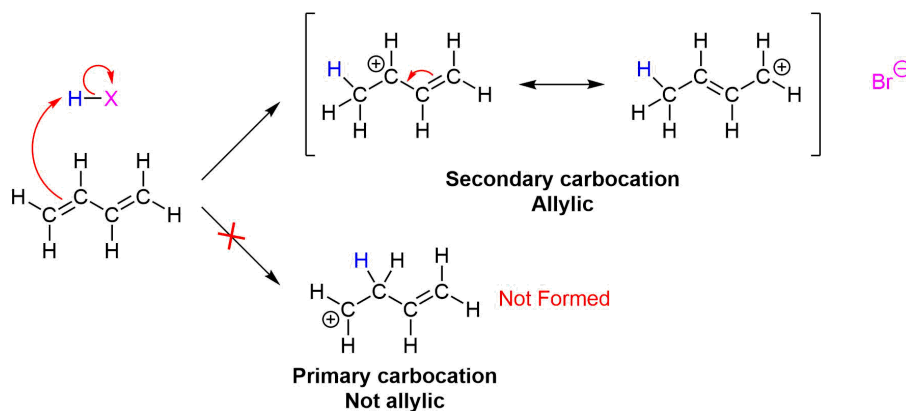


Although there are various methods for effecting the relative ratio of 1,2 and 1,4 addition products during the electrophilic addition to a conjugated diene, a mixture of these products is almost always produced. When one equivalent HBr undergoes electrophilic addition to 1,3-butadiene, 1,2 addition provides the expected Markovnikov product 3-bromo-1-butene in a 70% yield. This process is called a 1,2 addition because the hydrogen from HBr (labeled blue) bonds to the first carbon of the diene and the bromine from HBr bonds to the second carbon of the diene. The compound 1-bromo-2-butene is also produced in a 30% yield during the reaction as product of 1,4 addition. Here the hydrogen of HBr bonds to the first carbon of the diene and the Br bonds to the fourth carbon of the diene.

THE MECHANISM FOR ELECTROPHILIC ADDITION OF HBR TO A CONJUGATED DIENE

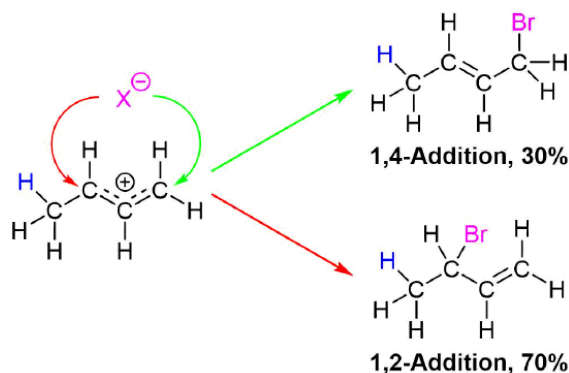
Regardless if the 1,2 or 1,4 addition product is formed, the first step of the mechanism is the protonation of one of the double bonds. In the same manner as the electrophilic addition of HX to an alkene, the protonation occurs regioselectively to give the more stable carbocation. In the case of a conjugated diene, the more stable cation is not only secondary, but also *allylic*, and therefore enjoys the stabilization created from the positive charge being distributed over two carbons by resonance. The resonance hybrid of the allylic carbocation intermediate can be depicted by two resonance forms (shown below), both of which have a full positive charge.

STEP 1)



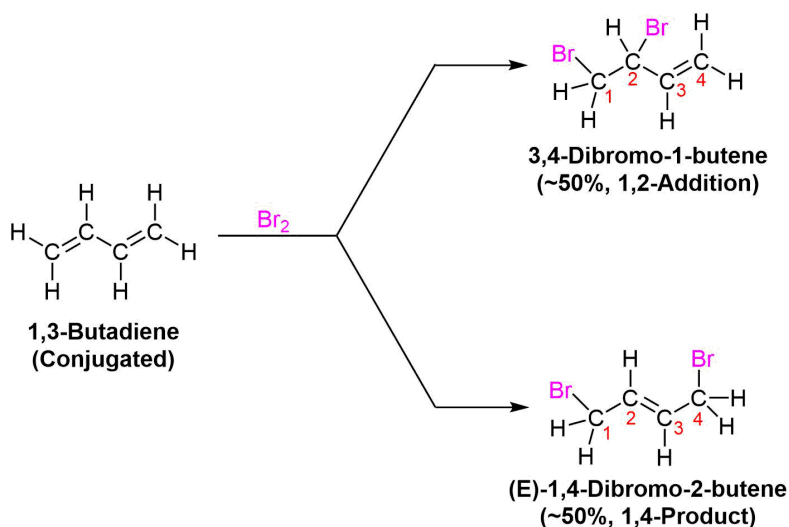
STEP 2)

This allylic carbocation, more properly denoted as the resonance hybrid shown below, has two carbons (C-2 and C-4, considering C-1 the one that H was added) which have a significant positive charge. The halide ion can attack either carbon. Attacking the central carbon, adjacent to the site of protonation, leads to the 1,2-addition product. Attacking the terminal carbon, distant from the site of protonation, leads to the 1,4 addition product.



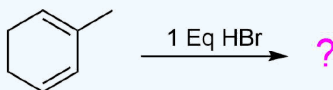
OTHER ELECTROPHILIC ADDITIONS

Formation of both 1,2- and 1,4-addition products occurs not only with hydrogen halides, but also with other electrophiles such as the halogens (X_2). The electrophilic addition of bromine to 1,3-butadiene is an example. As shown below, a roughly 50:50 mixture of 3,4-dibromo-1-butene (the expected 1,2 addition product) and 1,4-dibromo-2-butene (the 1,4 addition product) is obtained. The double bond of the 1,4 addition product is primarily formed as the (E) isomer.



✓ WORKED EXAMPLE 1.3.1

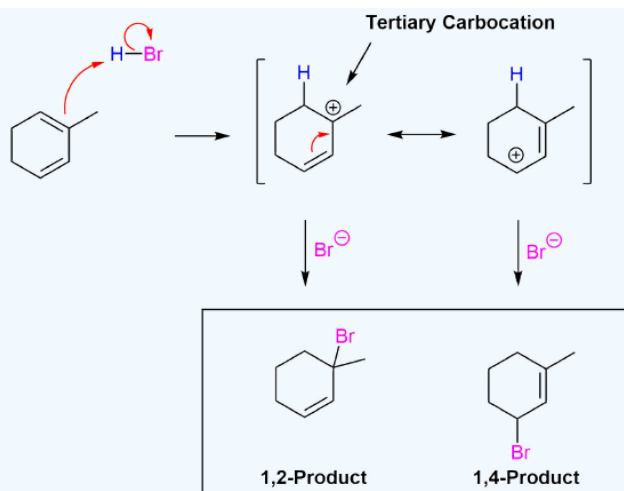
Give the expected products from the following reaction. Show both 1,2 and 1,4 addition products.



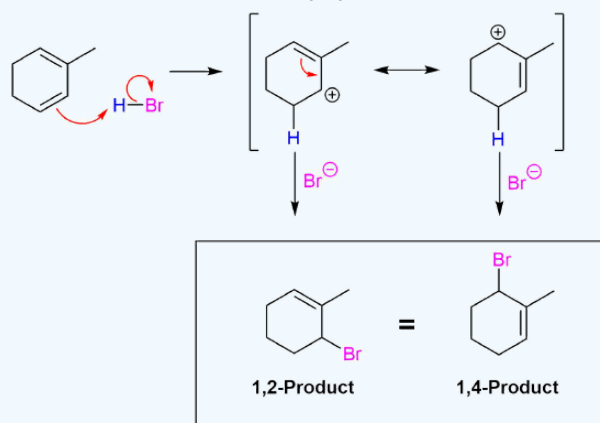
Solution

For this example the two double bonds in the diene are not equivalent and must be considered separately. Each double bond of the reactant has the possibility of forming a 1,2 and a 1,4 addition product so the reaction has the possibility of forming four product. Protonate each double bond separately and draw out the resonance forms of the allylic carbocation intermediate created. Then react each resonance form with Br^- to create the two possible products. Repeat this process with the second double bond to create the four possible product. Lastly, look for symmetry in the products to see if any are same molecule. Also, consider the stability of each carbocation created during this process. The most stable carbocation will generally product the favored product of the reaction.

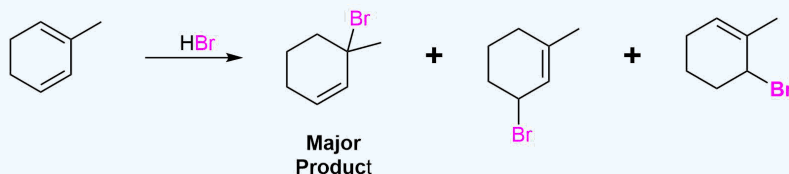
Addition to the first double bond creates a resonance form with a tertiary carbocation intermediate. Due to the stability of the tertiary carbocation this product will most likely go one to be the preferred product of this reaction.



The Addition to the second double bond gives a symmetrical carbocation, whose two resonance forms are equivalent. Thus, the 1,2 adduct and the 1,4 adduct have the same structure: 6-Bromo-1-methylcyclohexene.



The reaction would be expected to form three products. Of the two possible modes of protonation, the first yields a more stable tertiary allylic cation rather than a less stable secondary allylic cation, given the major product under kinetic conditions.

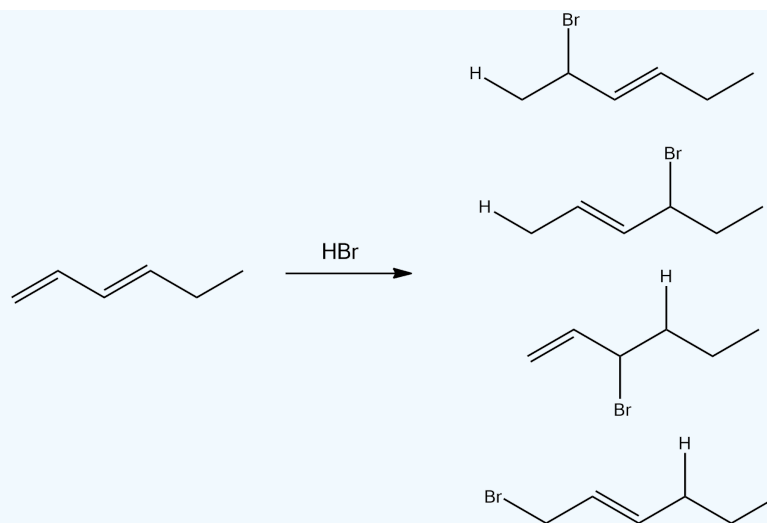


? EXERCISE 1.3.1

1. Give the structure of 1,2 and the 1,4 products of the addition of one equivalent of HBr to 1,3-hexa-diene.
2. Look at the possible carbocation intermediates produced during addition of HBr to 1,3-hexa-diene, and predict which 1,2 adduct predominates. Which 1,4 adduct predominates?

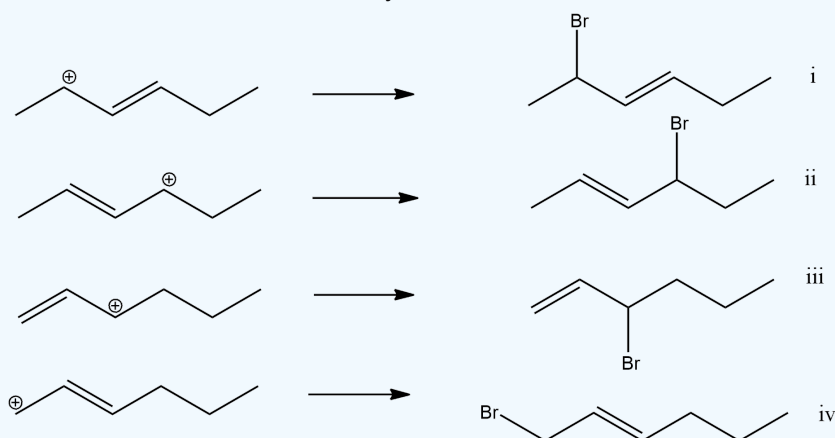
Answer

1)



2) Products i and iii are 1,2 adducts; both show a secondary cation intermediate. Both are likely to form as they have the same energy.

Products ii and iv are 1,4 adducts; Product ii shows a secondary cation intermediate, which is more stable than primary.



Therefore Products i, ii, and iii would be major products, and the iv product would be the minor product.

? EXERCISE 1.3.2

1- Give the structures of both 1,2 and 1,4 adducts resulting from reaction of 1 equivalent of HCl with 1,3-pentadiene.

2- Look at the possible carbocation intermediates produced during the addition of HCl to 1,3-pentadiene (the problem above) and predict which 1,2 adduct predominates. Which 1,4 adduct predominates?

Answer

1- It's your time to draw the structures. 1-Chloro-2-pentene, 3-chloro-1-pentene, 4-chloro-2-pentene

2- 4-Chloro-2-pentene predominates in both.

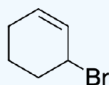
? EXERCISE 1.3.3

1. Write out the products of 1,2 addition and 1,4- addition of HBr to 1,3-cyclohexadiene.

2. What is unusual about the products of 1,2- and 1,4- addition of HX to an unsubstituted cyclic 1,3-diene?

Answer

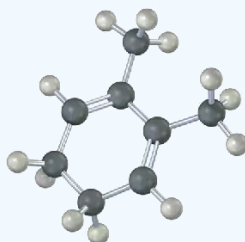
1-The same product will result from 1,2 and 1,4 addition.



2- The addition of the HX to unsubstituted cycloalkyl-1,3-dienes in either 1,2- or 1,4- manner gives the same product because of symmetry.

? EXERCISE 1.3.4

Give the structures of both 1,2 and 1,4 adducts resulting from the reaction of 1 equivalent of HBr with the following compound:



Answer

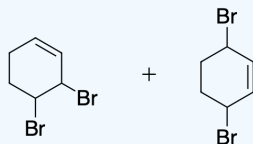
1,2 Addition: 6-bromo-1,6-dimethylcyclohexene. 1,4 Addition: 3-bromo-1,2-dimethylcyclohexene.

? EXERCISE 1.3.5

Write out the products of 1,2 addition and 1,4- addition of Br₂ to 1,3-cyclohexadiene.

Answer

Both 1,2 and 1,4 products will form.



📌 KEY TERMS

Make certain that you can define, and use in context, the key terms below.

- 1,2-addition
- 1,4-addition

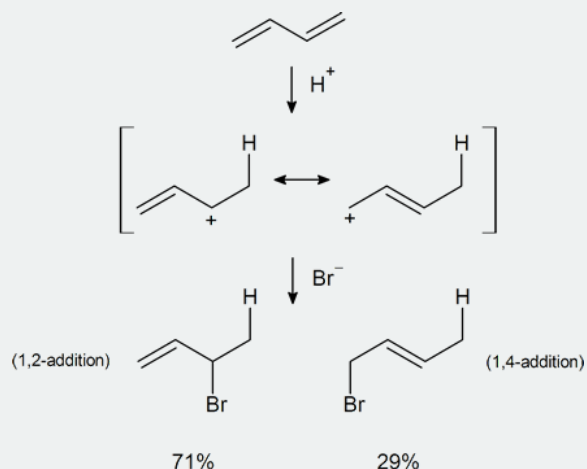
📌 STUDY NOTES

Notice that the numbers used in the expressions 1,2-addition and 1,4-addition do *not* refer to the positions of the carbon atoms in the diene molecule. Here, 1,2 indicates two neighbouring carbon atoms, while 1,4 indicates two carbon atoms which are separated in the carbon chain by two additional carbon atoms. Thus in 1,2- and 1,4-additions to 2,4-hexadiene, the additions actually occur at carbons 2 and 3, and 2 and 5, respectively.

The term “monoadduct” should be interpreted as meaning the product or products formed when one mole of reagent adds to one mole of substrate. In the objectives above, this process is referred to as the addition of one mole equivalent (or one mol equiv).

In Section 7.9 we saw that electrophilic addition to a simple alkene would follow Markovnikov's rule, where the stability of the carbocation intermediate would increase: primary < secondary < tertiary. With conjugated dienes the allylic carbocation intermediate generated has different resonance forms. The following scheme represents the mechanism for the addition of HBr to 1,3-butadiene (at 0°C). Note the resonance contributors for the allylic carbocation intermediate and that the product resulting from the secondary cation is generated in higher yield than from the primary cation as you might expect from our discussions until now. However, in the next

section you will see that the resulting product ratio can be drastically affected by a number of reaction conditions, including temperature.



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