Chem 150, Spring 2015

Unit 6 - Alcohols, and Hydration & Dehydration Reactions

Introduction

Question:

What do the words hydration and dehydration mean to you?

10.1 The Hydration Reaction

- In the last unit we introduced the concept of functional groups.
  - *A functional group is a group of atoms the combine to give a molecule a characteristic set of chemical and physical properties.*

10.1 The Hydration Reaction

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TABLE 9.10 Some Representative Functional Groups in Organic Chemistry

Functional Group	Name	An Example of a Compound That Contains This Group:
$>C=C<$	alkene	$CH_3-CH=CH_2$ propene
$-C\equiv C-$	alkyne	$CH_3-C\equiv CH$ propyne
$-\overset{\mid}{\underset{\mid}{C}}-\ddot{\underset{..}{Cl}}:$	chloroalkane	$CH_3-CH_2-CH_2-Cl$ 1-chloropropane
$-\overset{\mid}{\underset{\mid}{C}}-\ddot{\underset{..}{O}}-H$	alcohol	$CH_3-CH_2-CH_2-OH$ 1-propanol
$-\overset{\mid}{\underset{\mid}{C}}-\overset{\mid}{\underset{..}{N}}-$	amine	$CH_3-CH_2-CH_2-NH_2$ propylamine
$-\overset{\ddot{O}:}{\overset{\Vert}{C}}-H$	aldehyde	$CH_3-CH_2-\overset{O}{\overset{\Vert}{C}}-H$ propanal
$-\overset{\ddot{O}:}{\overset{\Vert}{C}}-\ddot{\underset{..}{O}}-H$	carboxylic acid	$CH_3-CH_2-\overset{O}{\overset{\Vert}{C}}-OH$ propanoic acid

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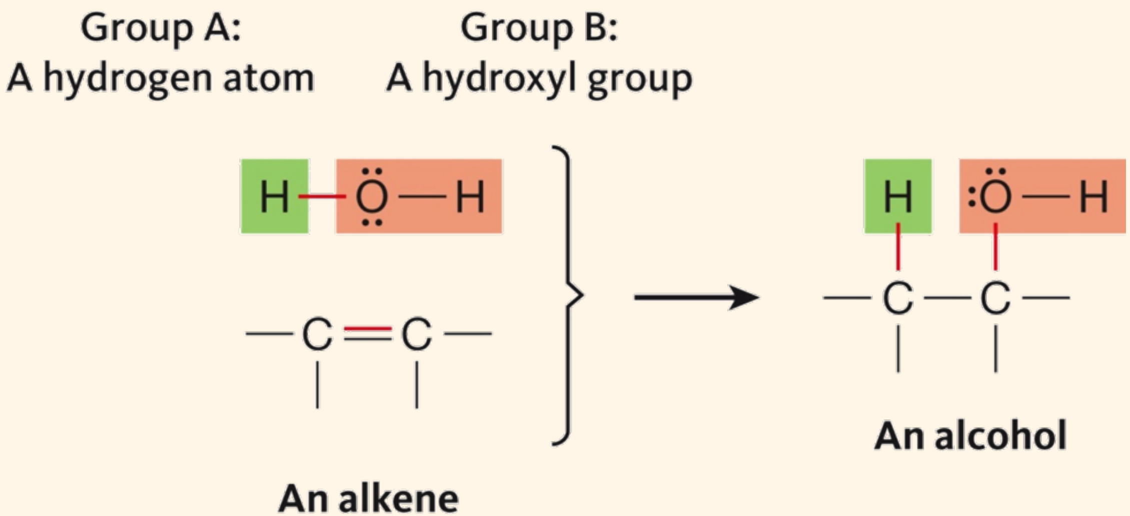
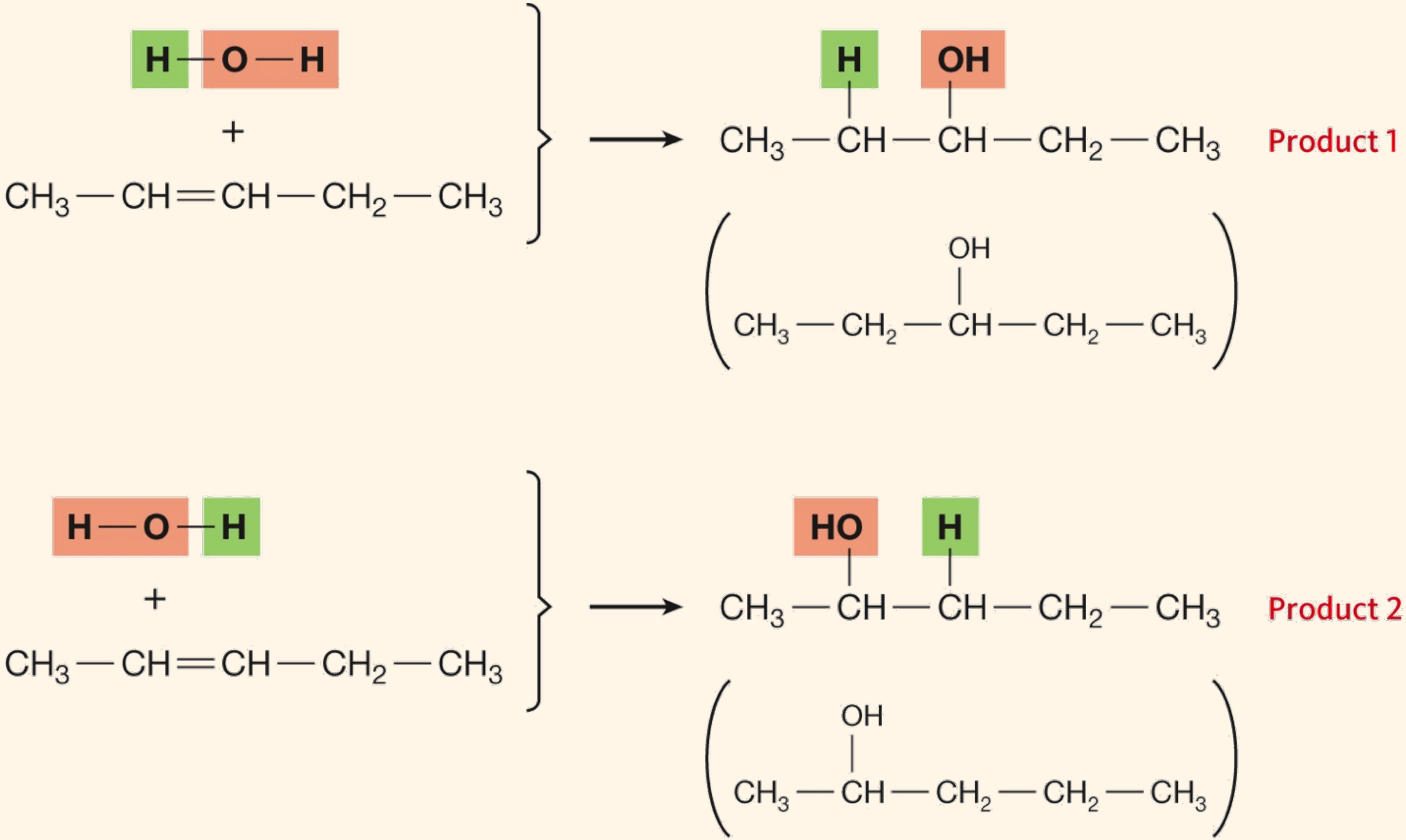
  - For example, the **alkene** functional group can react with water to produce the **alcohol** functional group

10.1 The Hydration Reaction

- An reaction that alkenes undergo in biological chemistry is the hydration reaction.
- The product of a hydration reaction is called an alcohol and contains a hydroxyl group.

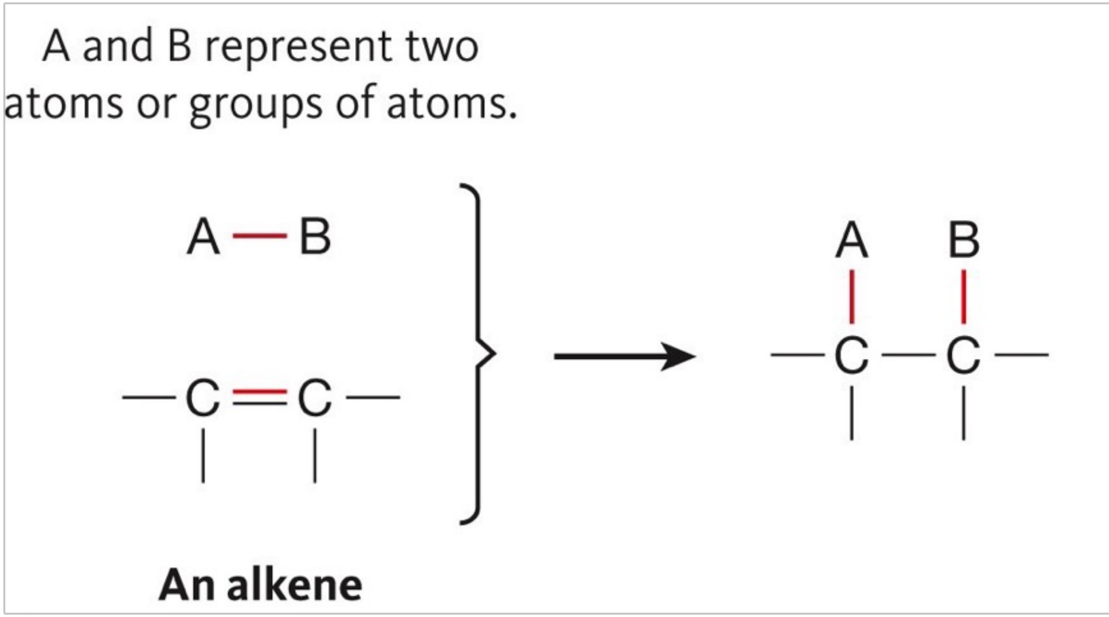


Many Alkenes Produce Two Hydration Products



Many Alkenes Produce Two Hydration Products

- Alkenes can also participate in other addition type reactions

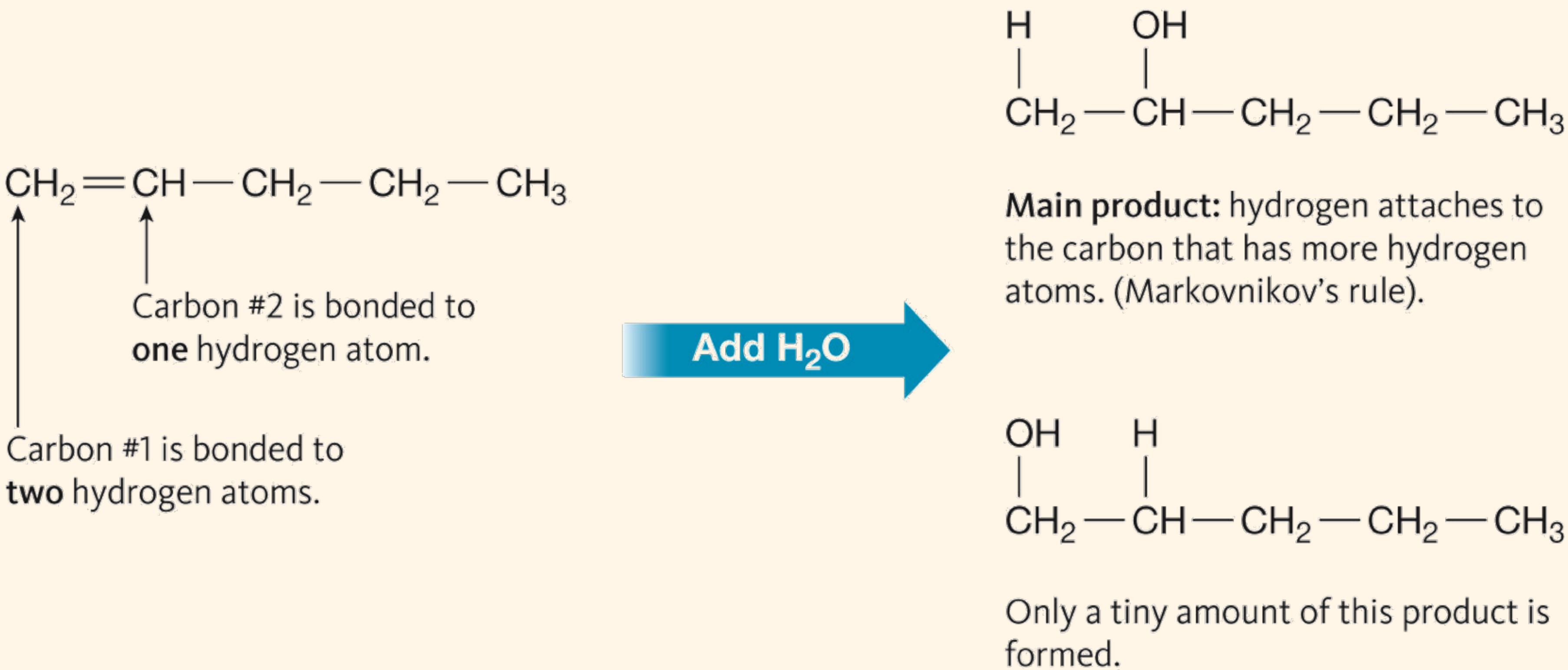


Some examples of molecules that can react with alkenes:

Molecule	A	B
H_2	H	H
Cl_2	Cl	Cl
HCl	H	Cl
H_2O	H	OH

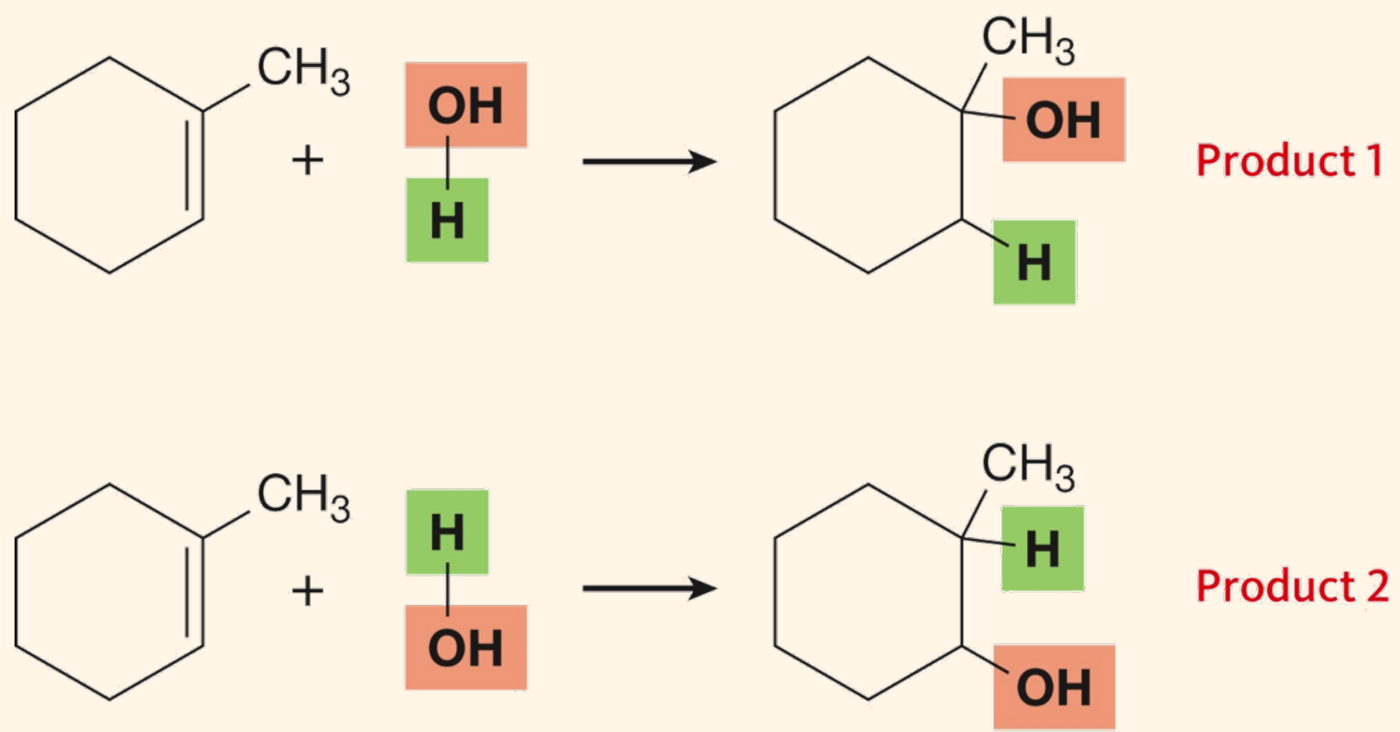
Markovnikov's Rule

- If there is an option, *the hydrogen atom of water prefers to become attached to the alkene carbon that is bonded to the greater number of hydrogen atoms.*



Cycloalkenes Can Be Hydrated

- Cycloalkenes can also react with water to form alcohols.



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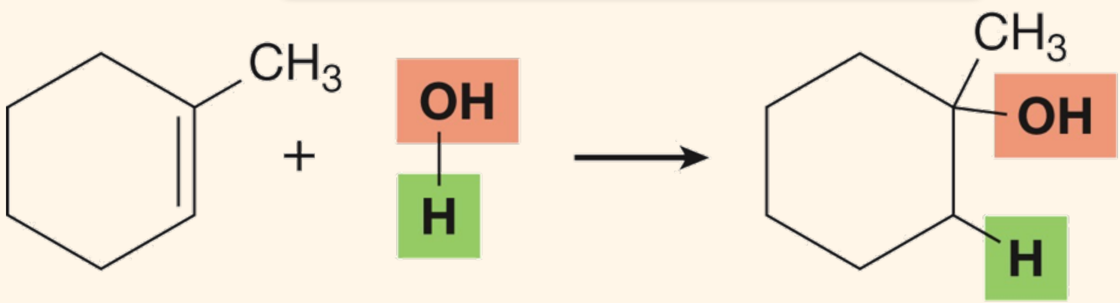
Clicker Question:

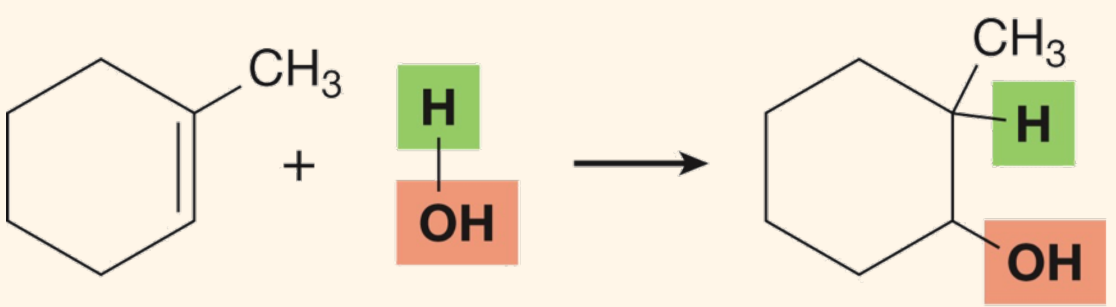
Which is the main product?

A. Product 1

B. Product 2



Product 1



Product 2

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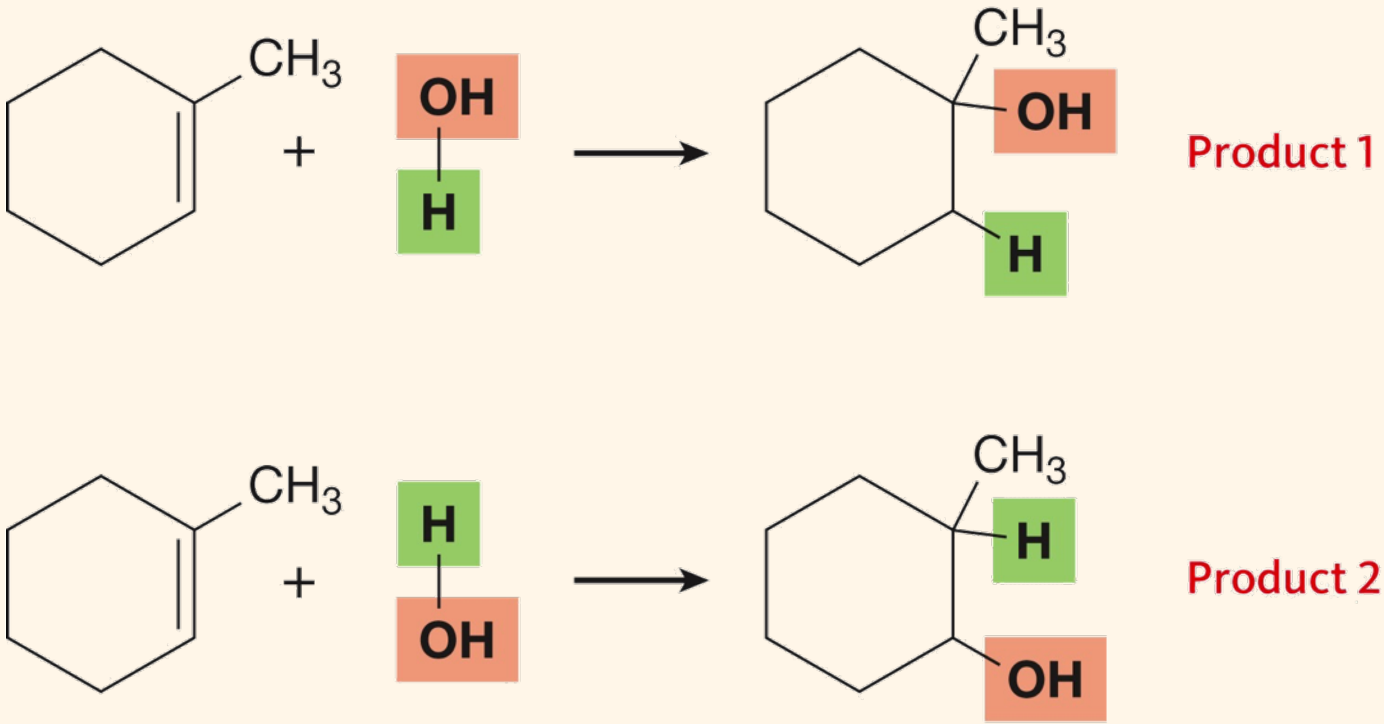
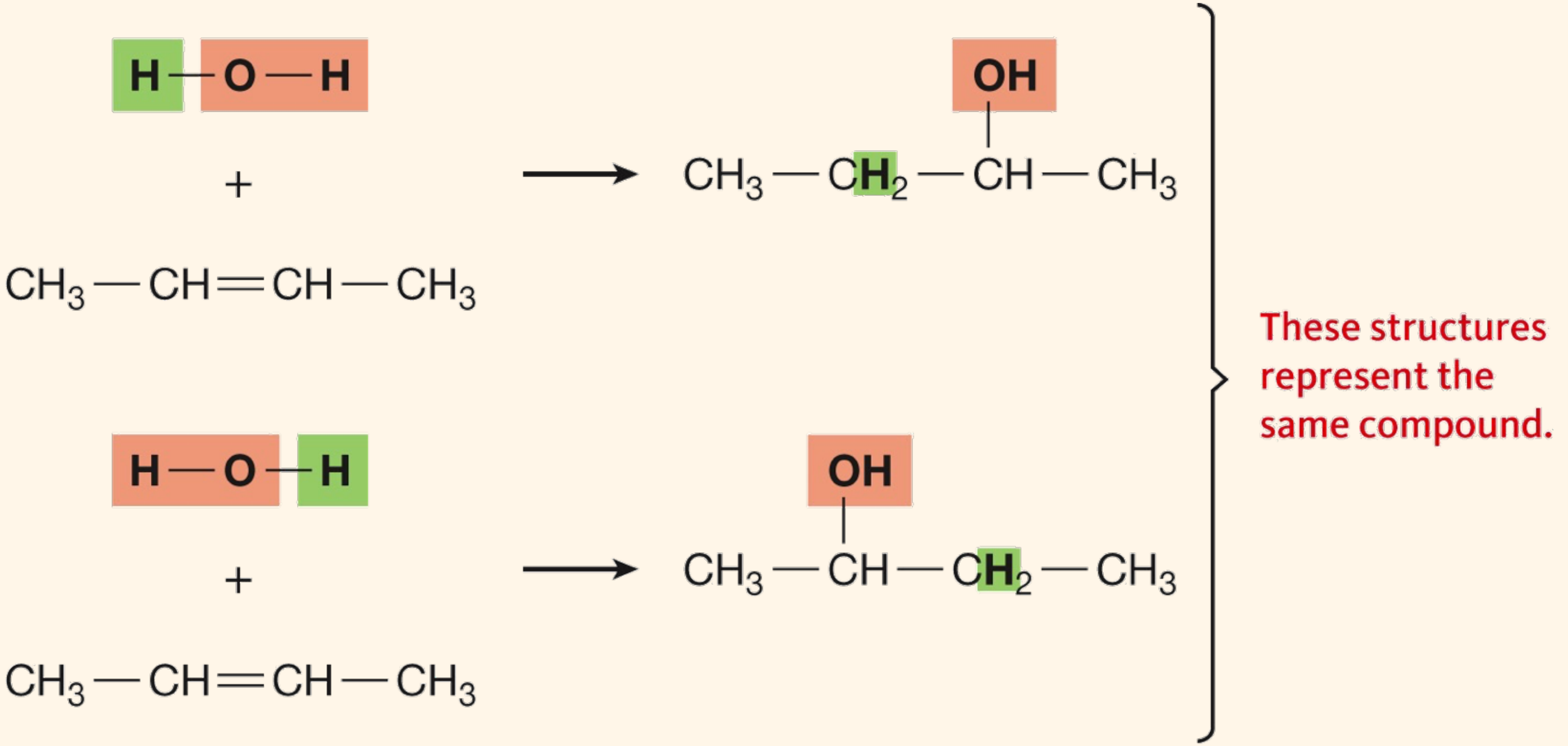


Symmetrical Alkenes Produce Only One Hydration Product

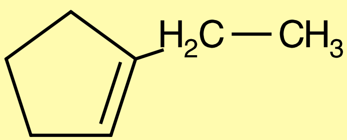


Try It!

Question:

Draw the structure(s) of the hydration products for each of the following alkenes.

A. $H_2C{=}CH-CH_2-CH_2-CH_3$

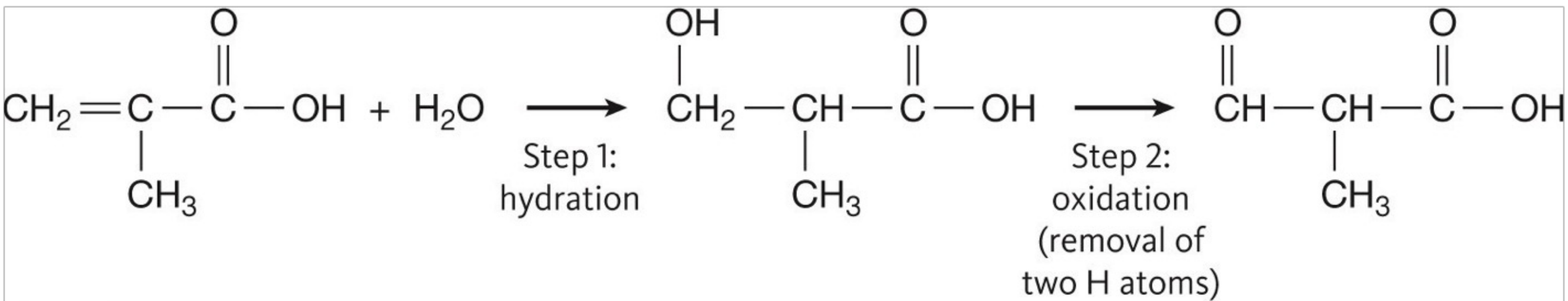
B. 

10.2 Controlling the Product: An Introduction to Enzymes

- Living organisms carry out many reactions. These reactions occur in specific sequences, in which each product becomes the starting material for the next reaction.

- Living organisms solve the problem of multiple products using enzymes.
  - Enzymes are biological catalysts that produce a single product.
  - Enzymes are also selective about the reactants that they can use so they will only react with certain compounds.

Enzyme Selectivity in a Hydration Reaction



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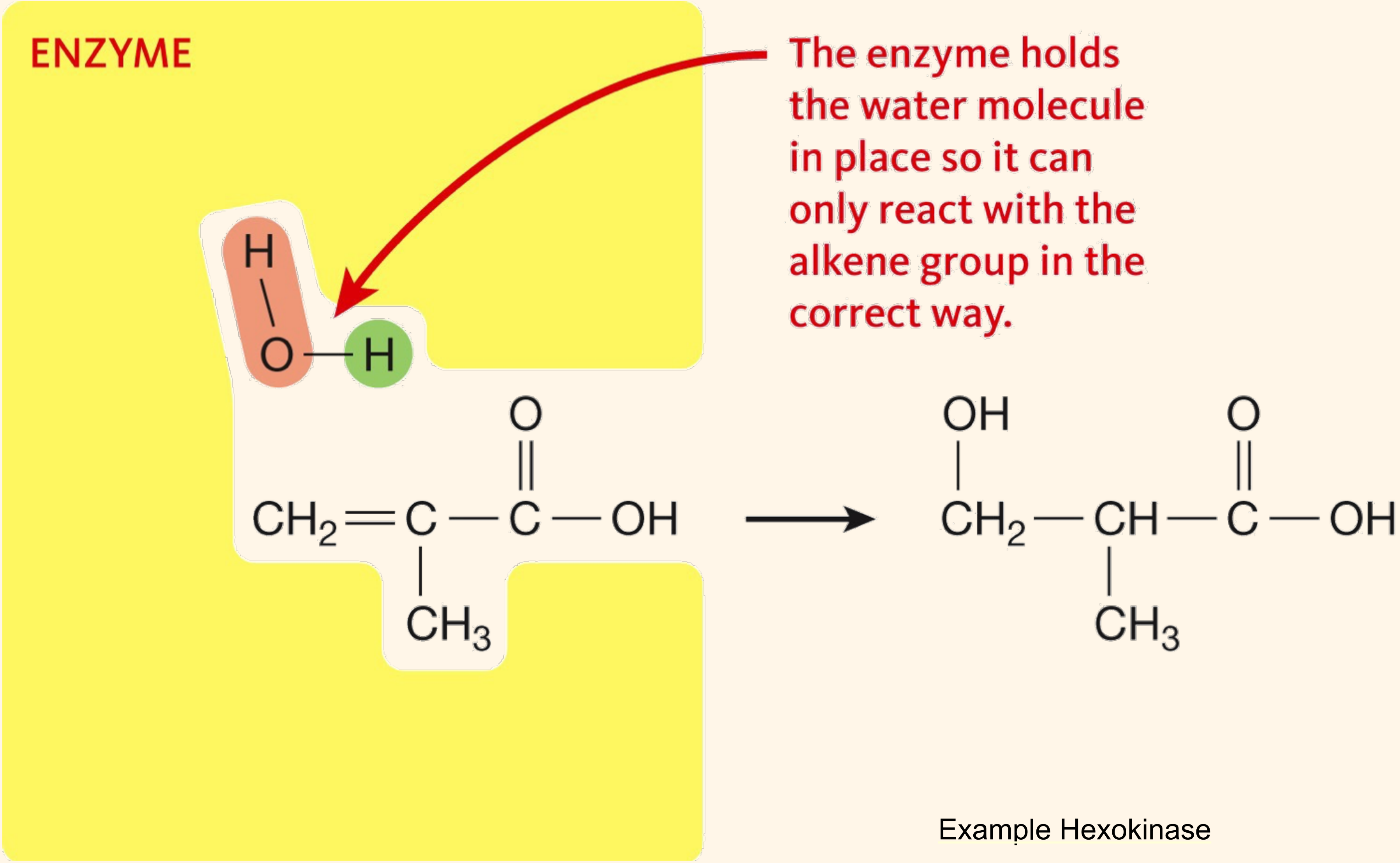


Example Hexokinase

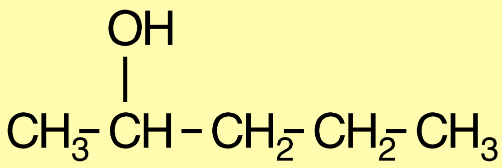
10.3 Naming Alcohols

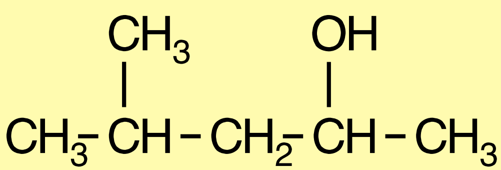
1. Name the hydrocarbon framework.
2. Identify the functional group by modifying the ending of the alkane name. For alcohols, change the end of the name of the corresponding hydrocarbon from *–e* to *–ol*.
3. To complete the root name, add a number to tell where the functional group is located. Number from the end of the carbon chain closest to the hydroxyl group.
4. Identify and locate any alkyl groups and append their names to the front of the root name.

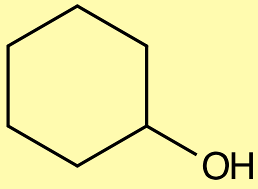
Try It!

Questions:

Give the IUPAC name for the following molecules

A. 

B. 

C. 

Try It!

Questions:

Draw structures for the following named molecules.

A. 3-isopropyl-1-nonol

B. 2-propanol

Commonly Used Trivial names

CH_3-OH

Methyl alcohol
(methanol)

CH_3-CH_2-OH

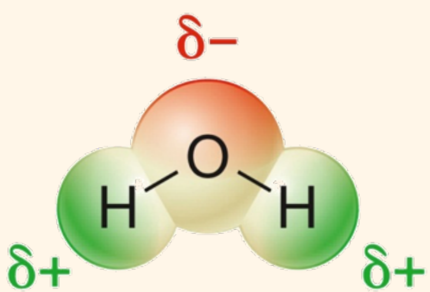
Ethyl alcohol
(ethanol)

$$\begin{array}{ccccc} & & OH & & \\ & & | & & \\ CH_3 & - & CH & - & CH_3 \end{array}$$

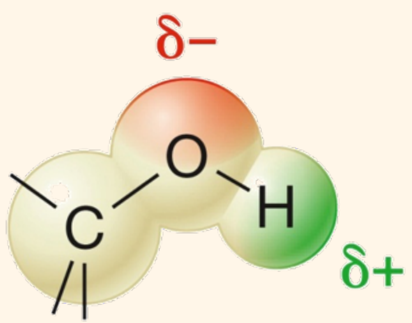
Isopropyl alcohol
(2-propanol)

10.4 The Physical Properties of Alcohols

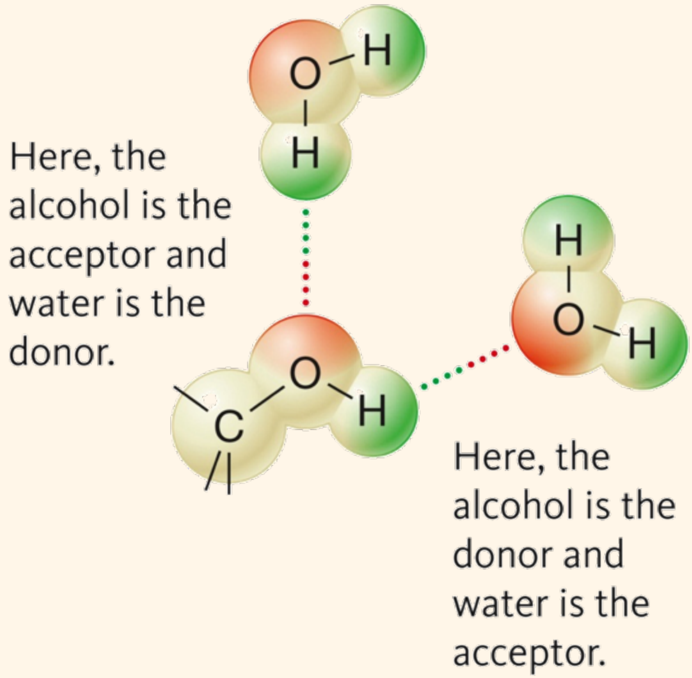
- The two covalent bonds in the alcohol functional group are strongly polar.
- The polar O-H bond allows alcohols to form hydrogen bonds.
- The ability to form hydrogen bonds gives alcohols quite different physical properties from those of hydrocarbons.



The arrangement of atoms in **water**



The arrangement of atoms in an **alcohol**



Boiling Points of Some Alkanes and Alcohols

TABLE 10.1 The Physical Properties of Some Alkanes and Alcohols

Alkane	Boiling Point	State at Room Temperature	Alcohol	Boiling Point	State at Room Temperature
Methane	−161°C	Gas	Methanol	65°C	Liquid
Butane	−1°C	Gas	1-Butanol	117°C	Liquid
Octane	126°C	Liquid	1-Octanol	194°C	Liquid

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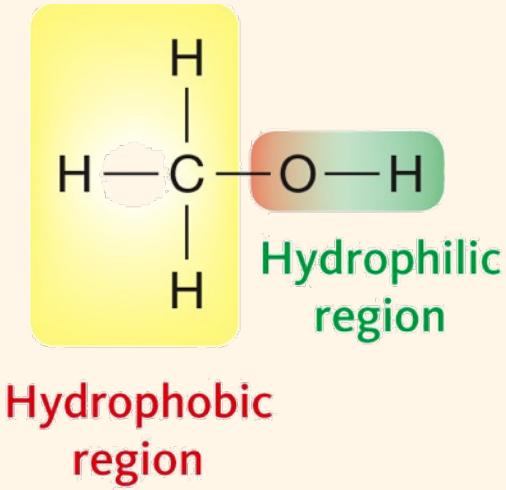
Hydrophobic and Hydrophilic Regions

- The solubility of a molecular compound depends on the relative sizes of the hydrophilic (-OH) and hydrophobic regions (CH_3CH_2-…) in the molecule.



Methanol has a small hydrophobic region, so it has a high solubility in water.

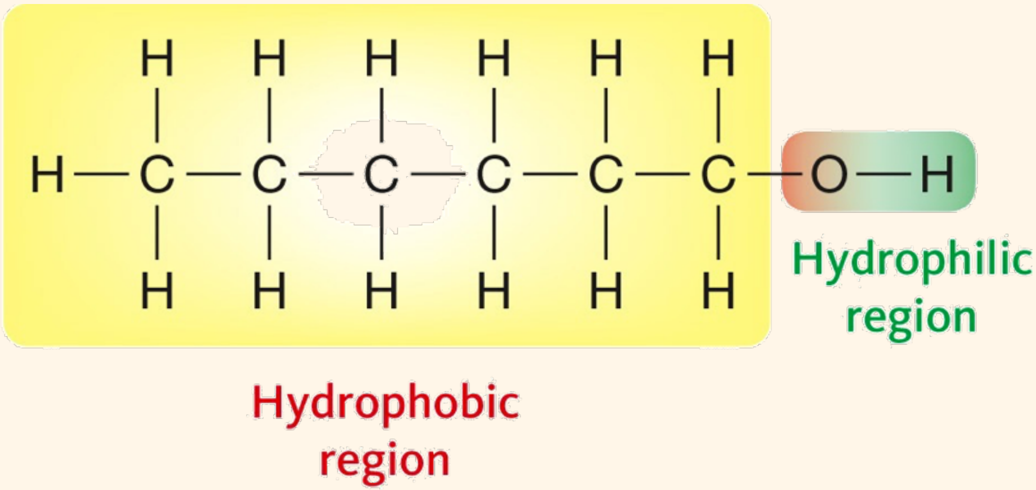


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TABLE 10.2 The Solubilities of Some Alcohols

Compound	Carbon Atoms	Solubility in 100 g of Water
Methanol	One	No limit (any amount of these alcohols will mix with water)
Ethanol	Two	
1-Propanol	Three	
1-Butanol	Four	7.4 g
1-Pentanol	Five	2.7 g
1-Hexanol	Six	0.7 g
1-Heptanol	Seven	0.1 g

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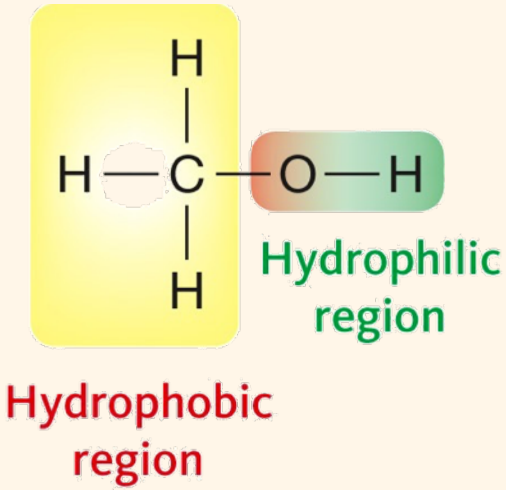

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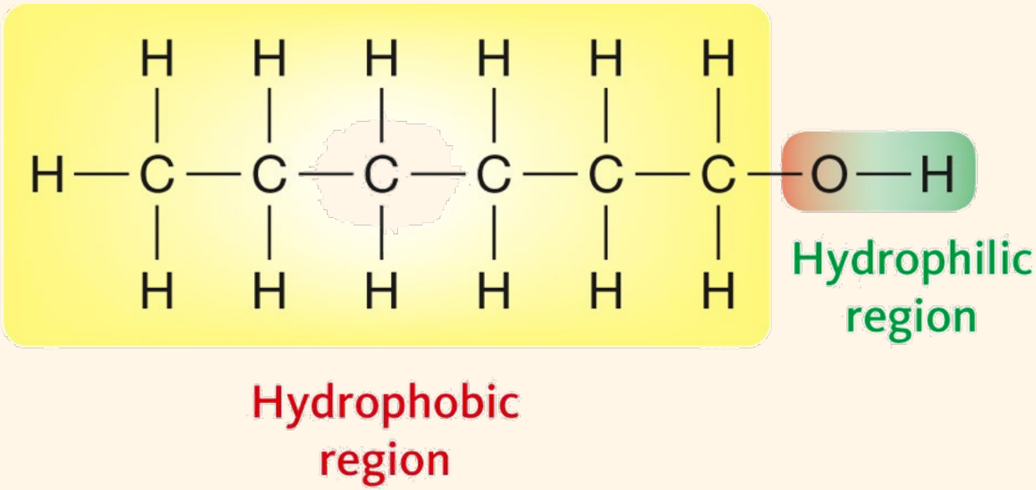

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TABLE 10.3 The Dependence of Solubility on the Number of Hydroxyl Groups

Compound	OH Groups	Solubility in 100 g of H_2O
$CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$	None	0.04 g
OH (on C1) $CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$	One	0.7 g
OH (on C1), OH (on C6) $CH_2-CH_2-CH_2-CH_2-CH_2-CH_2$	Two	6 g
OH (on C1), OH (on C3), OH (on C6) $CH_2-CH_2-CH-CH_2-CH_2-CH_2$	Three	No limit

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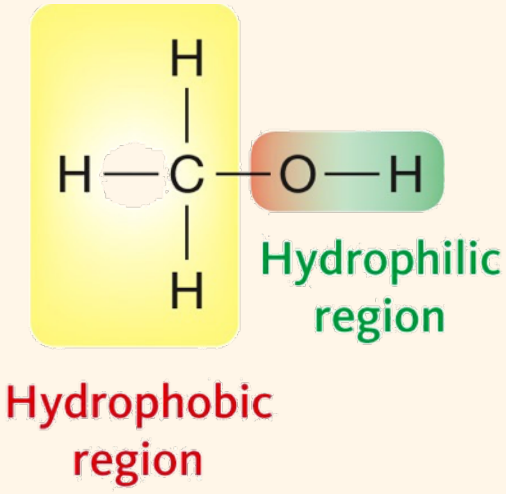

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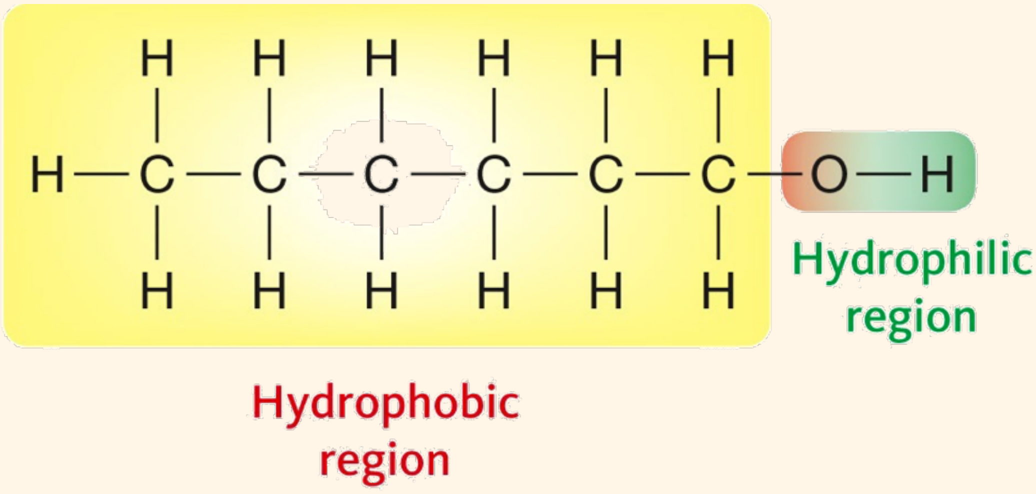

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Solubility Trends

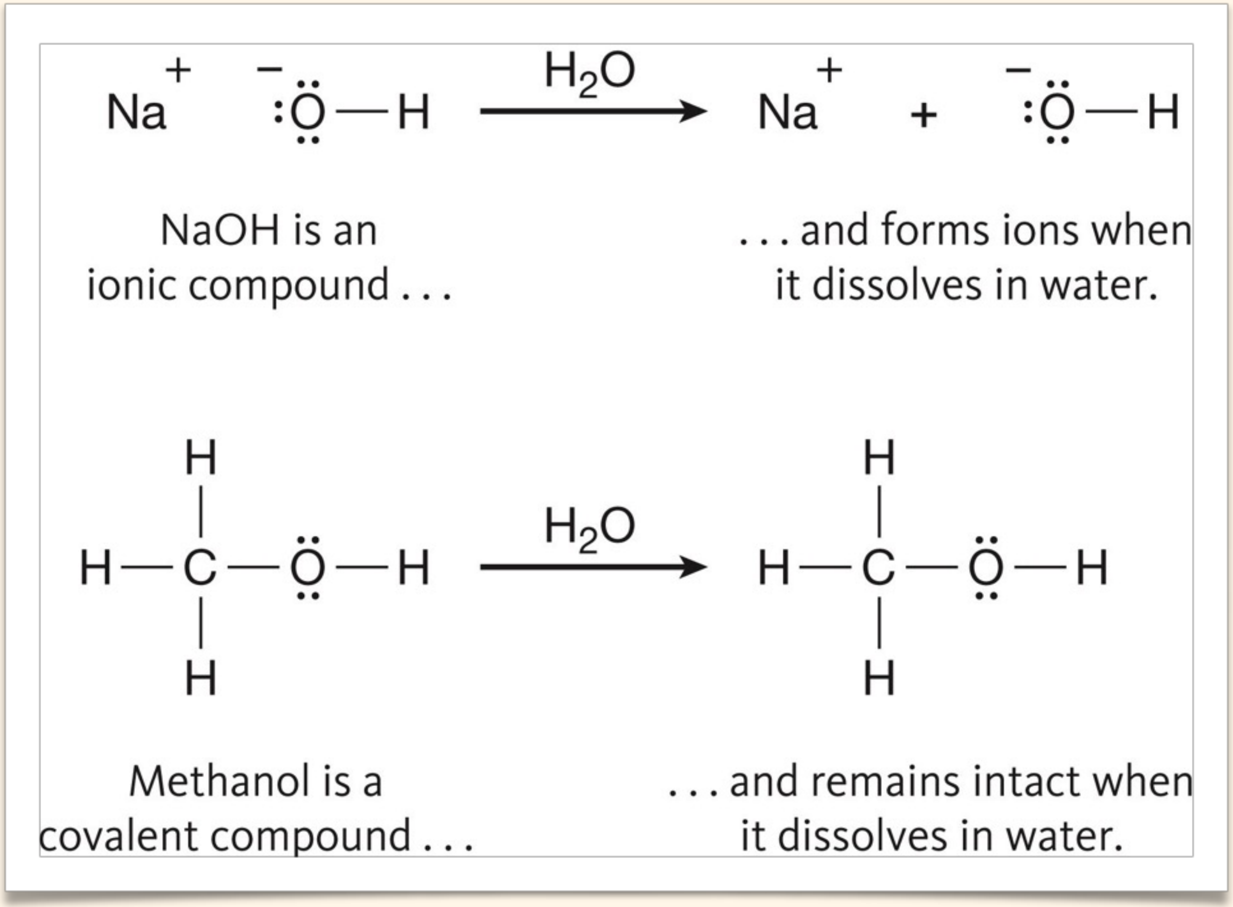
- Compounds with a hydrogen-bonding group (hydrophilic) dissolve better than compounds that cannot form hydrogen bonds, regardless of the sizes of the molecules.
- If two compounds have the same hydrophilic group, the molecule with the *smaller carbon framework* is the more soluble.
- If two compounds have the same carbon framework, the molecule with *more hydrophilic groups* is the more soluble.

Organic Compounds Generally Mix

- There is a wide range of common organic solvents, and there is no simple way to work out which compounds dissolve in which solvents.
- Most organic compounds dissolve reasonably well in organic solvents.
- Only compounds that approach water in their ability to form hydrogen bonds do not dissolve in hydrocarbons.
    - They do, however, dissolve well in alcohols because they can hydrogen to the solvent as well.

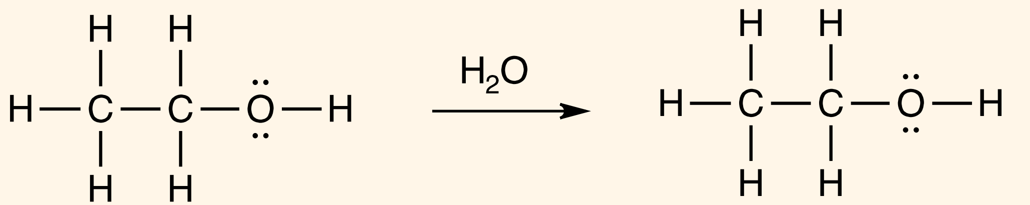
Alcohols Are Not Acidic or Basic

- Alcohols do not contain hydroxide ions and solutions in water are not appreciably acidic or basic.



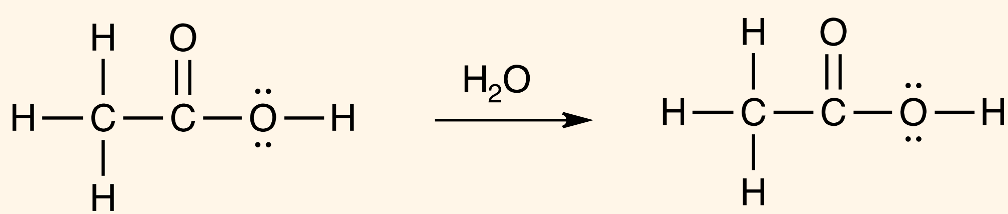
Alcohols Are Not Acidic or Basic

- The hydroxyl group is covalently bonded to a carbon atom in an alcohol, and it does not dissociate from the rest of the molecule when the alcohol dissolves in water.
  - ✦ This is not true of carboxylic acid groups, which can dissociate in water.



Ethanol is a covalent (molecular) compound ...

... that remains intact when dissolved in water



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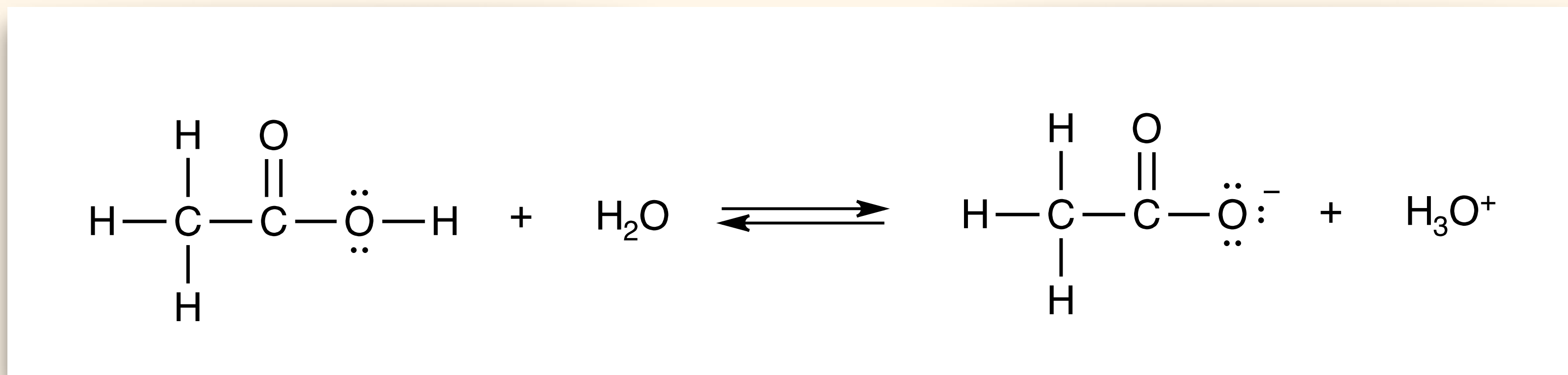

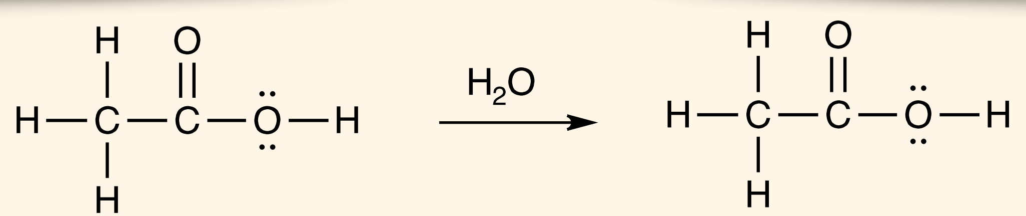

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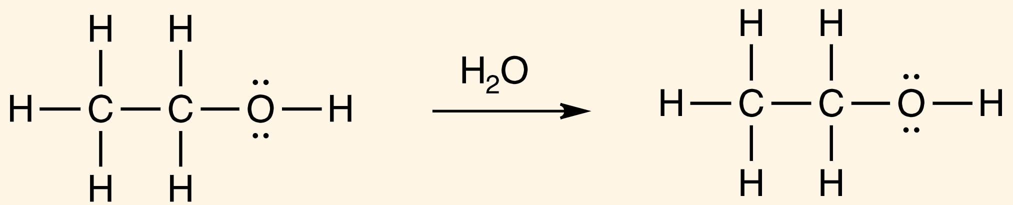

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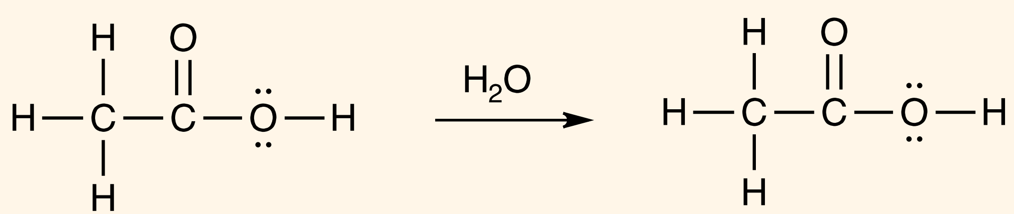

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10.5 Chirality in Organic Molecules

- A chiral object is an object that cannot be superimposed on its mirror image.
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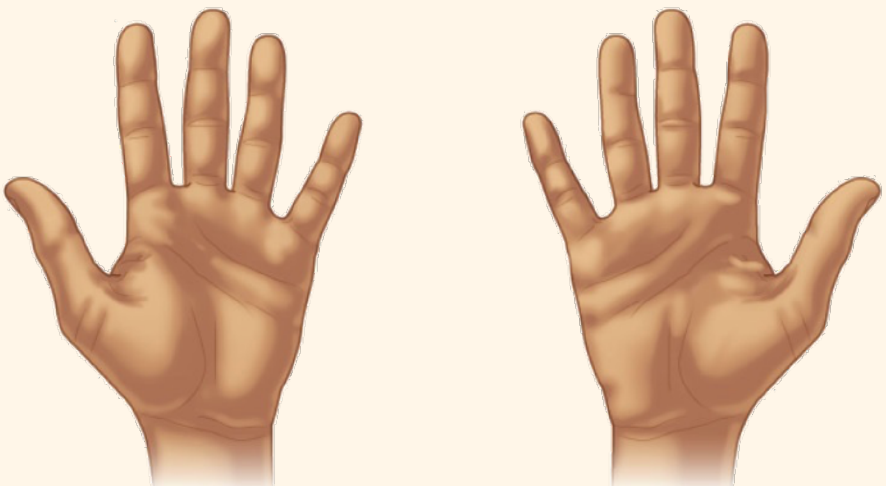

A left hand is chiral, because it cannot be superimposed on its mirror image (a right hand).

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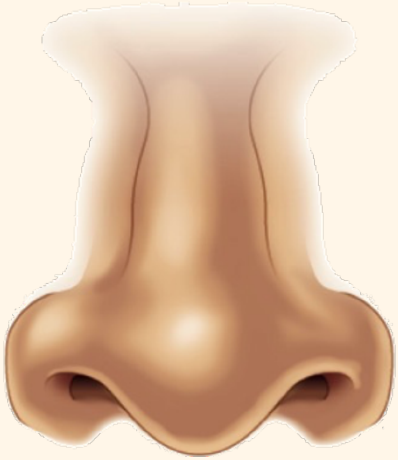

A nose is achiral, because it is identical to its mirror image.

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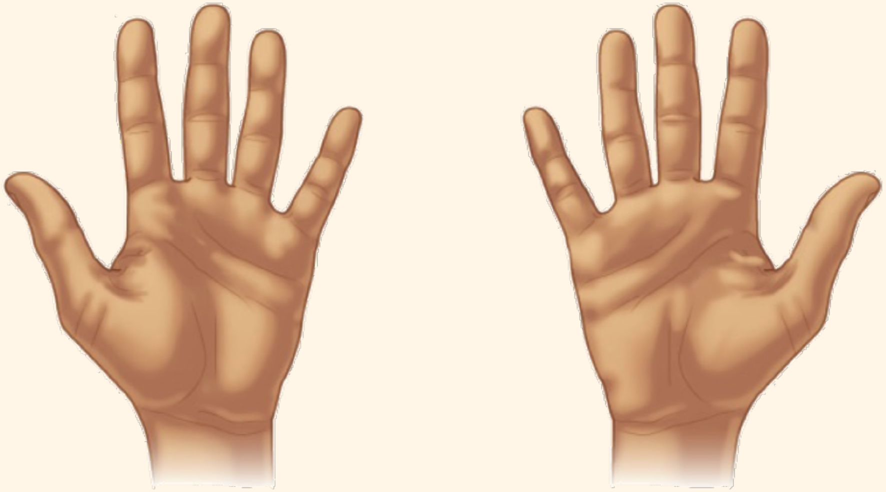

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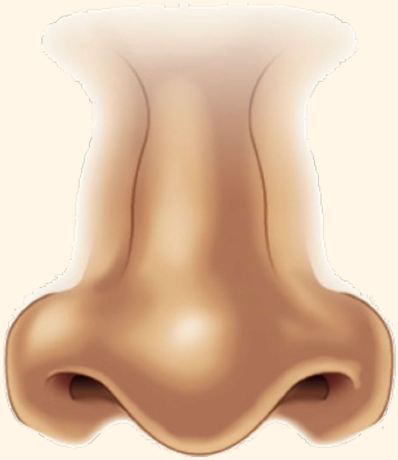

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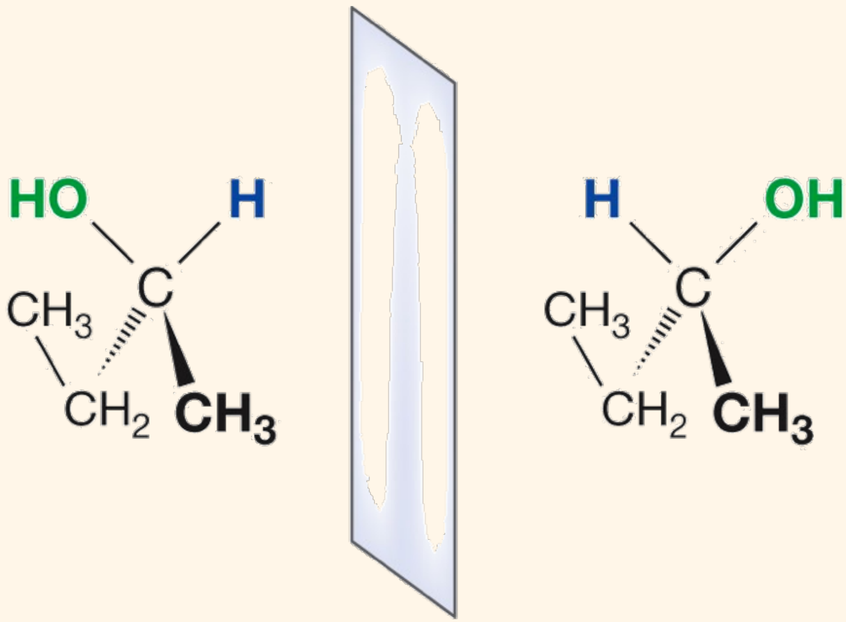
Enantiomers

- The two mirror-image forms of a chiral molecule are called enantiomers.

One form of 2-butanol looks like this:

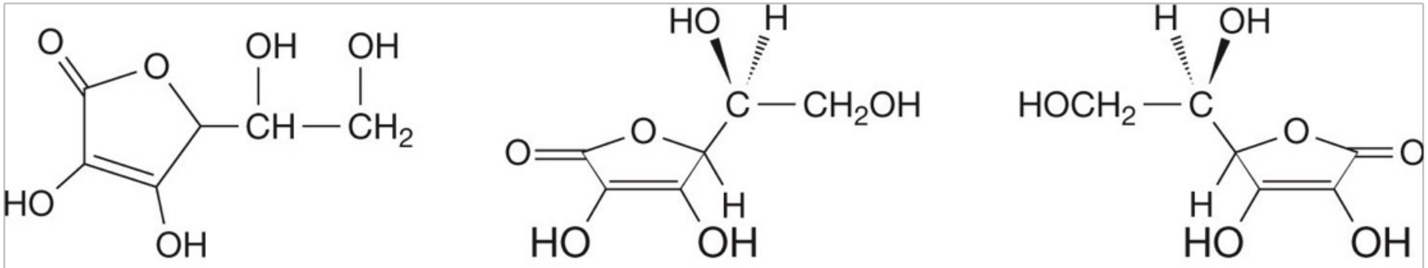


The other form of 2-butanol is the mirror image of the first form.

Chirality and Biomolecules

- Many important substances in medicine and biochemistry are chiral, including all proteins, most fats, all common carbohydrates, cholesterol, and a range of medications.
- All enzymes are chiral molecules, so they can distinguish between the two forms of other chiral molecules.
- Our bodies can normally use only one of the two forms of a chiral compound. The other form has little or no activity, and it may even be harmful.

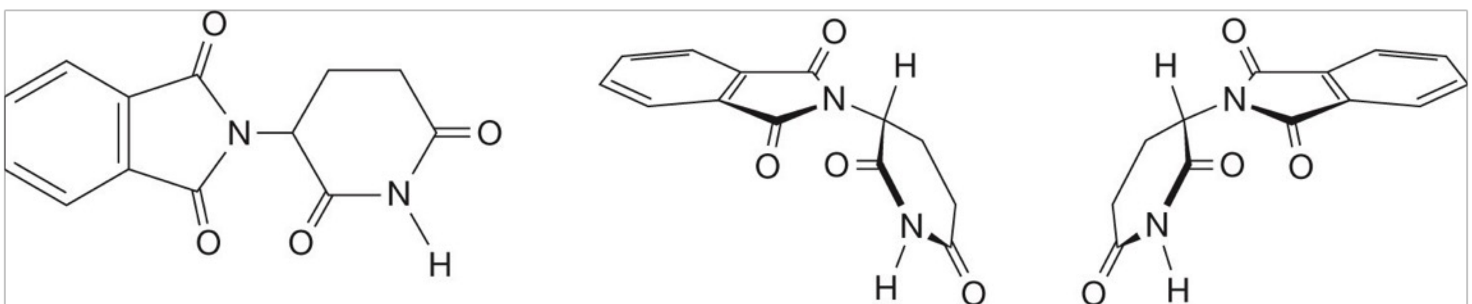
Chirality and Biomolecules



Ascorbic acid (vitamin C)

The active enantiomer of vitamin C

The inactive enantiomer of vitamin C

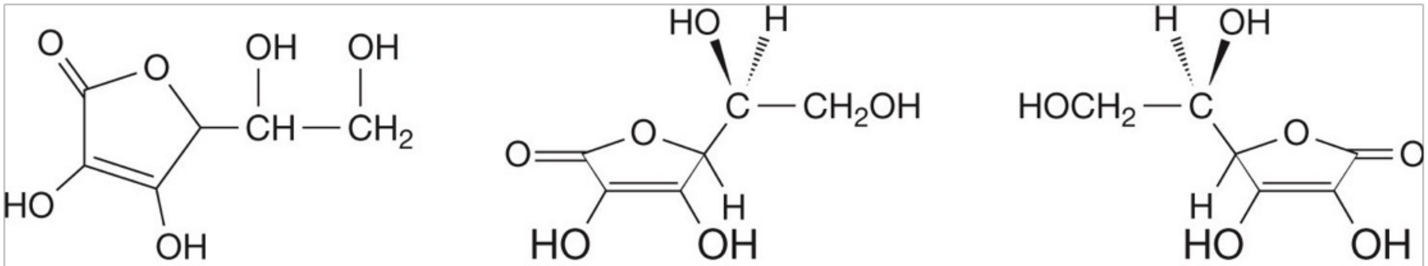


Thalidomide

This enantiomer of thalidomide is an effective medication.

This enantiomer of thalidomide causes birth defects.

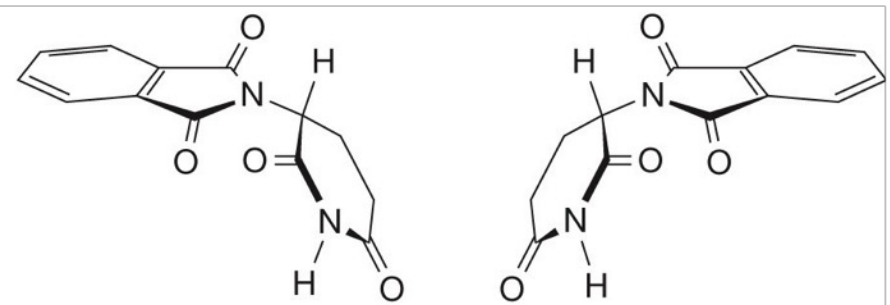
Chirality and Biomolecules



Ascorbic acid

The active enantiomer of vitamin C

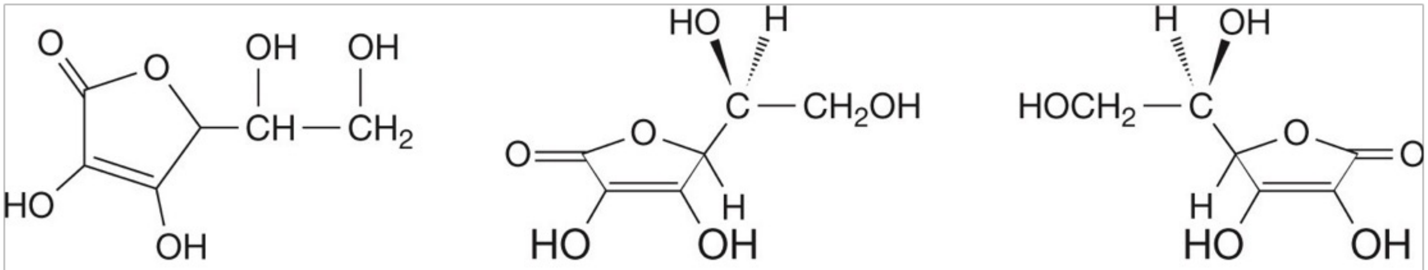
The inactive enantiomer of vitamin C



This enantiomer of thalidomide is an effective medication.

This enantiomer of thalidomide causes birth defects.

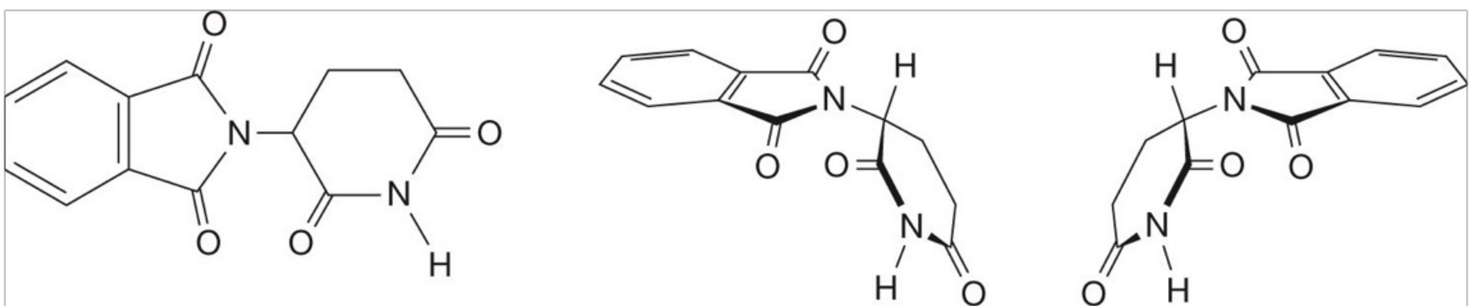
Chirality and Biomolecules



Ascorbic acid (vitamin C)

The active enantiomer of vitamin C

The inactive enantiomer of vitamin C



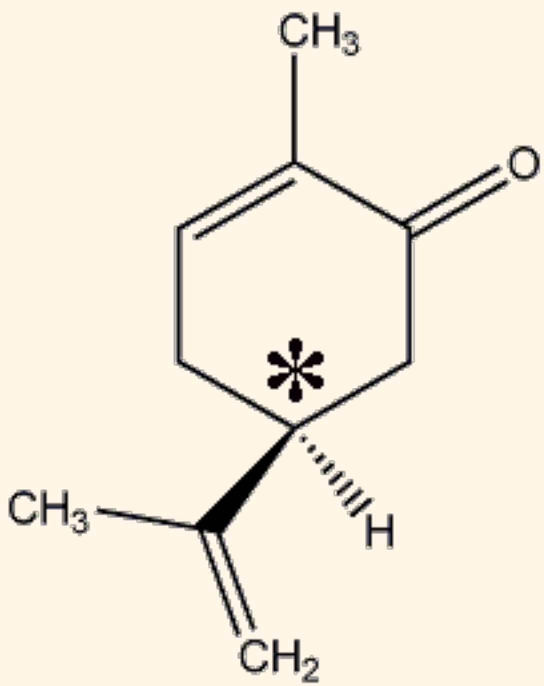
Thalidomide

This enantiomer of thalidomide is an effective medication.

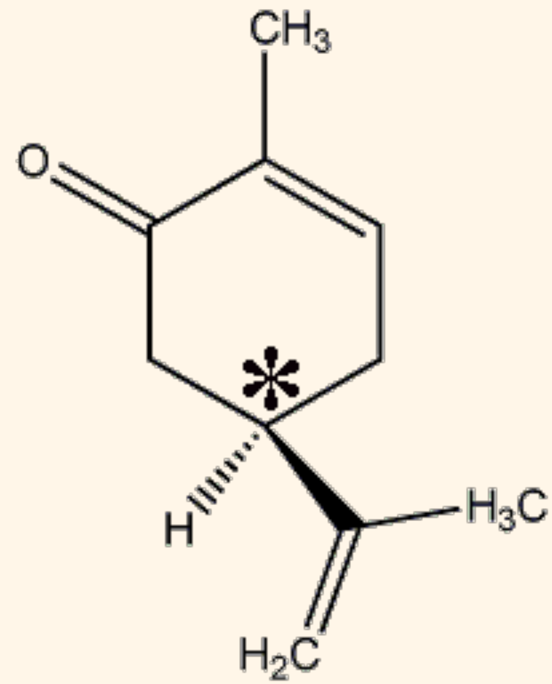
This enantiomer of thalidomide causes birth defects.

Chirality and Biomolecules

- Receptor protein in our nose can distinguish between the two enantiomers of chiral molecule Carvone



oil of caraway



spearmint oil

Identifying Chiral Molecules

- Chiral molecules contain a chiral carbon. A carbon is chiral when it is bonded to four different groups of atoms.
- Many important molecules in biology and medicine contain more than one chiral carbon atom. All molecules that contain just one chiral carbon atom are chiral, but molecules that have two or more chiral carbon atoms are not necessarily chiral.
- You should be able to identify a chiral carbon.

Identifying Chiral Molecules

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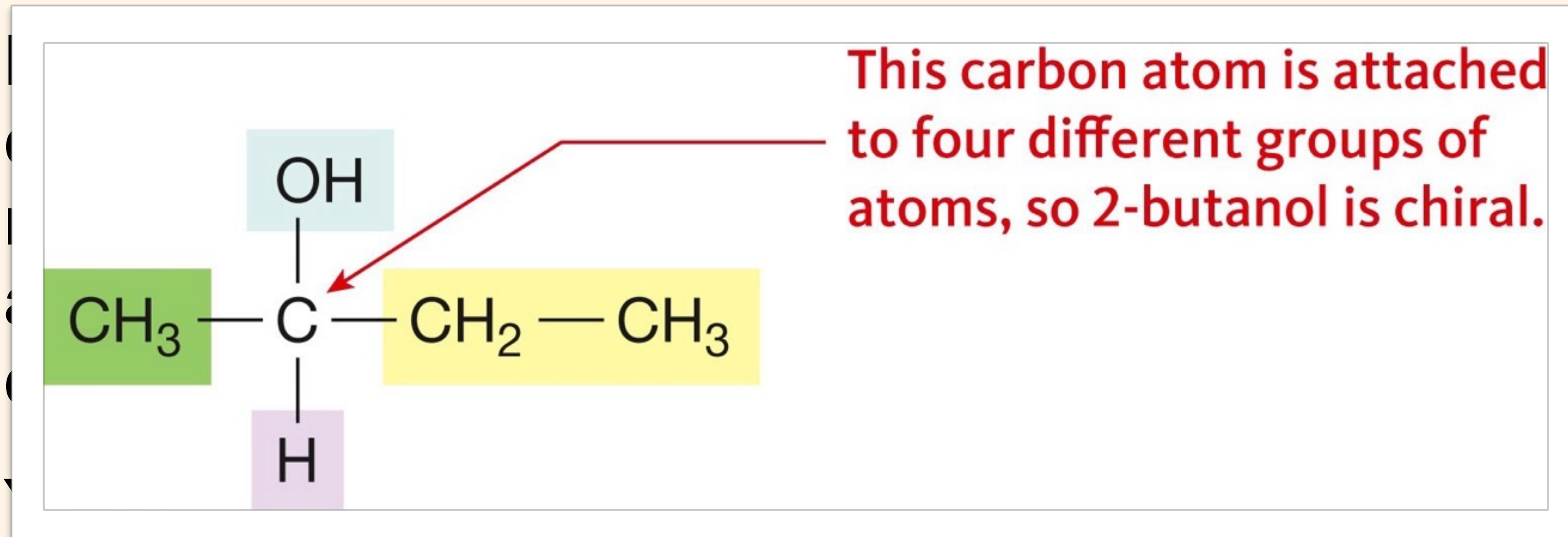

Identifying Chiral Molecules

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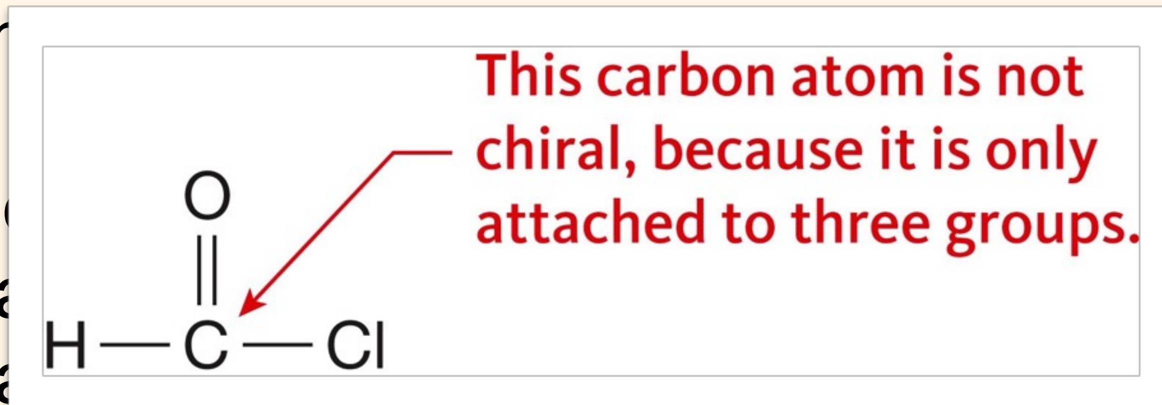
- Many im edicine
contain All
molecul n atom
are chira ore chiral
carbon a



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Identifying Chiral Molecules

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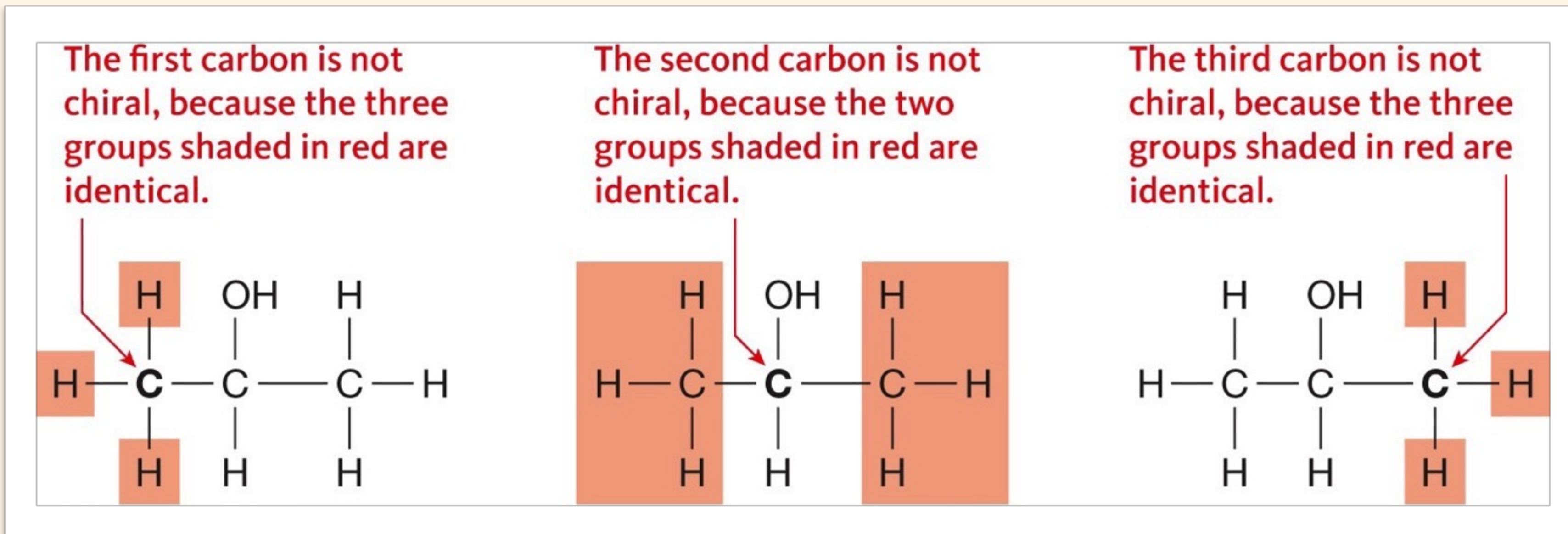


al

Identifying Chiral Molecules

- Chiral molecules contain a chiral carbon. A carbon is chiral when it is bonded to four different groups of atoms.
- Many important molecules in biology and medicine contain more than one chiral carbon atom. All molecules that contain just one chiral carbon atom are chiral, but molecules that have two or more chiral carbon atoms are not necessarily chiral.
- You should be able to identify a chiral carbon.

Try It!

Question

Draw the structures for the following biological compounds and circle the chiral carbons?

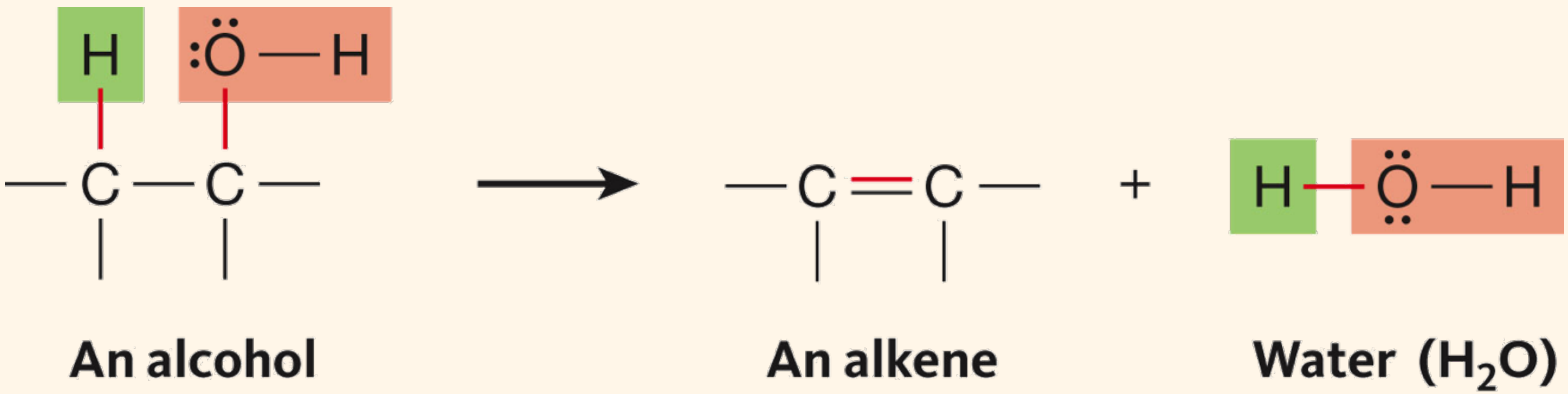
A. lactic acid

B. glucose

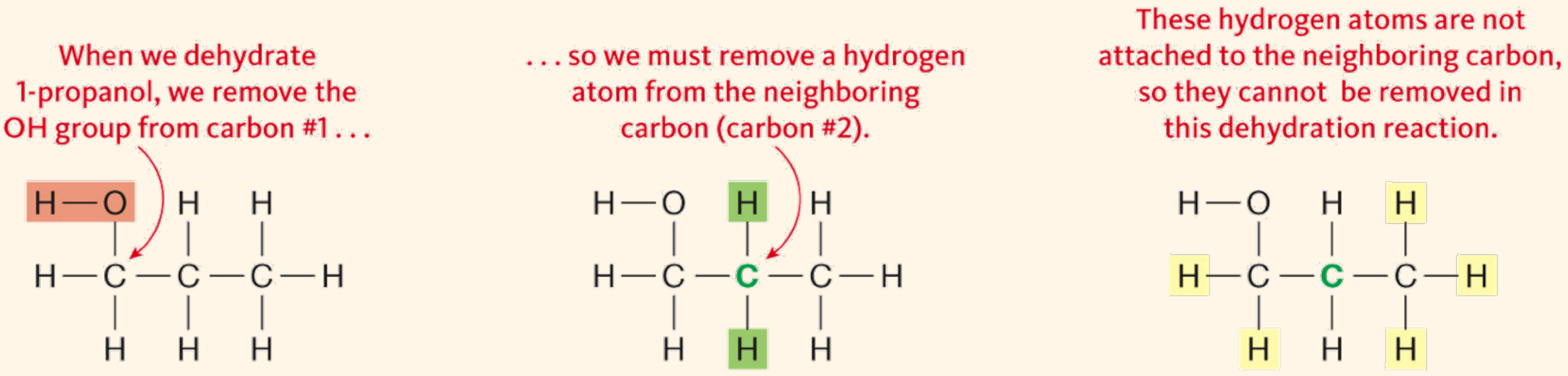
C. glyceraldehyde

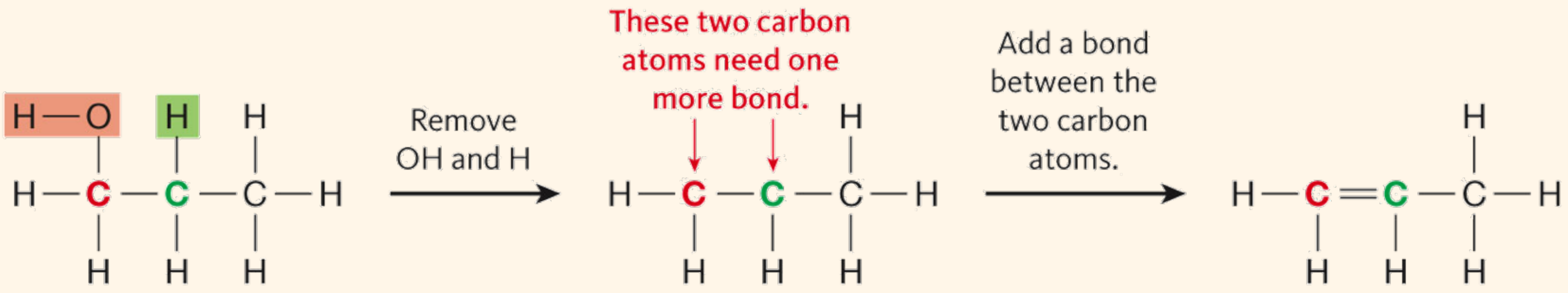
10.6 The Dehydration Reaction

- A dehydration reaction is one of the means by which our bodies remove oxygen from organic compounds.
- In the dehydration of an alcohol, the hydroxyl group and a hydrogen atom from an adjacent carbon are removed to make water and an alkene.



The Dehydration of 1-Propanol

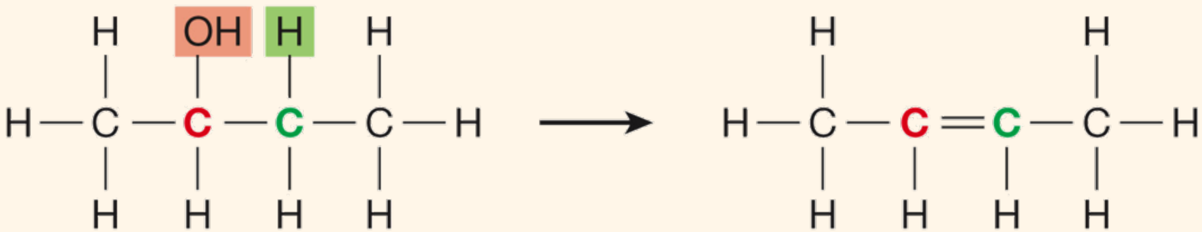




Many Dehydration Reactions Produce More Than One Product

- If an alcohol has more than one carbon atom next to the functional group, it can usually form more than one dehydration product.

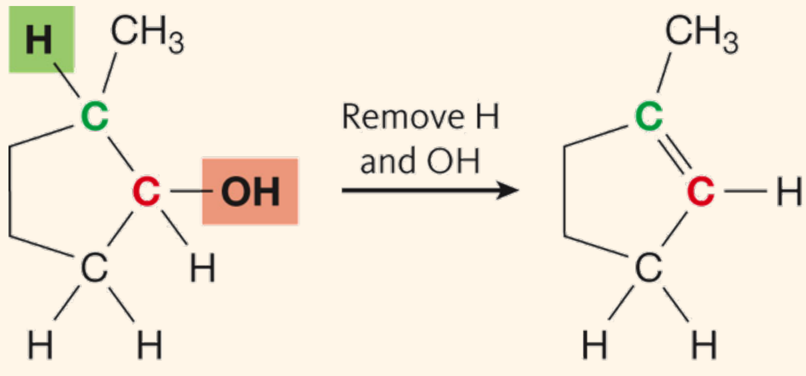
Removing H from carbon #1 produces 1-butene.



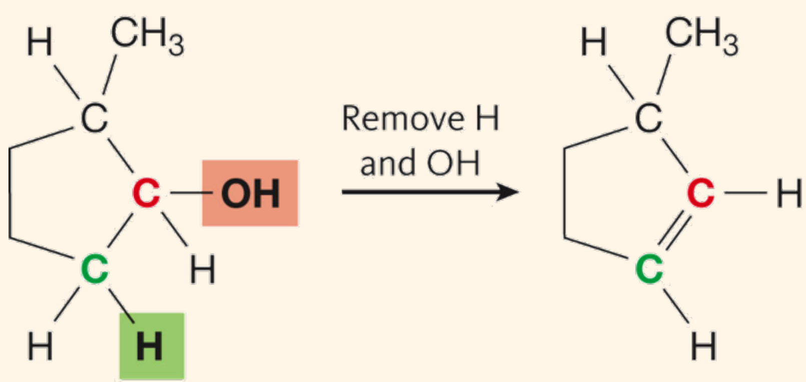
Removing H from carbon #2 produces 2-butene (both the *cis* and *trans* isomers).

The Dehydration of Cyclic Alcohols

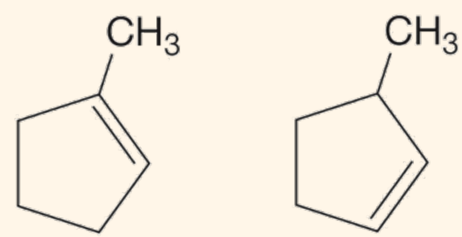
- Cyclic alcohols can also be dehydrated.



Product #1



Product #2

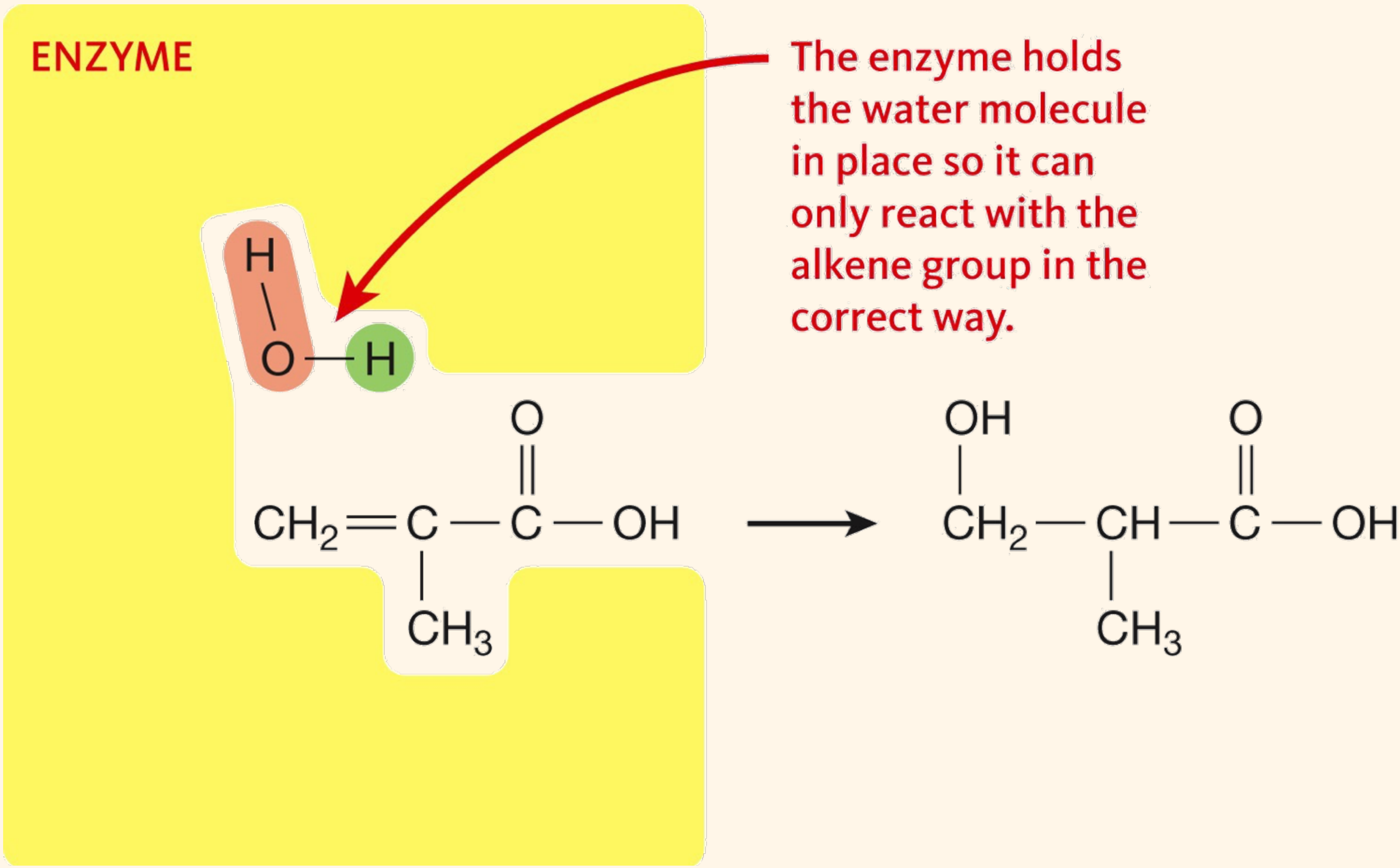


Line structures of the products

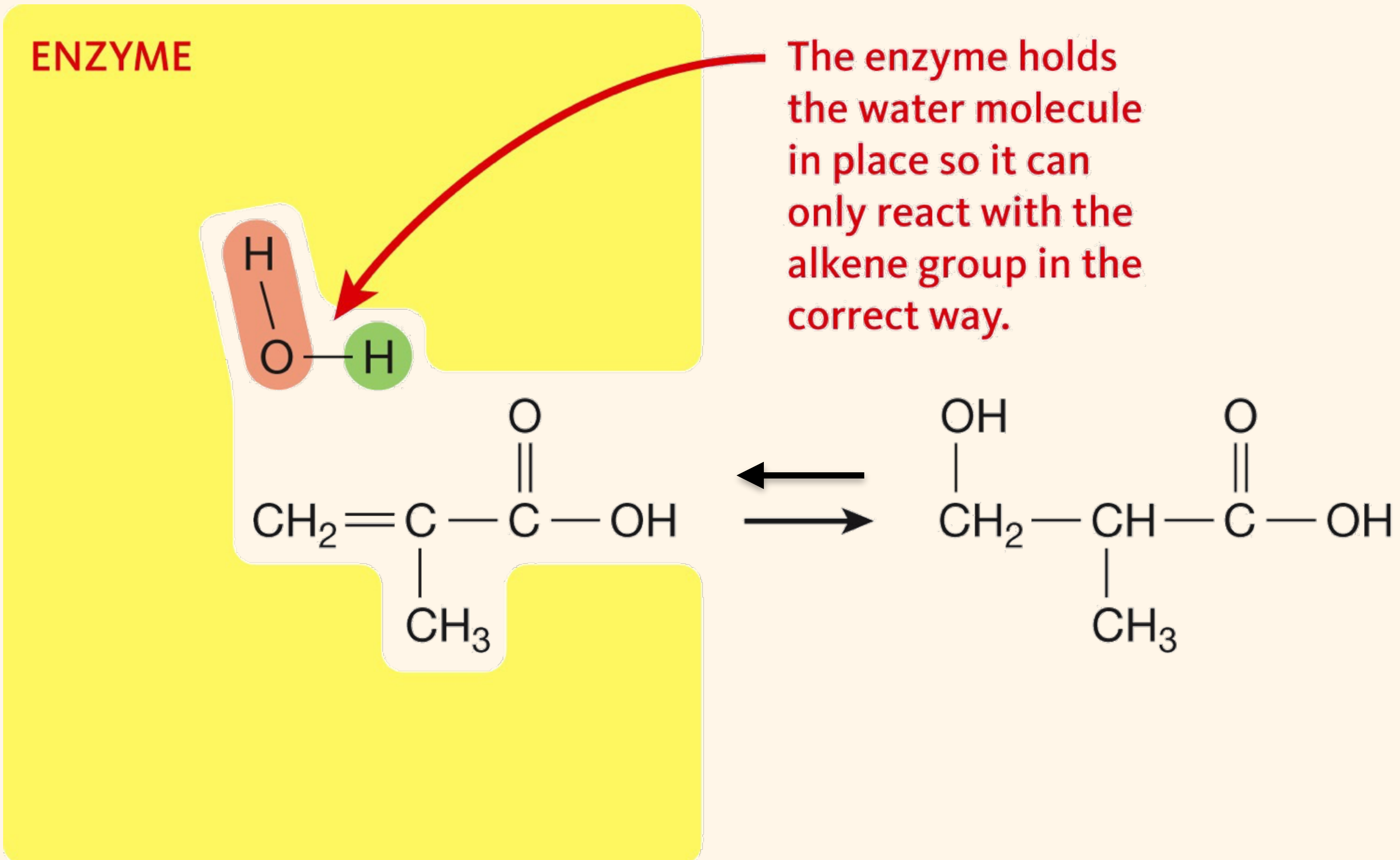
More on Dehydration Reactions

- Some alcohols do not have any hydrogen atoms attached to the adjacent carbon atoms and cannot be dehydrated.
- In our bodies, enzymes catalyze dehydration reactions.
  - Enzymes only make one alkene product when they dehydrate an alcohol.
  - This is important because the alkene products made are the specific ones your body needs for subsequent reactions.

More on Dehydration Reactions



More on Dehydration Reactions

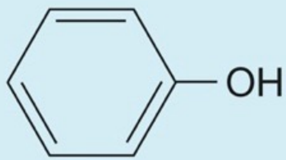
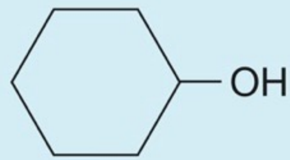


10.7 Phenols and Thiols

- A phenol is a compound that contains a hydroxyl group bonded to a benzene ring.
  - Phenols cannot be dehydrated like alcohols.
  - Phenols cannot be formed by adding water to an alkene like alcohols.
  - Phenols are weak acids, unlike alcohols which are neither acidic or basic.
  - The hydroxyl group in phenols can hydrogen bond just like the hydroxyl group in alcohols.

The Properties of a Phenol, an Alcohol, and a Hydrocarbon

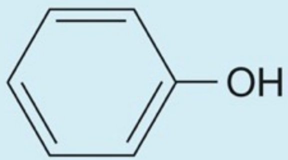
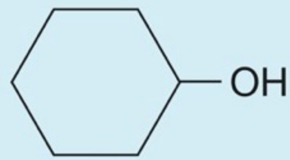
TABLE 10.5 The Properties of a Phenol, an Alcohol, and a Hydrocarbon

	Phenol	Cyclohexanol	Benzene
Structure			
Boiling point	182°C	161°C	80°C
Solubility in water	65 g/L	36 g/L	0.6 g/L
pH of 1% solution	5.5 (weakly acidic)	7.0 (neutral)	We cannot make a 1% solution.

The Properties of a Phenol, an Alcohol, and a Hydrocarbon

Question

Why are the boiling points for phenol and cyclohexanol substantially higher than that for benzene?

	Phenol	**Cyclohexanol**	**Benzene**
Structure			
Boiling point	182°C	161°C	80°C
Solubility in water	65 g/L	36 g/L	0.6 g/L
pH of 1% solution	5.5 (weakly acidic)	7.0 (neutral)	We cannot make a 1% solution.

Thiols

- Thiols are related to alcohols because a thiol is like a hydroxyl group where the oxygen is replaced with a sulfur.
    - The thiol group cannot form hydrogen bonds, so thiols have lower boiling points and evaporate more readily than alcohols and are less soluble in water.
    - The thiol group is weakly polar so it is attracted to water molecules. Thiols are more soluble in water than similar-sized alkanes.

The Properties of an Alcohol, a Thiol, and an Alkane

TABLE 10.6 The Properties of an Alcohol, a Thiol, and an Alkane

	Ethanol	Ethanethiol	Propane
Structure	CH_3-CH_2-OH	CH_3-CH_2-SH	$CH_3-CH_2-CH_3$
Boiling point	78°C	35°C	−42°C
Solubility in water	No limit	7 g/L	0.1 g/L

What Stinks?

- Thiols are known for their terrible odors.
- Low-molecular-weight thiols have some of the most offensive aromas in all of chemistry.
  - Examples: The odor of a skunk or freshly cut onions.
- Natural gas suppliers add a tiny amount of a thiol to natural gas (which has no odor) so leaks will be noticed and reported.
- An example of an exception (a good smell): a thiol is responsible for the pleasant aroma of grapefruit, coffee and garlic.

Next Up

- Unit 7: Carbonyls, Aldehydes and Ketons
  - Chapter 11 in Armstrong
  - Unit 7 Assignments due on 12. March, with deadline of 19. March.