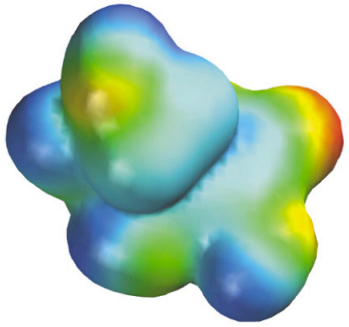
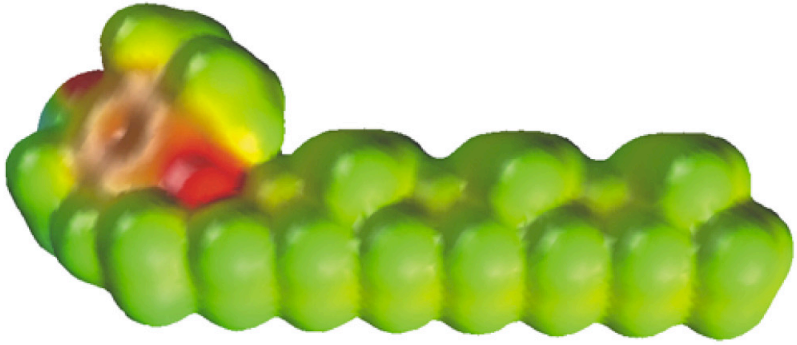
Chapter 9

Reactions of Alkanes

Radicals



vitamin C

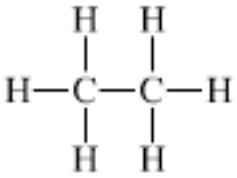


vitamin E

Irene Lee
Case Western Reserve University

Alkanes and halogens do not react unless light (or heat) initiates the radical chain reaction. Click "Light" to initiate the radical bromination of ethane.

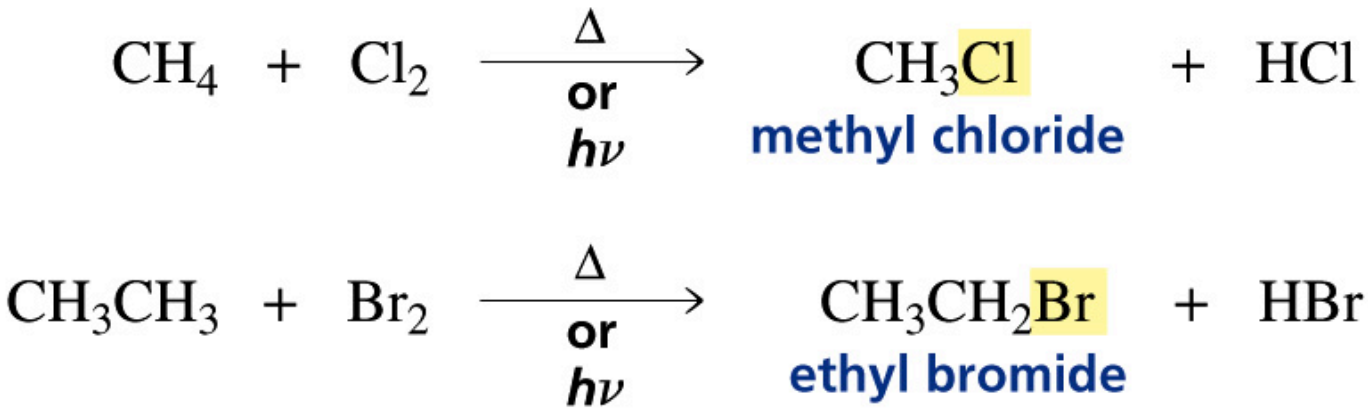
Br—Br



Light

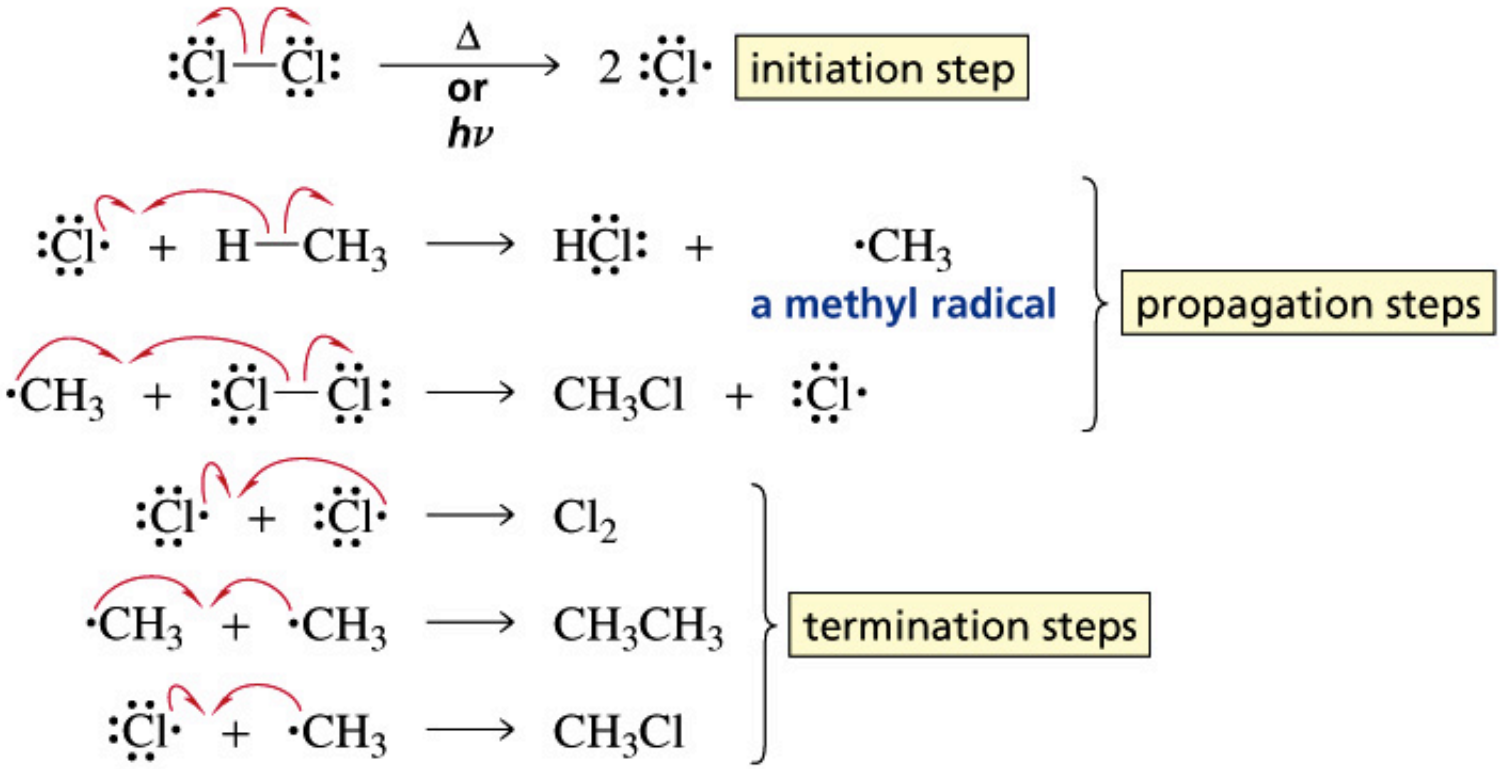
Alkanes are very unreactive compounds because they have only strong σ bonds and atoms with no partial charges

However, alkanes do react with Cl_2 and Br_2

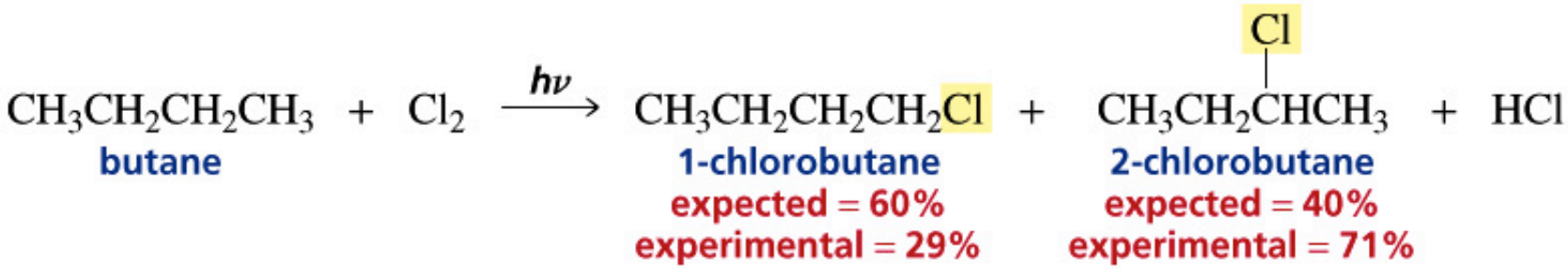


Reaction of Alkane with Cl_2 or Br_2

mechanism for the monochlorination of methane

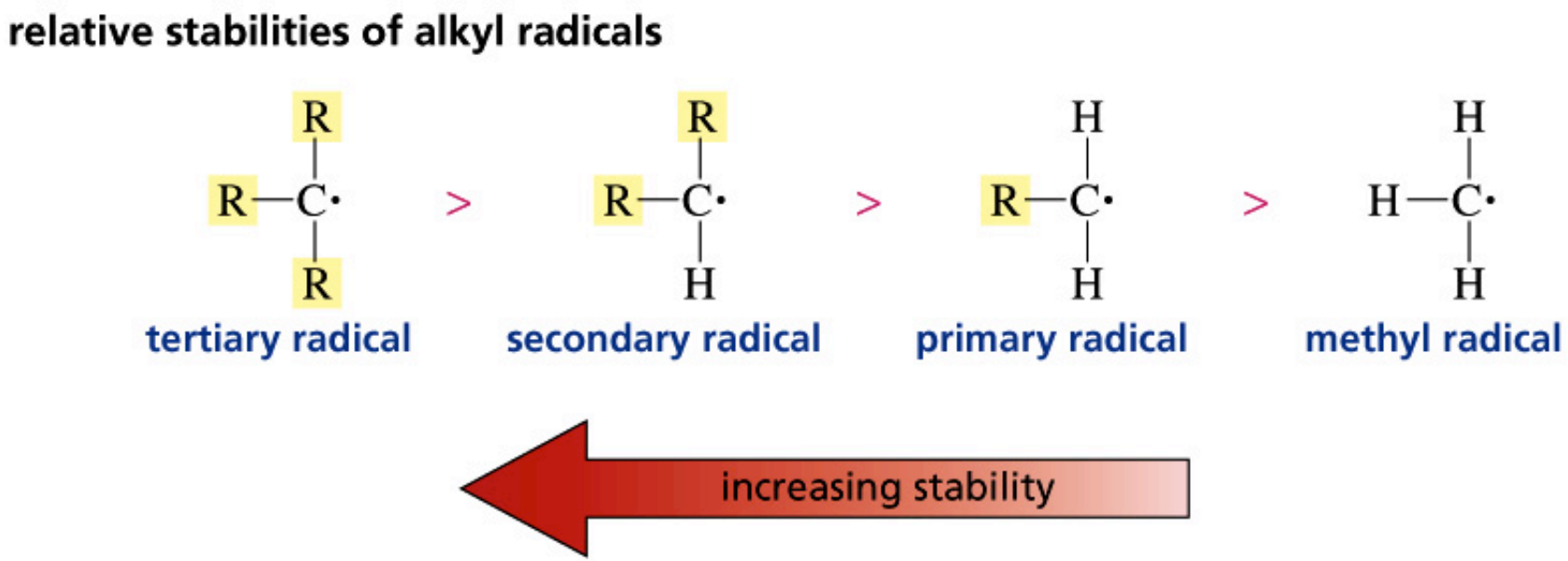


Factors that determine product distribution …

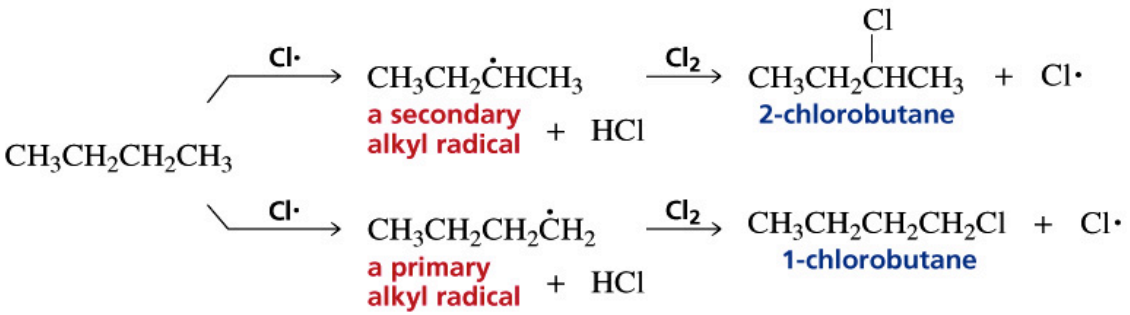


The rate-determining step of the overall reaction is hydrogen abstraction

Consider the relative stabilities of alkyl radicals,



The stable alkyl radical is formed faster, therefore 2-chlorobutane is formed faster



relative rates of alkyl radical formation by a chlorine radical at room temperature

tertiary > secondary > primary

5.0 3.8 1.0

Click on the carbon that will be brominated most rapidly in a radical bromination.

In determining the relative amounts of products obtained, both probability and reactivity should be considered

probability: the number of hydrogens that can be abstracted that will lead to the formation of the particular product

reactivity: the relative rate at which a particular hydrogen is abstracted

relative amount of 1-chlorobutane

number of hydrogens × reactivity

$$6 \times 1.0 = 6.0$$

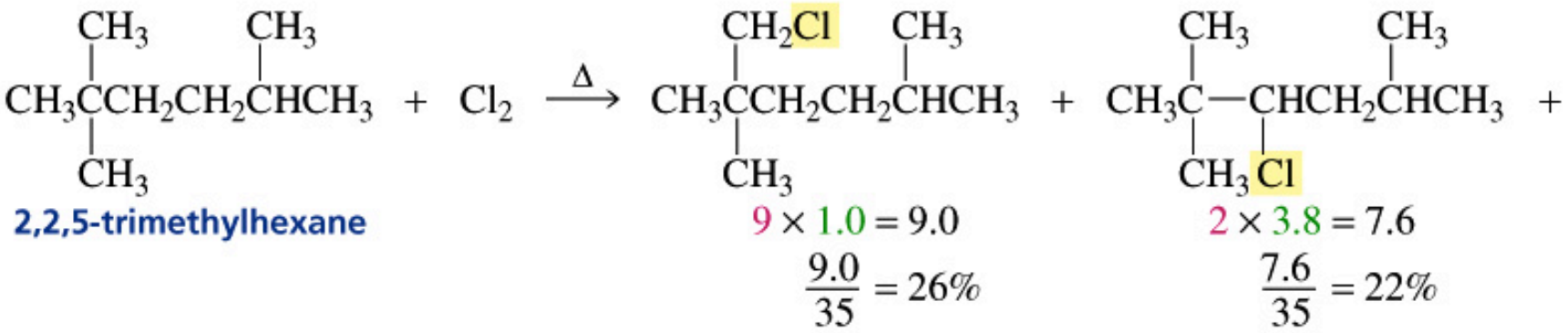
$$\text{percent yield} = \frac{6.0}{21} = 29\%$$

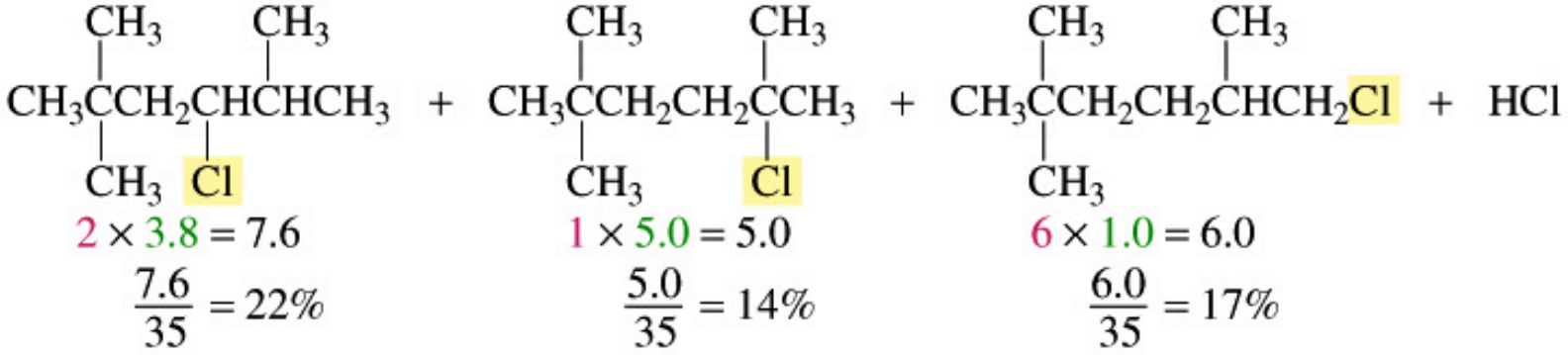
relative amount of 2-chlorobutane

number of hydrogens × reactivity

$$4 \times 3.8 = 15$$

$$\text{percent yield} = \frac{15}{21} = 71\%$$


CH3 CH3
CH3CCH2CH2CHCH3 + Cl2 Δ
CH3
CH2Cl CH3
CH3CCH2CH2CHCH3 +
CH3
CH3 CH3
CH3C—CHCH2CHCH3 +
CH3 Cl
2,2,5-trimethylhexane
9 × 1.0 = 9.0
9.0/35 = 26%
2 × 3.8 = 7.6
7.6/35 = 22%


CH3 CH3
CH3CCH2CHCHCH3 +
CH3 Cl
CH3 CH3
CH3CCH2CH2CCH3 +
CH3 Cl
CH3 CH3
CH3CCH2CH2CHCH2Cl + HCl
CH3
2 × 3.8 = 7.6
7.6/35 = 22%
1 × 5.0 = 5.0
5.0/35 = 14%
6 × 1.0 = 6.0
6.0/35 = 17%

The Reactivity–Selectivity Principle

A bromine radical is less reactive and more selective than a chlorine radical

relative rates of radical formation by a bromine radical at 125 °C

tertiary > secondary > primary

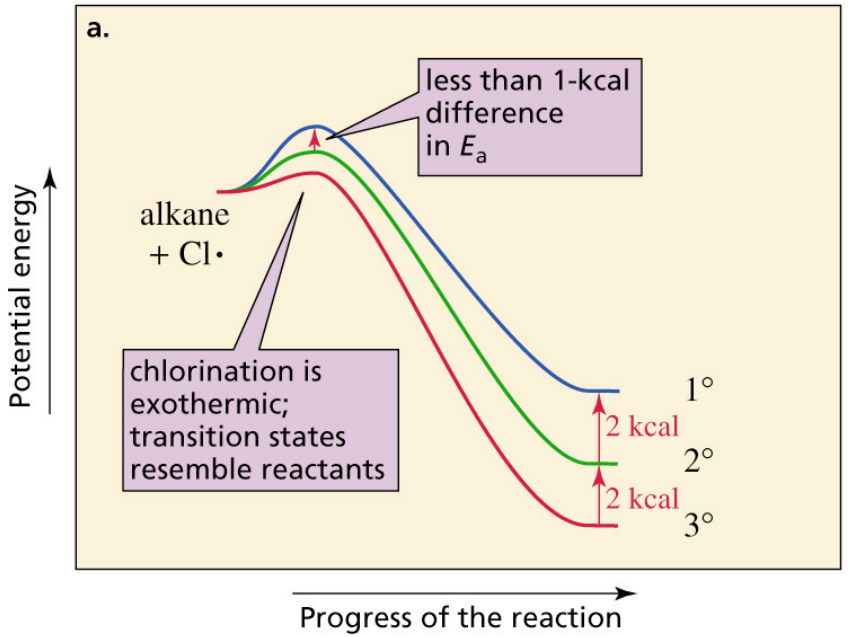
1600 82 1

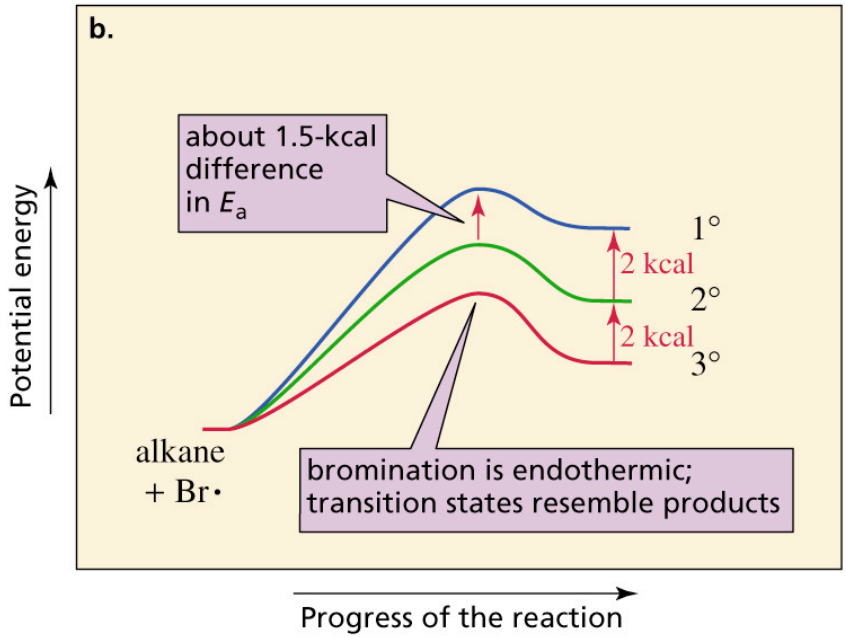
relative rates of alkyl radical formation by a chlorine radical at room temperature

tertiary > secondary > primary

5.0 3.8 1.0

Why are the relative rates of radical formation so different between the bromine versus the chlorine radical?





The more reactive a species is, the less selective it will be

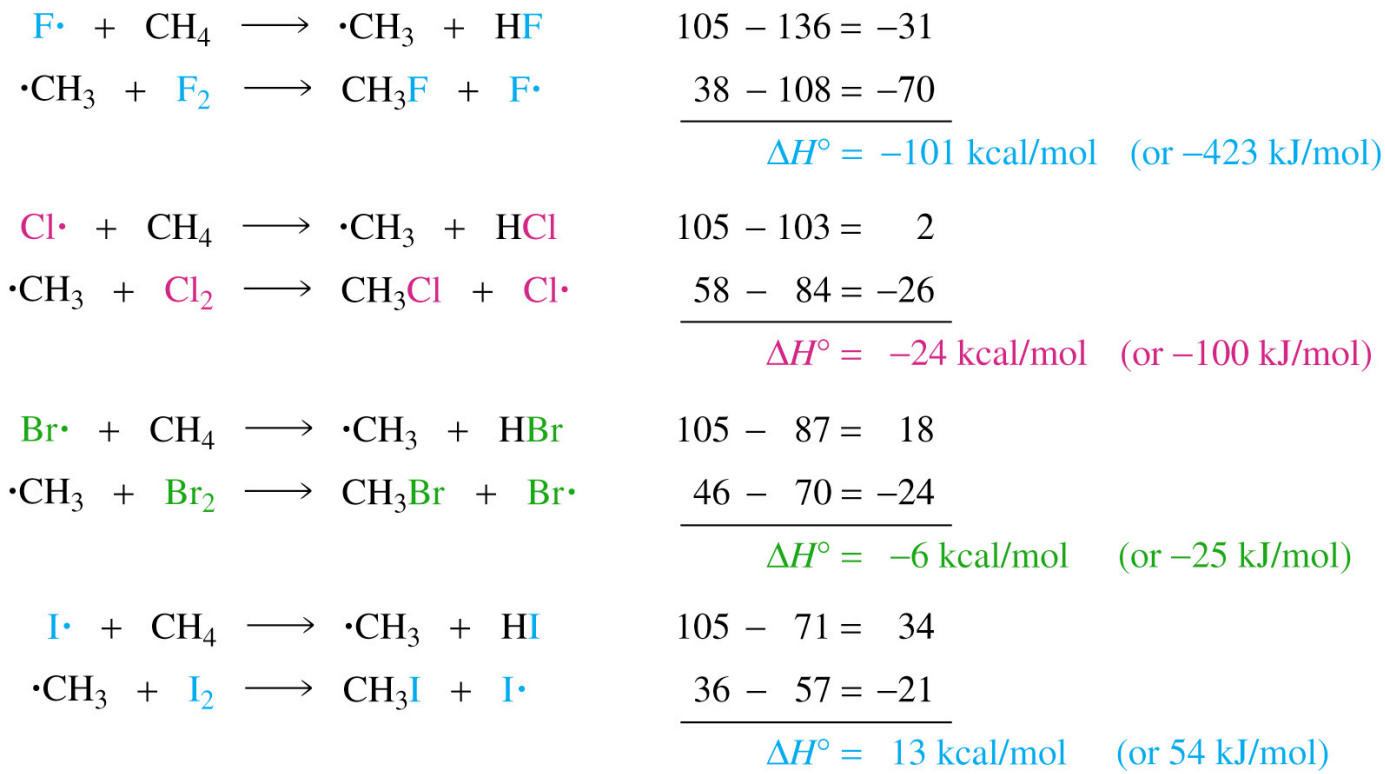
					ΔH° (kcal/mol)	ΔH° (kJ/mol)
$Cl\cdot$	+ $CH_3CH_2CH_3$	⟶	$CH_3CH_2\dot{C}H_2$	+ HCl	101 − 103 = −2	−8
$Cl\cdot$	+ $CH_3CH_2CH_3$	⟶	$CH_3\dot{C}HCH_3$	+ HCl	99 − 103 = −4	−17
$Cl\cdot$	+ $CH_3CH(CH_3)_2$	⟶	$CH_3\dot{C}(CH_3)_2$	+ HCl	97 − 103 = −6	−25

					ΔH° (kcal/mol)	ΔH° (kJ/mol)
$Br\cdot$	+ $CH_3CH_2CH_3$	⟶	$CH_3CH_2\dot{C}H_2$	+ HBr	101 − 87 = 14	59
$Br\cdot$	+ $CH_3CH_2CH_3$	⟶	$CH_3\dot{C}HCH_3$	+ HBr	99 − 87 = 12	50
$Br\cdot$	+ $CH_3CH(CH_3)_2$	⟶	$CH_3\dot{C}(CH_3)_2$	+ HBr	97 − 87 = 10	42

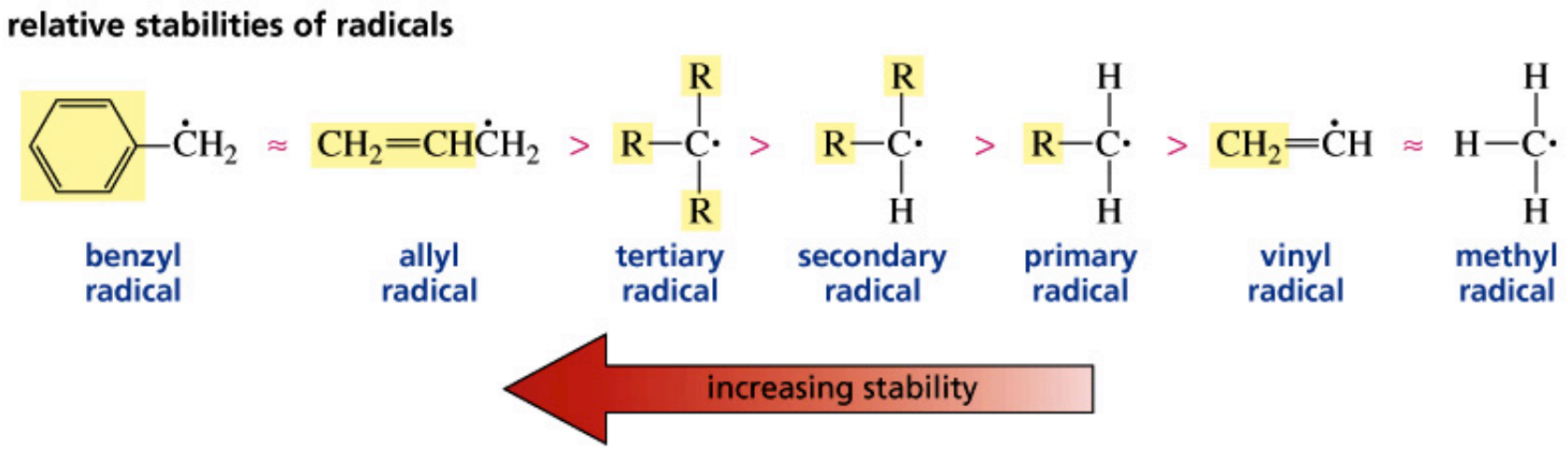
What about fluorination and iodination?

Alkanes undergo chlorination and bromination, but not iodination

Fluorination is too violent of a reaction to be useful



Consider the relative stabilities of radicals



Touch a label on the left to see the corresponding atoms, groups, or molecules.

allylic radical

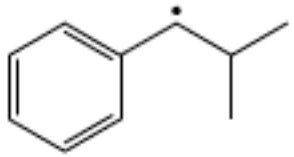
benzylic radical

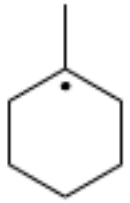
tertiary radical

tertiary hydrogen

delocalized electrons

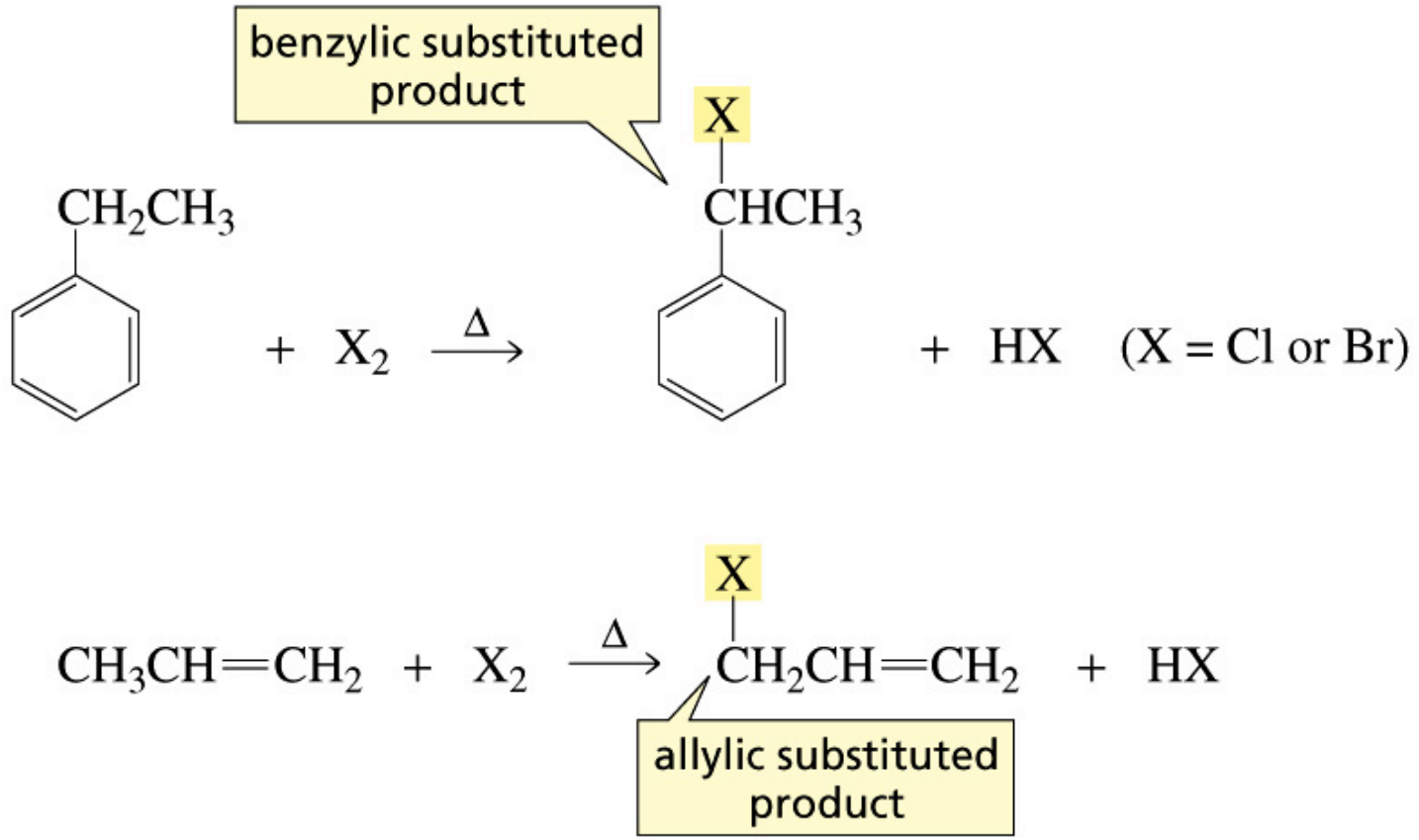
localized unpaired electrons





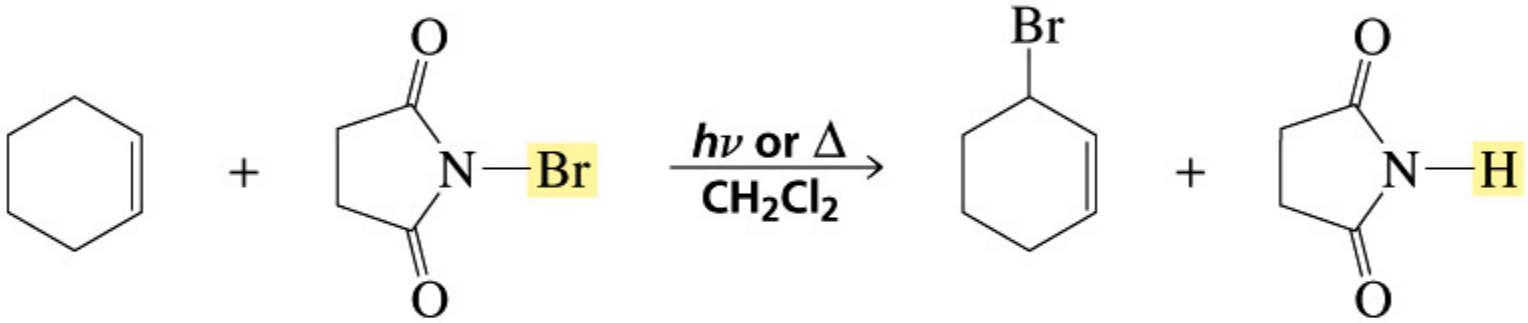
Radical Substitution of Benzylic Hydrogens

The more stable radicals form faster



Because of the reactivity of allylic hydrogens,

a milder brominating reagent can be used

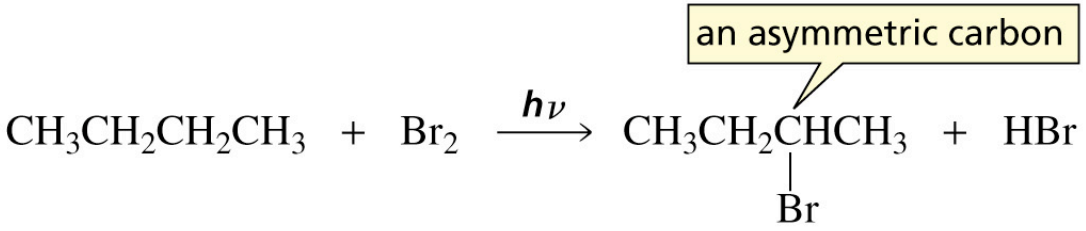


N-bromosuccinimide
NBS

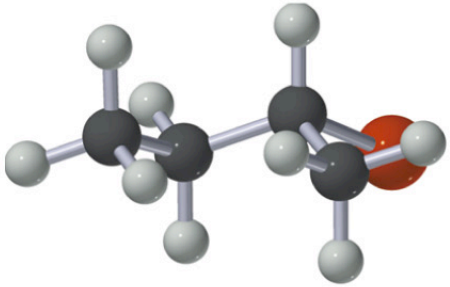
succinimide

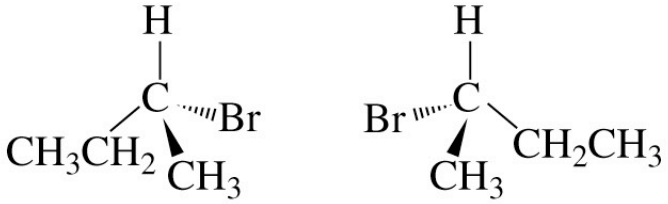
A very important and useful reaction

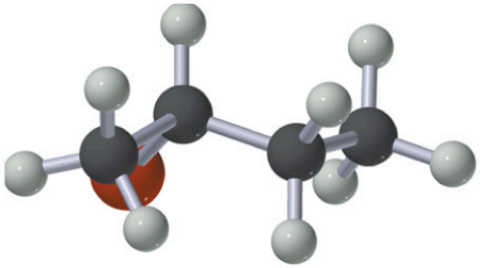
Stereochemistry of Radical Substitution Reactions



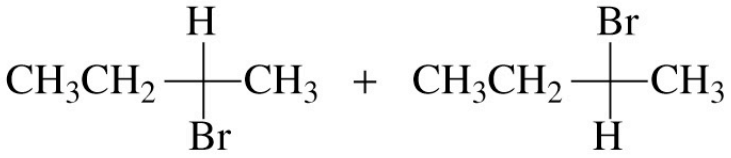
configuration of the products







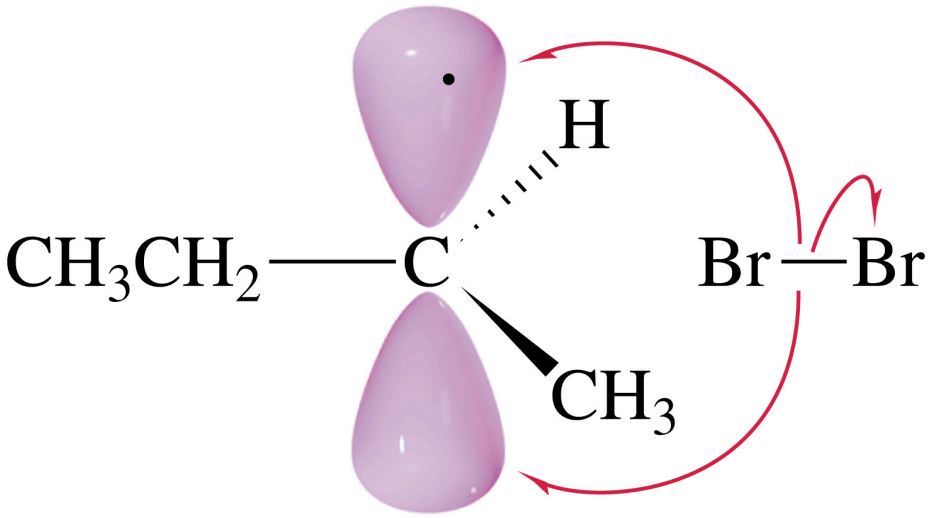
a pair of enantiomers
perspective formulas



a pair of enantiomers
Fischer projections

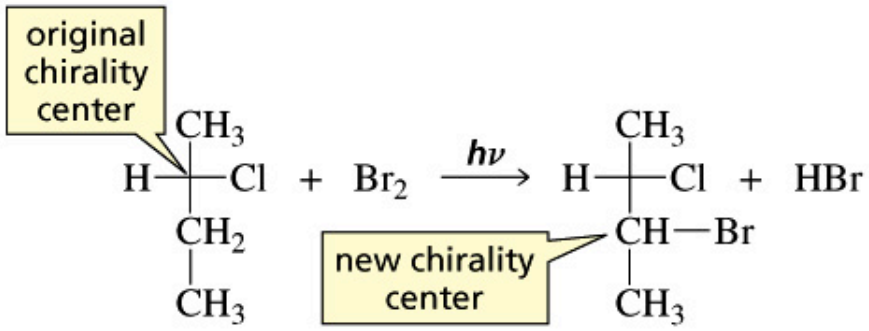
Why are both enantiomers formed?

Consider the first propagation step



a radical intermediate

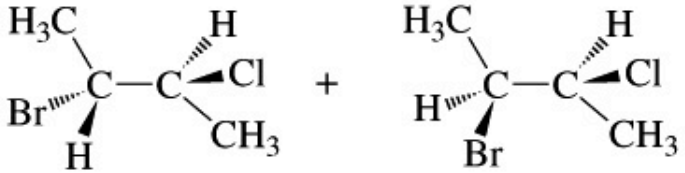
What happens if the reactant already has an asymmetric carbon and the radical substitution reaction creates a second asymmetric carbon?



stereochemistry of the product

a pair of diastereomers

Fischer projections

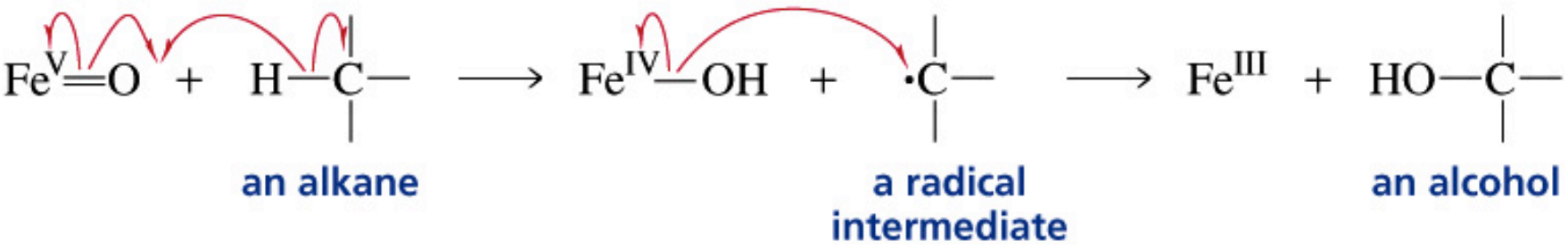


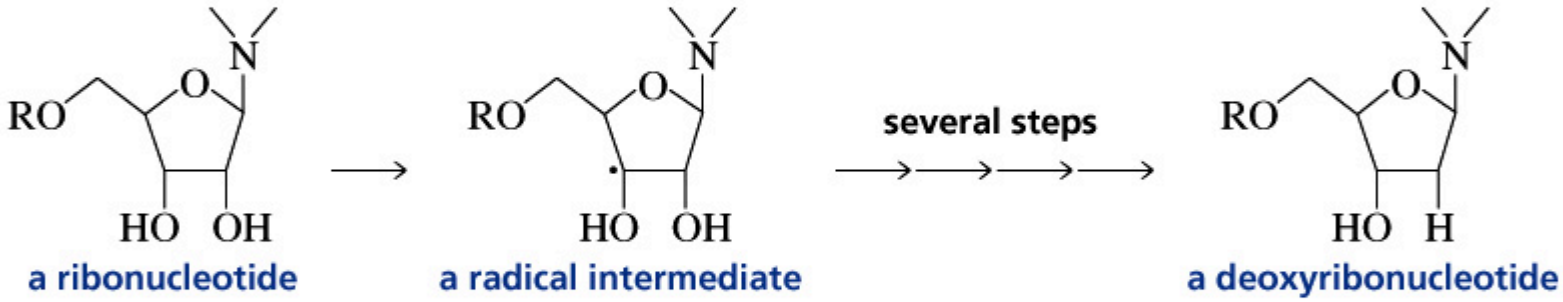
a pair of diastereomers

perspective formulas

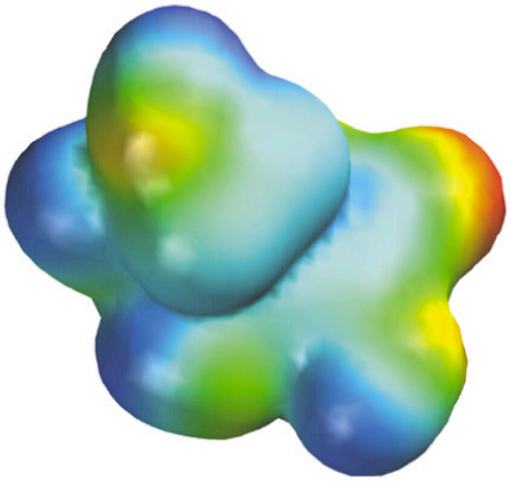
Radical Reactions in Biological Systems

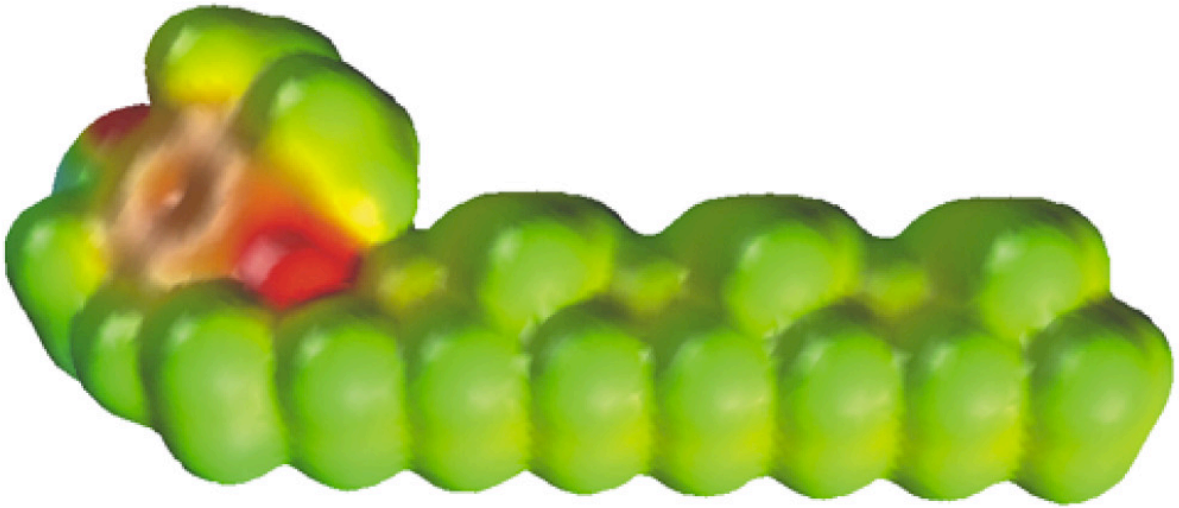
Liver enzymes & cytochrome P_{450}

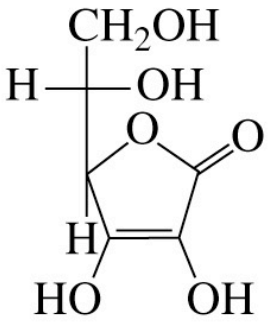



RO
O
N
HO
OH
several steps
H
a ribonucleotide
a radical intermediate
a deoxyribonucleotide

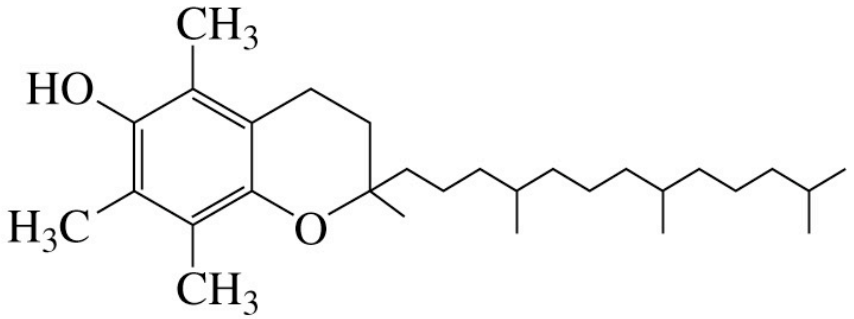
Radical Inhibitors/ Antioxidants







vitamin C
ascorbic acid



vitamin E
α-tocopherol

BHA & BHT: are synthetic chemicals “bad”?