Free Radicals

Definition: Any chemical species with one or more unpaired electrons

Examples of radical species

Na •

any atom with unpaired electrons NO & NO₂ odd electron

molecules

diradical molecule

 $O_{2} \qquad R \cdot Ar \cdot RO \cdot ArO \cdot \begin{array}{c} O & O \\ R - C \cdot R - C - O \cdot ROO \\ (Ar) & (Ar) \end{array} \xrightarrow{(Ar)} ROO$

Nature of Free Radicals

Geometry

Example I:

$$\begin{array}{cccc} H_{1} & H_{1} & C_{2}H_{5} - C_{1} - CH_{2}Cl & Br_{2} & C_{2}H_{5} - C_{1} - CH_{2}Cl & Br_{2} & C_{2}H_{5} - C_{1} - CH_{2}Cl & + C_{2}H_{5} - C_{1} - CH_{2}Cl & + C_{2}H_{5} - C_{1} - CH_{2}Cl & + C_{2}H_{5} - C_{1} - CH_{2}Cl & H_{3} & H_{1} & H_{2} \\ CH_{3} & CH_{3} & CH_{3} & CH_{3} & H_{1} & H_{2} & H_{3} & H_{1} & H_{2} \\ (S)-enantiomer & racemic mixture & H_{3} \\ \end{array}$$

Example II:



racemic mixture

RATIONALIZATION TO ACCOUNT FOR RACEMIZATION IN RADICAL REACTIONS

<u>Explanation I:</u>

Participation by a planar radical species capable of undergoing "top" or "bottom" attack with equal likelihood



Explanation II:

Participation by a rapidly equilibrating pair of enantiomeric pyramidal radical species that would lead to racemic products



Evidence in favor of the "pyramidal" radical

Consider the following reaction:



Object: Change R- from a group that can easily adopt a planar geometry to one that cannot. If planar geometry is favored for free radicals, that fact should be reflected in a low RCI: RCOCI ratio.



Conclusion: The formation of pyramidal radicals is **not** accompanied by adverse energy considerations. In fact, the opposite is true.

More evidence in favor of the "pyramidal" radical?

Consider the following observation:



Both stereogenic centers remain intact

Plausible explanation

Loss of carbon dioxide leads to a pyramidal alkyl radical that rapidly recombines with incipient oxyradical before inversion of configuration can occur (an example of the "cage effect").



Stability of Free Radicals

Observation: Measurement of Bond Dissociation Energies

 $R = CH_3 \qquad CH_3 - H \qquad RCH_2 - H \qquad R_2CH - H \qquad R_3C - H$ $435 \text{ kj/mole} \qquad 406 \text{ kj/mole} \qquad 395 \text{ kj/mole} \qquad 380 \text{ kj/mole}$

Conclusion: The order of radical stability is tertiary>secondary>primary>methyl

Observation:



Rationale: Abstraction of either benzylic or allylic hydrogen atoms to produce benzyl or allylic radicals is a lower energy process than that for corresponding saturated systems due to the possibility of π -delocalization of the odd electron in the former systems.

Observation:

 $CH_{3} \cdot C_{6}H_{5}CH_{2} \cdot (C_{6}H_{5})_{2}CH \cdot (C_{6}H_{5})_{3}C \cdot C_{6}H_{5}C \cdot C$

Increasing stability, decreasing reactivity, greater selectivity

Rationale: The greater the possibility for π -delocalization, the greater the stability of the radical species.

Stabilities of Substituted Benzyl Radicals

Observation:

$$CH_3$$

+ RO· Z + ROH $\rho = -0.38$
Relative stabilities:

Z =	CH ₃	OCH ₃	Н	Br	CN	NO ₂
	1.9	1.2	1.0	1.8	3.7	4.0

Conclusions:

- 1. Based on the measured rho value for benzyl radical formation, the reaction is relatively insensitive to substituent electronic effects.
- 2. Both electron donating and electron withdrawing substituents stabilize the benzyl radical produced.

Rationale:



Substituted Benzyl radicals Steric effects

Consider the following dissociation reaction:



Observations: As the size of R increases (methyl, ethyl, isopropyl, t-butyl),

- a) the magnitude of the equilibrium constant increases
- b) the reactivity of the resulting benzyl radical decreases
- c) the benzyl radical with the largest ortho-substituents forms fastest (at a fixed temp.)
- d) the benzyl radical with the largest ortho-substituents is formed under the mildest reaction conditions (under variable temp. conditions)

Rationale:

As R increases in size, the reactant is destabilized.Production of the substituted benzyl radical serves to relieve steric strain.

Once formed, the benzyl radical with the largest ortho-substituents will experience the greatest steric hindrance to recombination or to other reactions at the radical site.

Generation of Free Radicals

* Thermolysis* Photolysis

$$C_{6}H_{5}-C_{-}O-O-C_{-}C_{6}H_{5} \xrightarrow{R} 2 C_{6}H_{5}-C_{-}O \xrightarrow{R} 2 C_{6}H_{5} + 2 CO_{2}$$

c)
$$(CH_3)_3C - O - C(CH_3)_3 \xrightarrow{140^\circ - 150^\circ C} 2 (CH_3)_3C - O \cdot$$

e)
$$\text{RONO}_2 \xrightarrow{200^{\circ}\text{C}} \text{RO} + \text{NO}_2$$

a

h

f)
$$2 RMgX + CoCl_2 \longrightarrow R_2Co \xrightarrow{35^{\circ}C} 2R \cdot + Co$$

a)
$$CH_3 - C - C - CH_3 \longrightarrow 2 CH_3 - C \cdot U = 0$$

 $O = O = O = O = O$

b)
$$CH_3 - C - CH_2Cl \longrightarrow CH_3 - C - CH_2 + Cl \cdot$$



Characteristics of Badical Beactions

- * Most radical reactions occur readily in the gas phase
- * Radical reactions generally are not influenced by solvent polarity
- Radical reactions generally are not influenced by acid or base catalysis
- Unlike cations or anions, radicals generally are not influenced by electron-donating or electron-withdrawing substituents
- Radical reactions are often preceded by an induction period during which time they are subject to inhibition
- Radical reactions are frequently chain reactions
- Radical reactions generally are not accompanied by skeletal rearrangements

A Typical Radical Reaction *Overall reaction* $H_3C CH_3$ bv low temp.

A Typical Radical Reaction: Mechanism

 $H_3C - CH_3 \rightarrow CH_3 + H_3C - C \cdot (homolytic decomposition)$ $CH_3 \cdot + H_3C - C \cdot \longrightarrow H_3C - C - CH_3$ (recombination) $CH_3 \cdot + CH_3 \cdot \longrightarrow C_2H_6$ (dimerization) (dimerization) $H_3C-C \cdot + H_3C-C \cdot \longrightarrow H_3C-C-C-CH_3$ (abstraction/transfer) $CH_3 \cdot + H_3C - C \cdot \longrightarrow CH_4 + H_2C = C = O$ $CH_3 \cdot + H_3C - CH_3 \longrightarrow CH_4 + H_3C - CH_2 \cdot (abstraction/transfer)$ $H_{3}C-C-CH_{2} + H_{3}C-C-CH_{2} \rightarrow H_{3}C-C-CH_{2}CH_{2} - C-CH_{3} \quad (dimerization)$ $H_3C-C-CH_2 + CH_3 + CH_3 + CH_3 + CH_3 + CH_2CH_3$ (recombination) $H_{3}C-C \cdot + H_{3}C-C \cdot \longrightarrow H_{3}C-C-H + H_{2}C=C=O$ (disproportionation) $H_{3}C-C-CH_{2} + H_{3}C-C + H_{3}C-C + H_{3}C-C + CH_{2} - CH_{3}$ (recombination) (abstraction) $H_3C - C - CH_2 + H_3C - C + H_3C - C + H_3C - CH_3 + H_2C = C = O$ $H_3C - C \cdot - C \cdot C H_3 \cdot + CO$ (decomposition)