Objective 14

Apply Reactivity Principles to Radical Reactions:
Identify radical reaction conditions
Describe mechanism
Use curved arrows for common radical steps to predict product

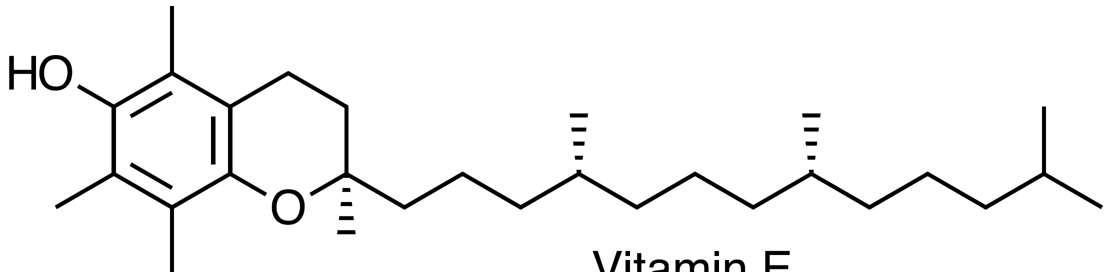
Radical Reactions

Radical = a substance with at least ***one unpaired electron***

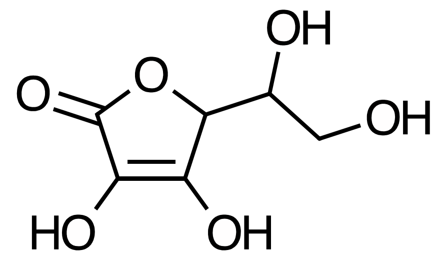
Radicals are ***very reactive*** substances.

Unsaturated Fat -- O_2 --> unstable hydroperoxide in allylic position via radical mechanism

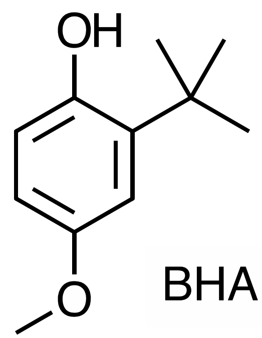
***Antioxidants* Trap Radicals to Prevent Hydroperoxide formation**



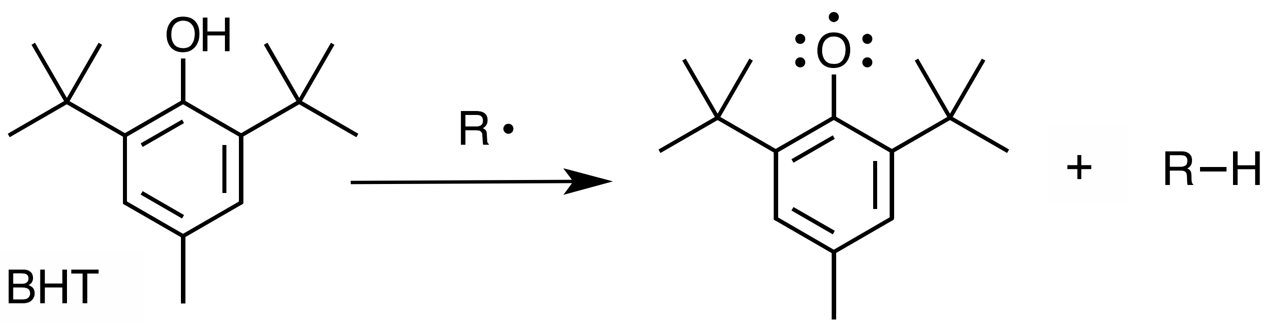
Vitamin E



Vitamin C



BHA



BHT

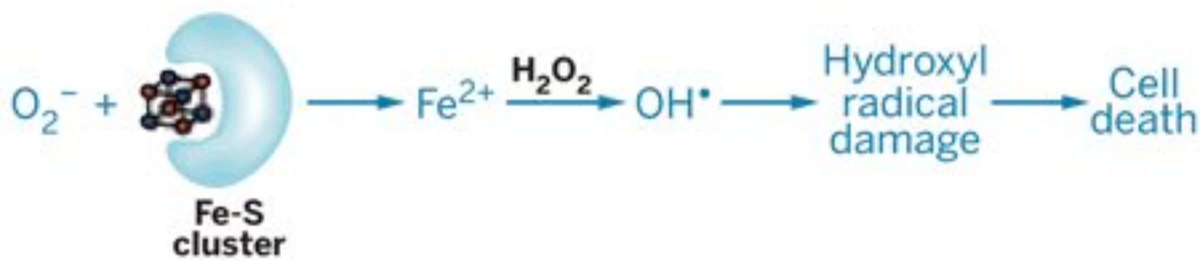
What do these structures have in common?

Draw the resonance structures of the radical product.

Antibiotics Generate OH radicals ---> Cell Death

Antibiotics are usually classified by their primary target: DNA replication, protein synthesis, or cell-wall synthesis. James J. Collins, professor of biomedical engineering at Boston University, and coworkers now report that these seemingly different antibiotics trigger a common cell death mechanism downstream of their initial targets, generating hydroxyl radicals that damage DNA, proteins, and lipids (Cell 2007, 130, 797). The findings point the way to improving existing antibiotics. (CEN, 9/10/07, p. 8)

KILL CYCLE Bactericidal antibiotics, whatever their initial drug target, trigger the tricarboxylic acid cycle, producing NADH that is used in the electron transport chain. Increased electron transport activity produces superoxide, which attacks iron-sulfur clusters in proteins, making Fe^{2+} available for the Fenton reaction, in which hydrogen peroxide is split to $OH^{\bullet}$. These radicals cause damage that leads to cell death.

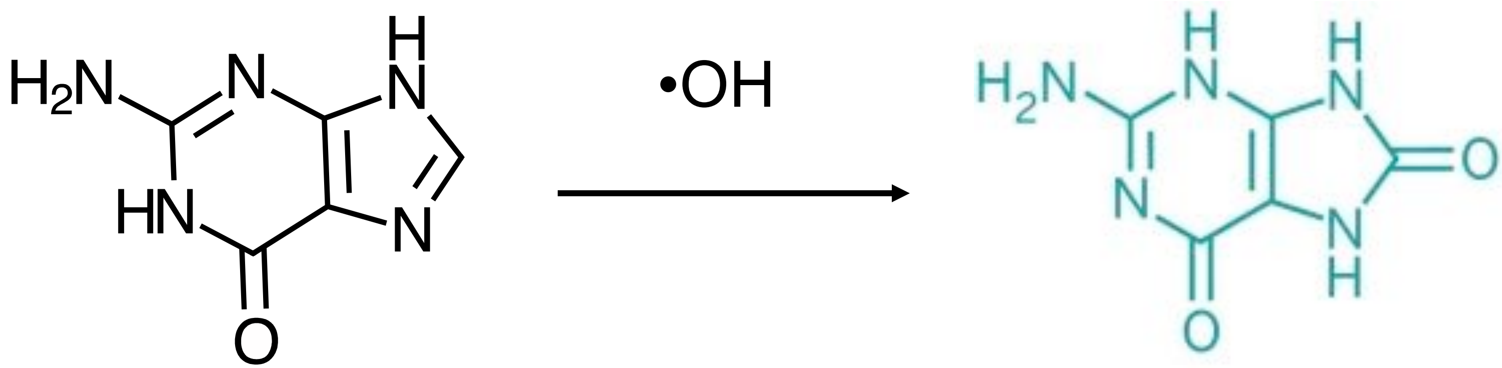


ADAPTED FROM CELL

http://cen.acs.org/articles/90/i17/Common-Antibiotic-Mechanism-Shown.html

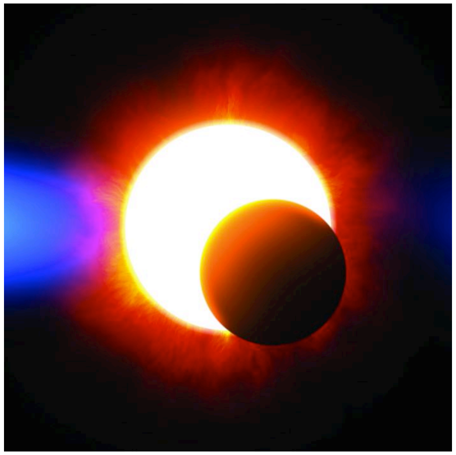
4/23/12, CEN, p. 6 "Common Antibiotic Mechanism Shown"

Guanine oxidation is the main cause of cell death by bactericidal antibiotics. Hydroxyl radicals oxidize the DNA base guanine to form 7,8-dihydro-8-oxoguanine, or 8-oxoguanine.

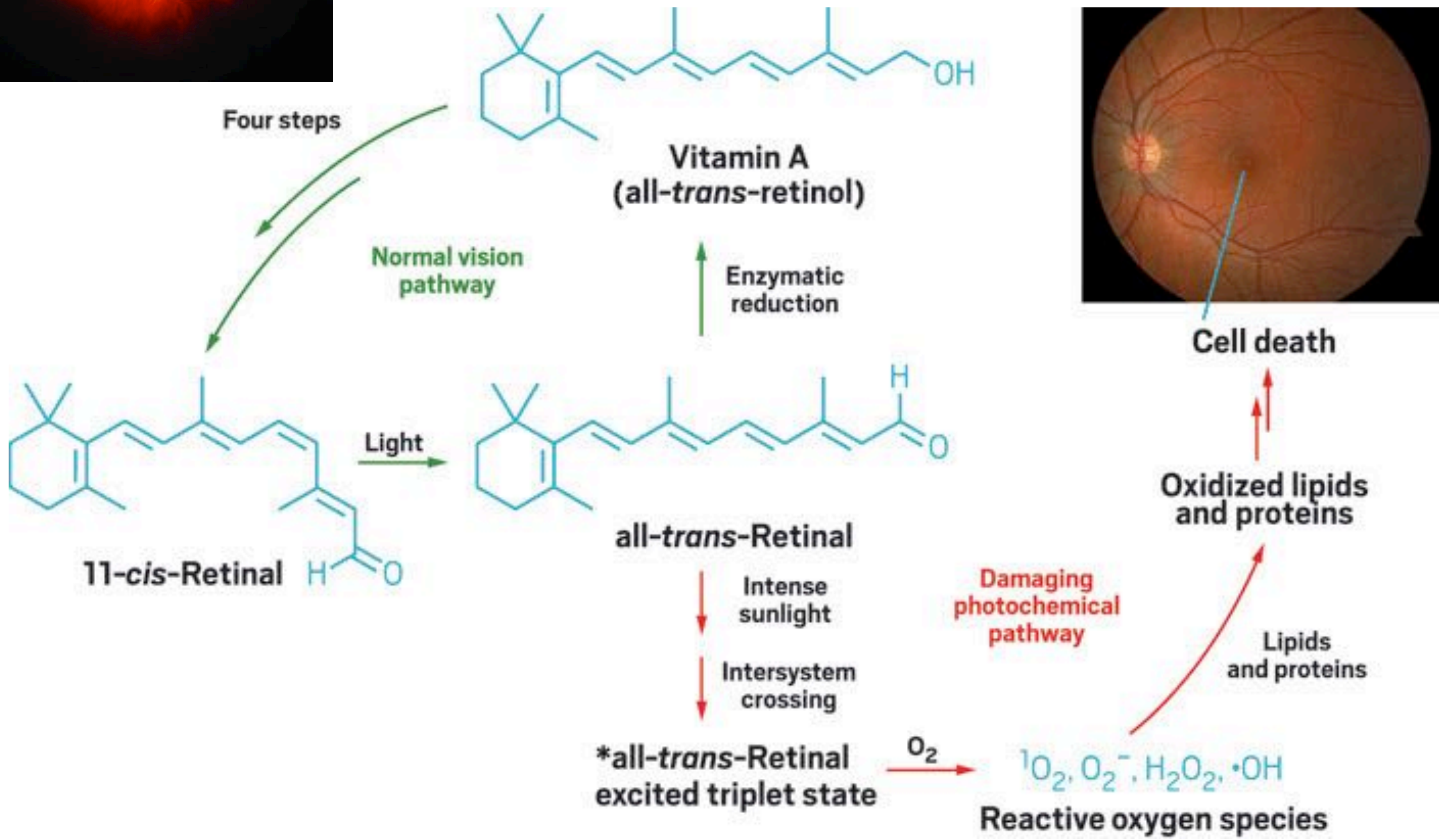


Guanine

8-Oxoguanine



C&EN, 8/21/17, p. 31 “Why staring at the solar eclipse is a bad idea”



Radical Reactions

A Radical is a substance with at least 1 unpaired electron

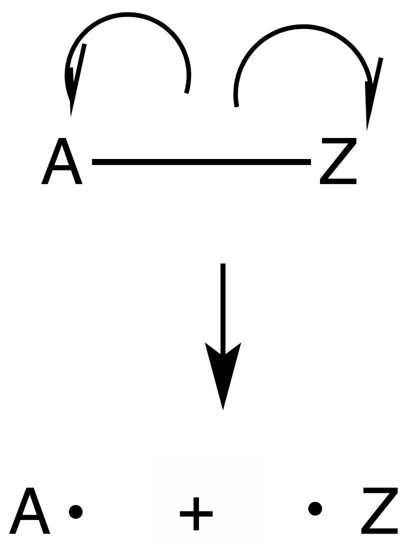
Be Able To: a. Predict Product(s) from Reactants
b. Use these reactions in Synthesis
c. Describe Radical Reaction Mechanism to Explain Product

Four Reactions involve a Radical:
1. Alkene + HBr/peroxides --> anti-Markovnikov product
2. Alkane Halogenation
3. Allylic Bromination: ID allylic carbon
4. Radical Polymerization

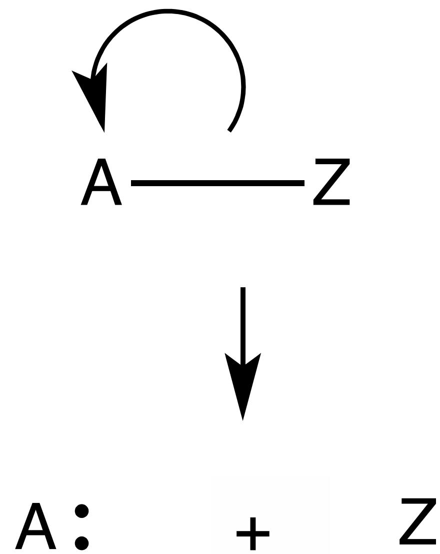
Radical Mechanism Steps:
1. Initiation
2. Propagation
3. Termination

Radical reaction involves ***Light*** or a Lot of ***Heat*** or ***Peroxides***

Curved arrows: use a ***half*** arrow (*fish hook*) to show movement of **single** electrons.



Radical reaction:
Homolytic bond breaking forms two radicals



Polar reaction:
Heterolytic bond breaking forms a lone pair

Light or Heat Breaks X-X or RO-OR Bond to Form Radicals

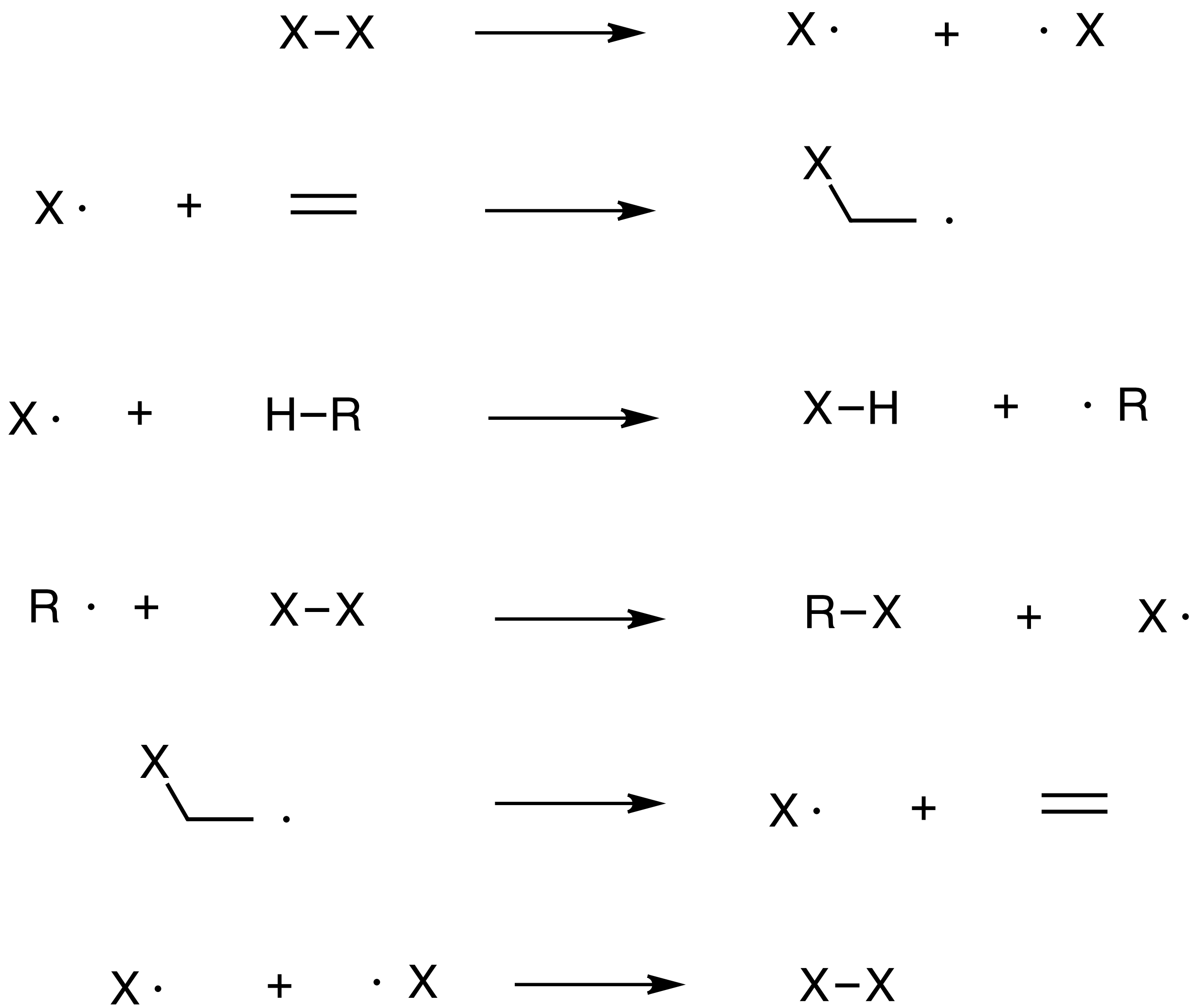
Radicals are very Reactive - reacts with C-H bond

Bond	BDE, kJ/mole	Bond	BDE, kJ/mole	Bond	BDE, kJ/mole
C-C	360	C-H	410		
F-F	159	C-F	448	H-F	569
Cl-Cl	242	C-Cl	339	H-Cl	431
Br-Br	192	C-Br	285	H-Br	368
I-I	151	C-I	222	H-I	297
RO-OR	151			H-OC	435
C=C	610	C-C π bond	≈ 250		

WEAK!

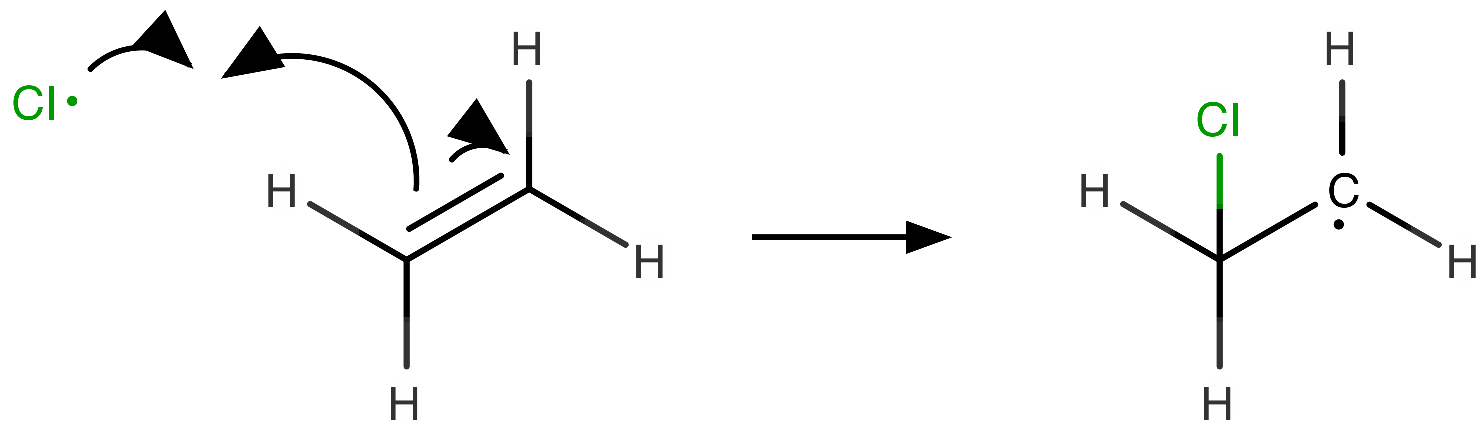
STRONG!

Radical reaction patterns:
Use curved arrows to show how bonds break and form



See Practice Problem 0.

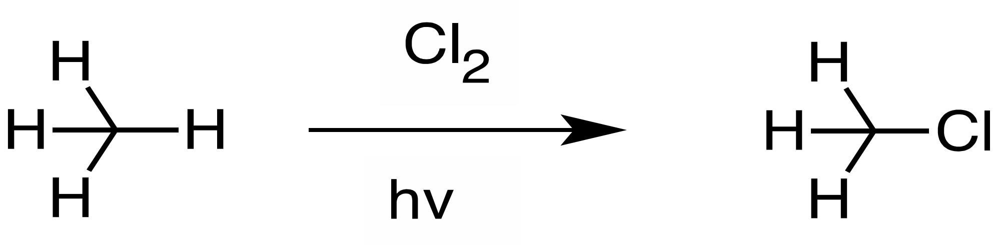
Curved arrows from X radical + alkene.
Arrows are HALF ARROWS (barbs)



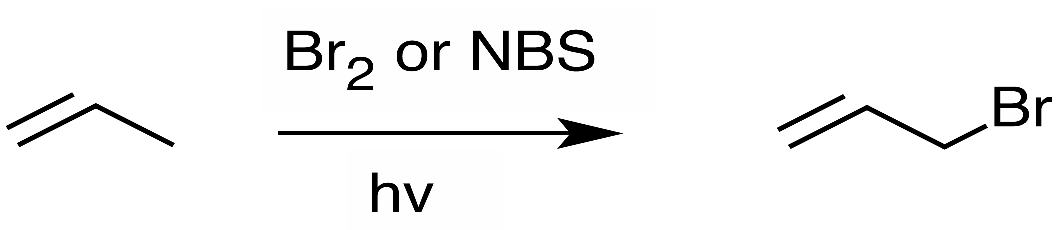
Pi bond breaks.
One electron from pi bond forms bond with Cl radical.
Other electron from pi bond is a radical (unpaired electron).

C-H Bonds are STRONG ***UnReactive*** but … Let There Be ***Light***!

(University of California motto: ***Fiat Lux***)



Alkane halogenation



Allylic bromination

hυ = light, NBS = N-bromosuccinimide

Br_2 also makes addition product; NBS won't

These two reactions occur by a RADICAL mechanism

1. What is the reaction type for these reactions?

   acid-base substitution elimination addition

2. What bond breaks? What bond forms?

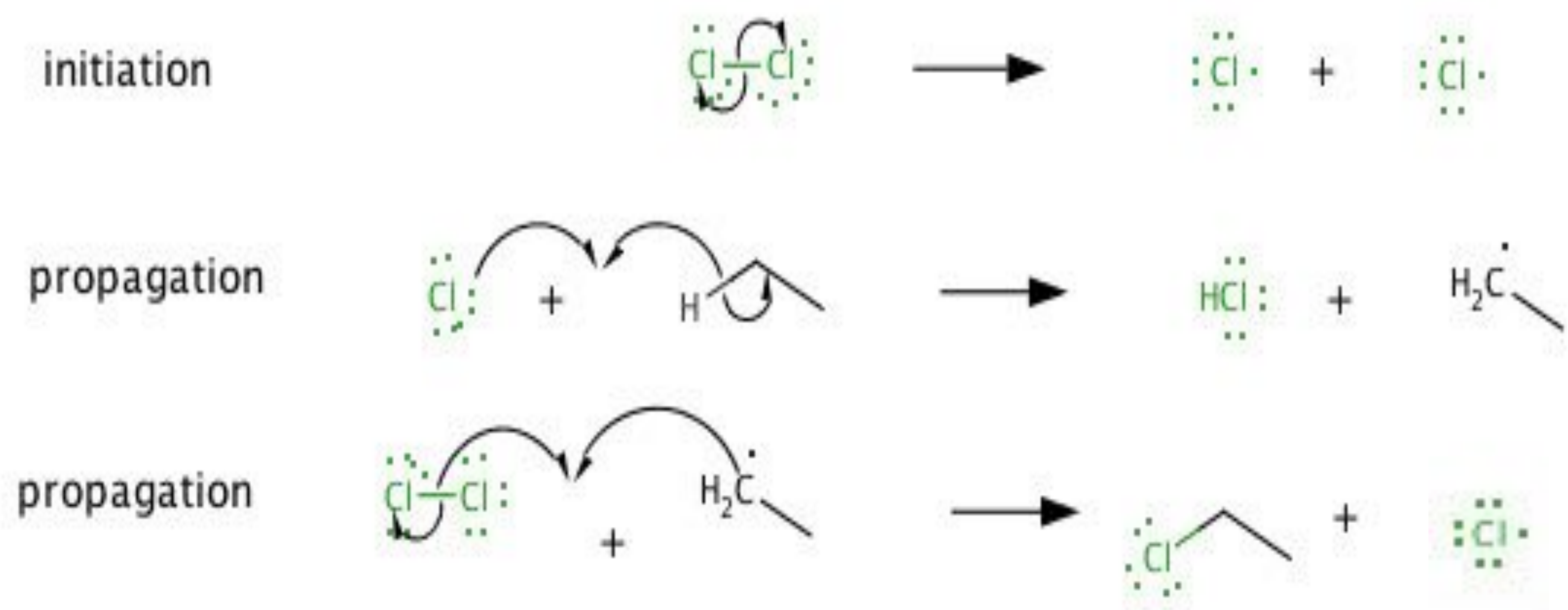
General Radical Mechanism: 3 steps

1. Initiation: non-radical --> 2 radicals

2. Propagation: radical + non-radical --> radical + non-radical
(may be more than 1 propagation step)

3. Termination: 2 radicals --> non-radical

Alkane Halogenation Mechanism

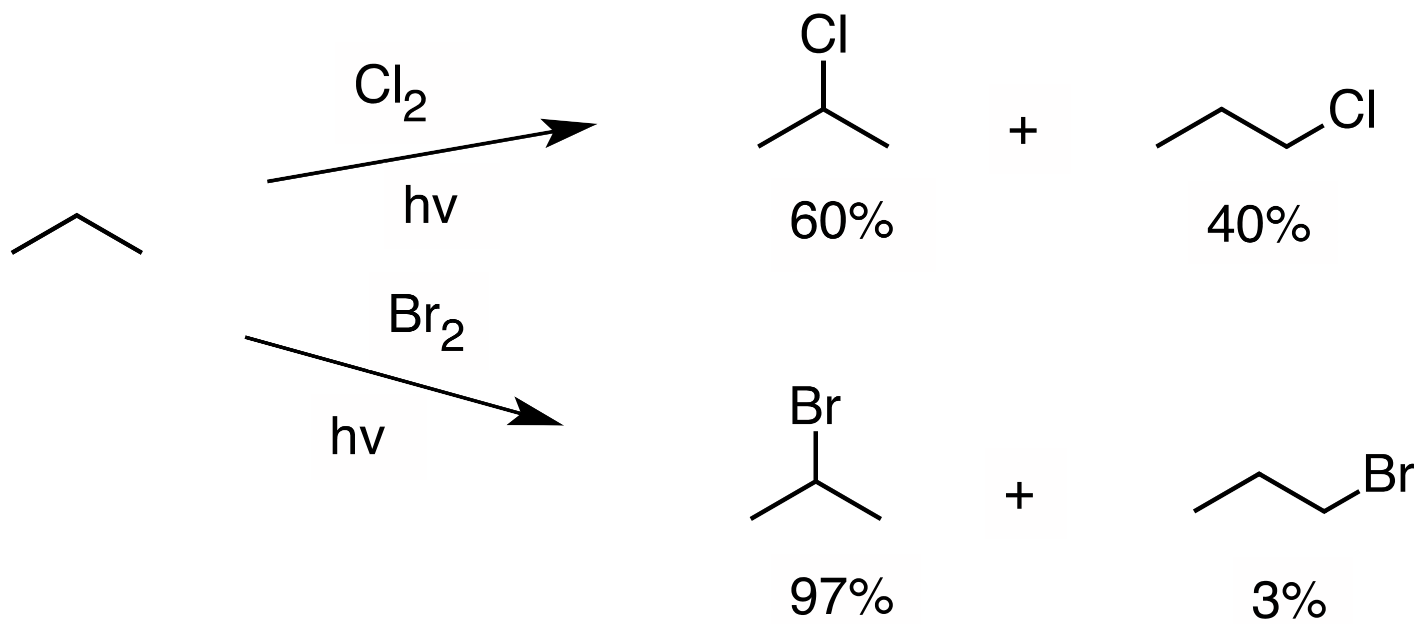


What happens next?

Alkane Halogenation:

Alkane Bromination is Selective (Br on more substituted C)

Chlorination is Not

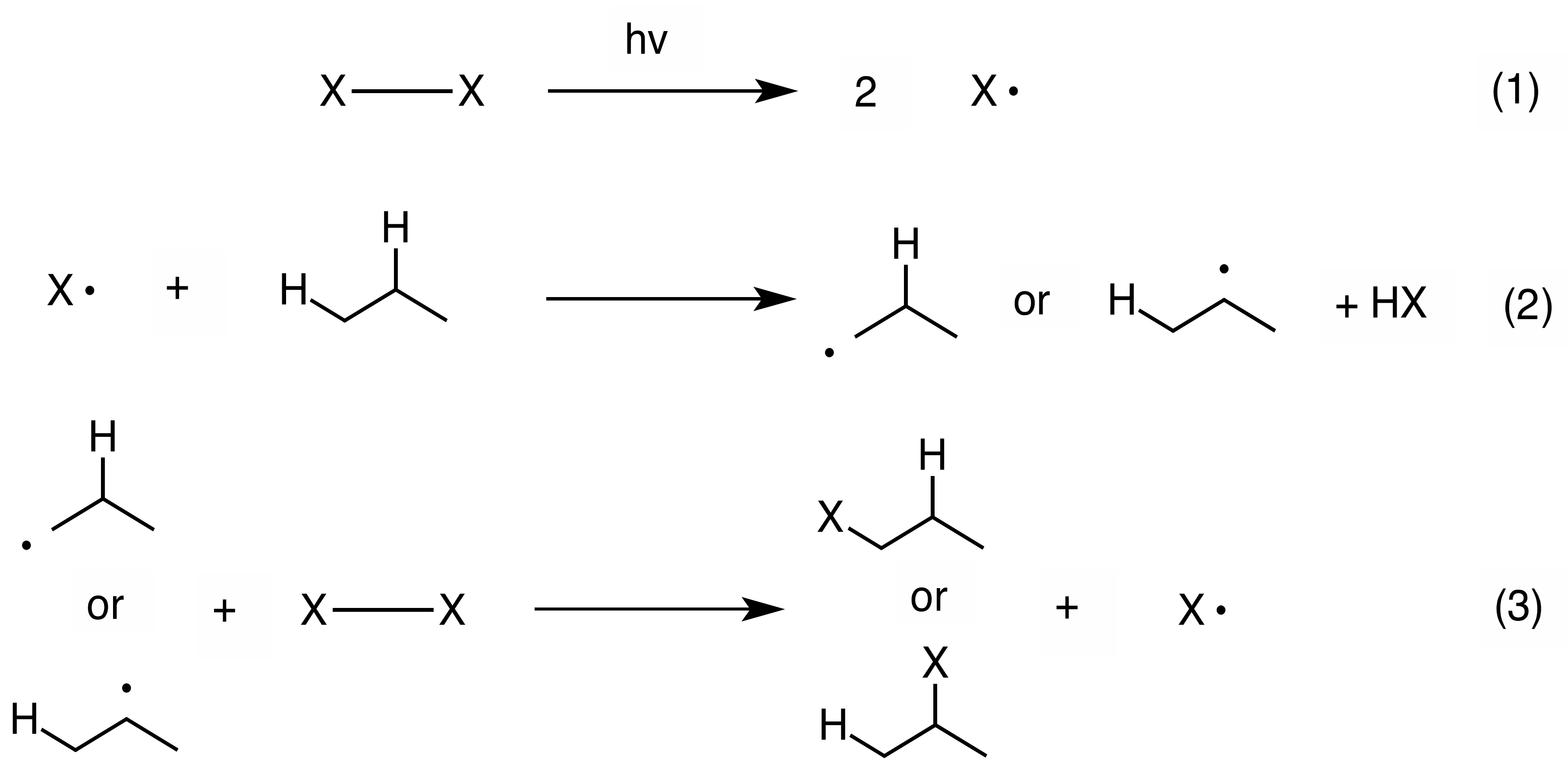


Describe the mechanism.

Fluorination is very exothermic - too vigorous for lab use.

Iodination does **not** occur (not thermo favored $\Delta H > 0$)

Alkane Halogenation: Br ***Selectively*** substitutes for H on more substituted C; Cl is ***not*** Selective.

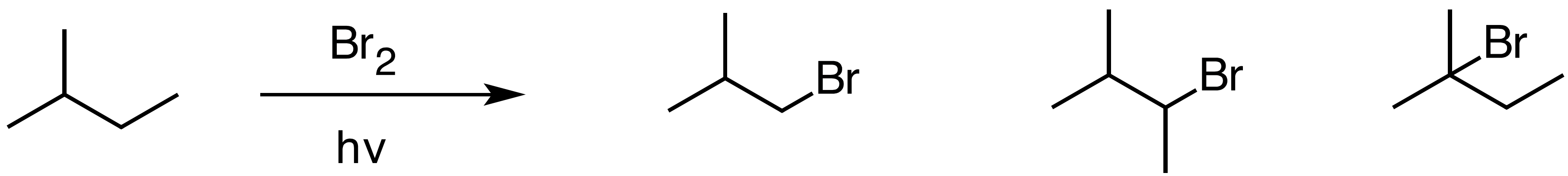


Stability: 3^{o} radical > 2^{o} radical > 1^{o} radical

X = **Cl** rate of formation of 2^{o} radical is ***slightly faster*** than 1^{o}

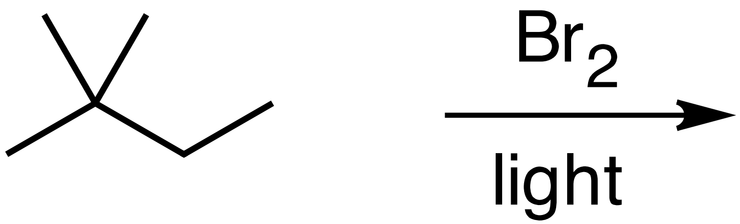
X = **Br** rate of formation of 2^{o} radical is ***much faster*** than 1^{o}

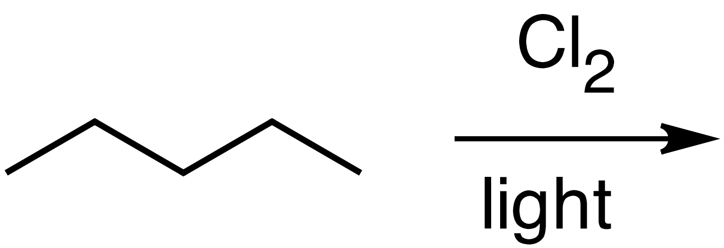
Identify each C in the reactant as 1°, 2°, or 3°.
Which C is the most substituted?
Predict the product of the reaction:



D E F

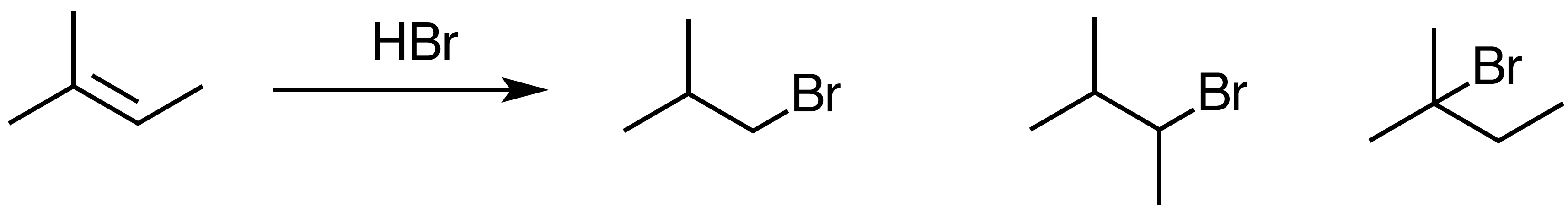
Predict the major product(s) for each reaction:



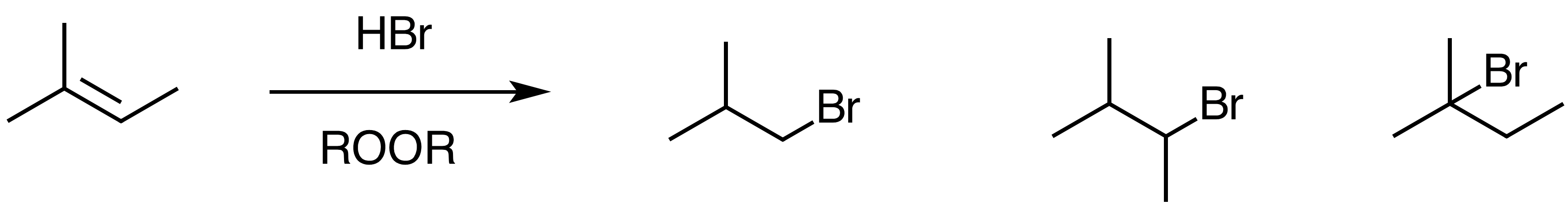


<u>Synthesis</u>: if you wanted to make RX from RH, would you use Alkane Chlorination or Bromination?

Alkene Addition of HBr. Predict the product of each reaction:

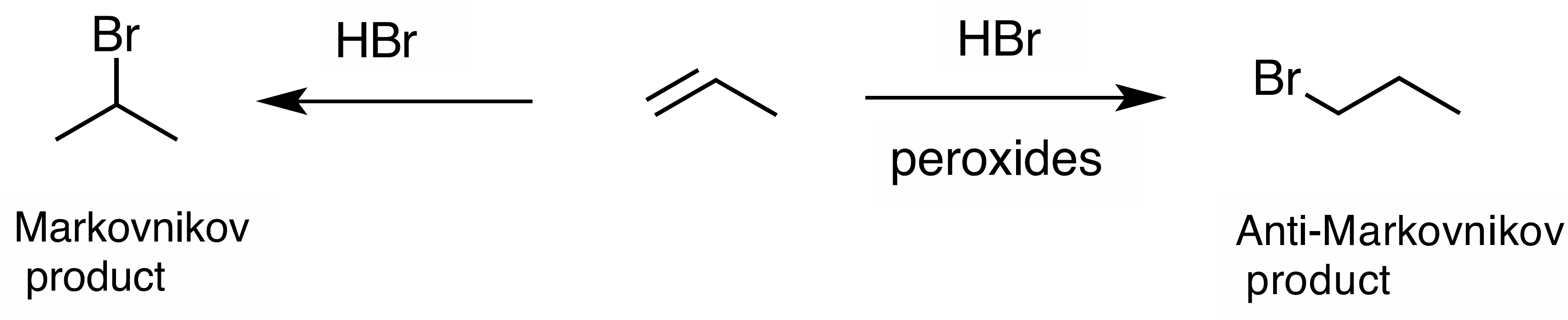


(i) (ii) (iii)



A B C

<u>Alkene Addition</u>: HBr adds across pi bond to form RX

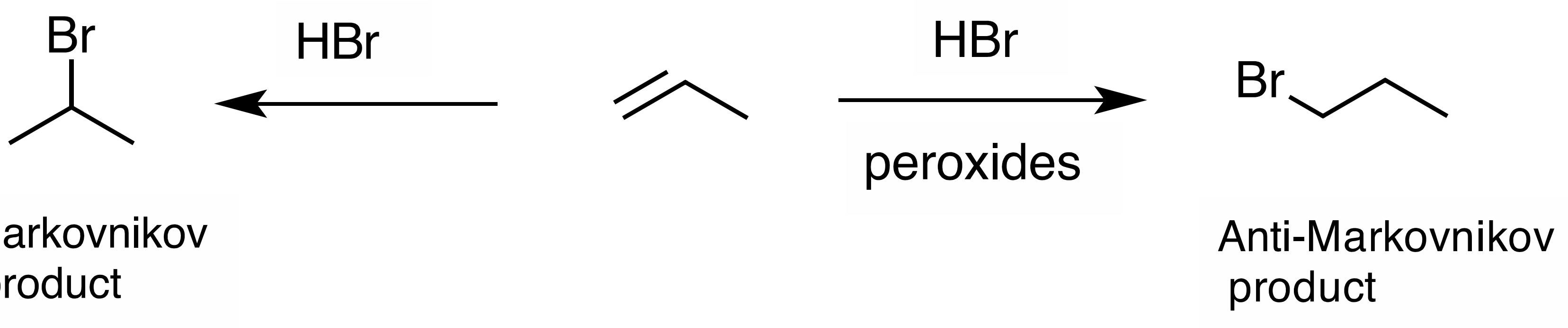


How is the Anti-Markovnikov product formed?
Describe the mechanism. (at least two propagation steps)

Initiation: RO-OR ⟶ 2 • OR

Propagation: • OR + ? ⟶

Alkene Addition: HBr adds across pi bond to form RX



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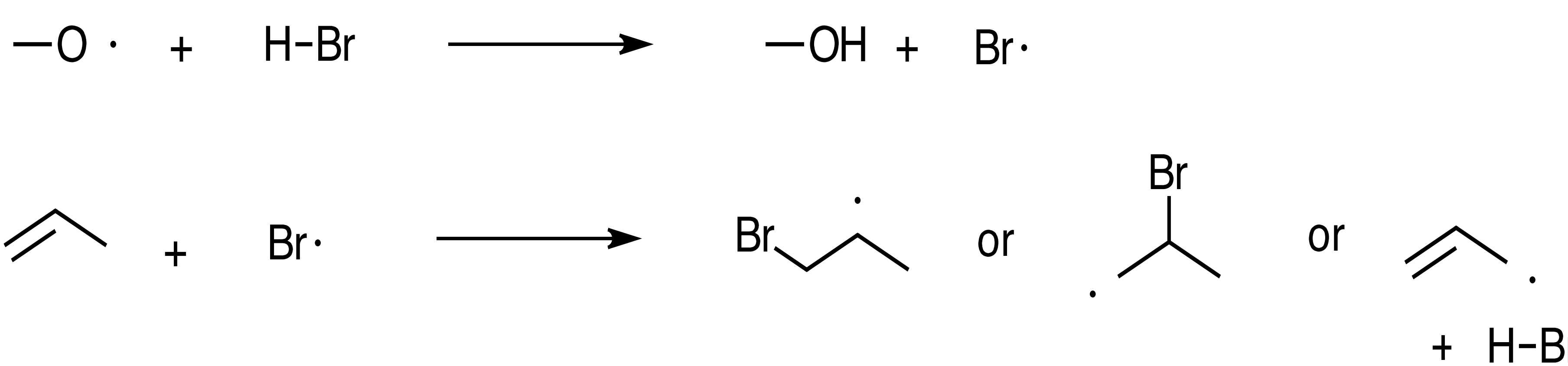
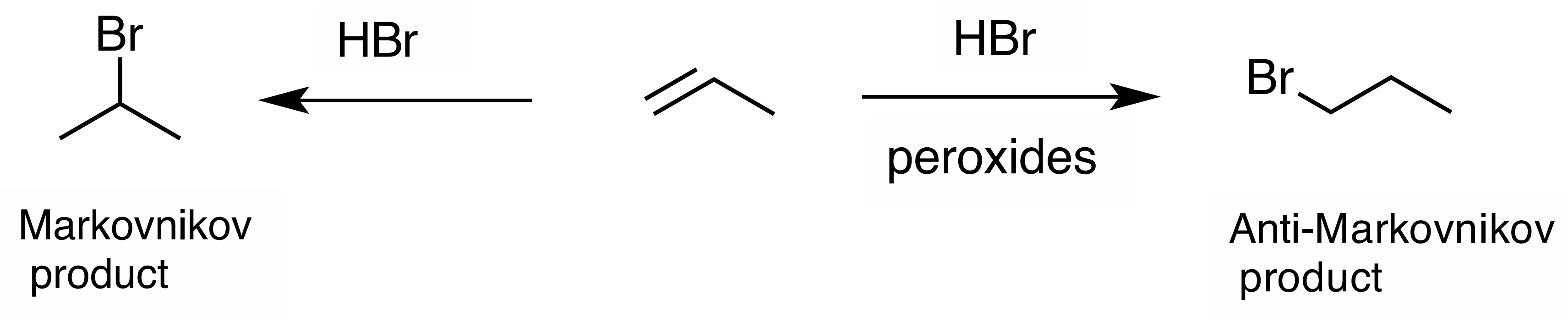


Use curved arrows to show how each product is formed.

Alkene Addition: HBr adds across pi bond to form RX



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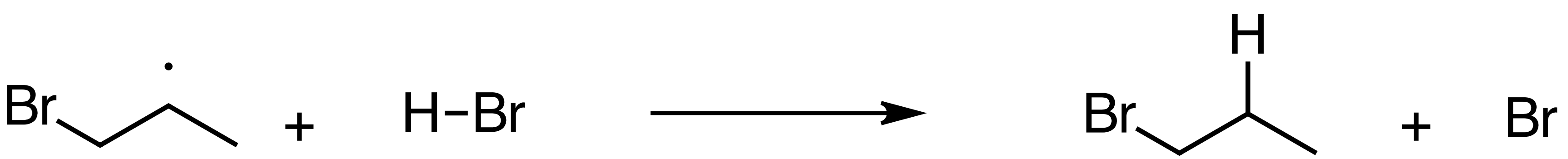


Use curved arrows to show how each product is formed.

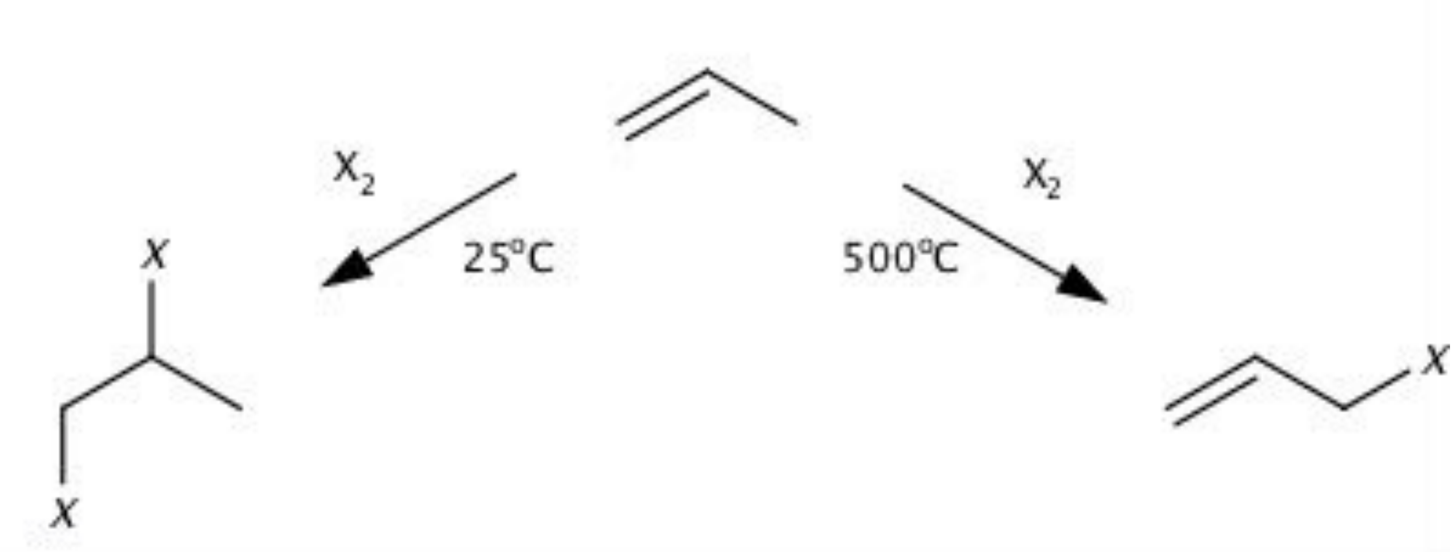
What does Br radical do next?

We have seen alkene addition of X_2:

$H_2C{=}CH{-}CH_3 + X_2$ -- 25°C --> $H_2XC{-}CHX{-}CH_3$ (1)

But at high T (or with NBS/hν)

$H_2C{=}CH{-}CH_3 + X_2$ -- 500°C --> $H_2C{=}CH{-}CH_2X$ (2)

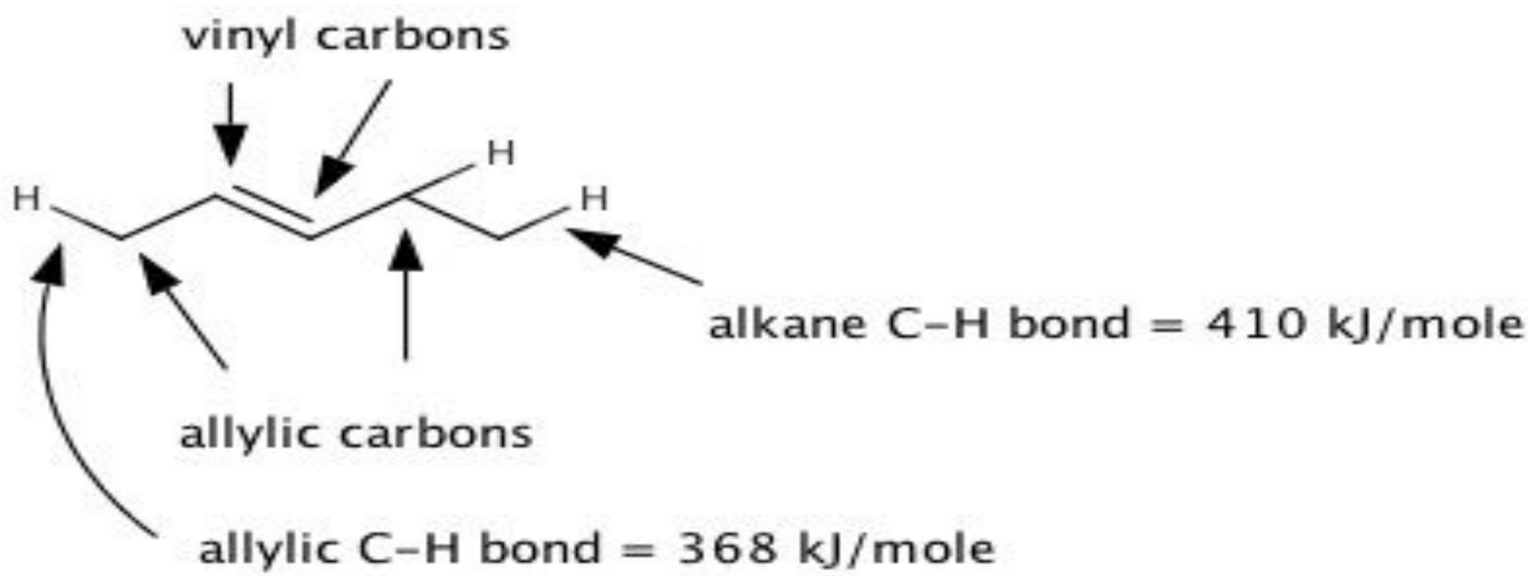


We have seen ***Radical Halogenation of Alkanes***: X Substitutes for H in C-H

In Reaction (2), X (Cl or Br) Substitutes at Allylic C-H to form ***Allylic Halide***

Allylic Carbon is a New Reactive Site

The C-H bond on the ***Allylic*** carbon is ***More*** Reactive than an Alkane C-H bond. Allylic C bond is adjacent to the C in the C=C bond.



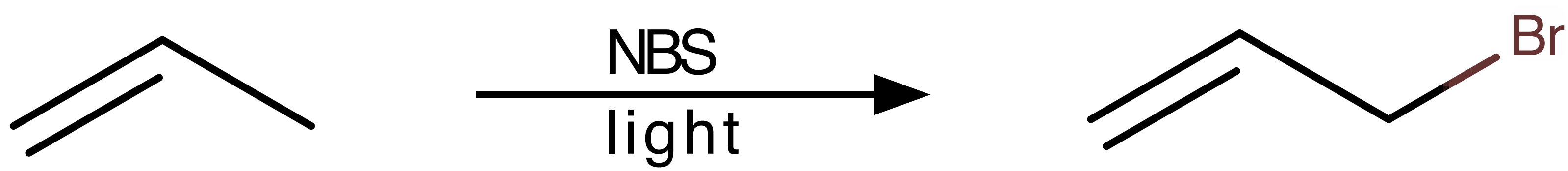
Since **allylic** C-H is ***weaker*** than **alkane** C-H bond, what reaction (and new functional group) occurs here?
(Hint: What reaction have we seen at a C-H bond?)

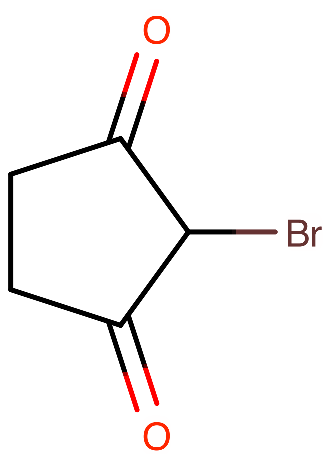
Allylic Bromination

Br_2 or NBS (preferred) are sources of Br radical

Br_2 also forms addition product. NBS will not.

Example: propylene + NBS –light--> 3-bromo-1-propene



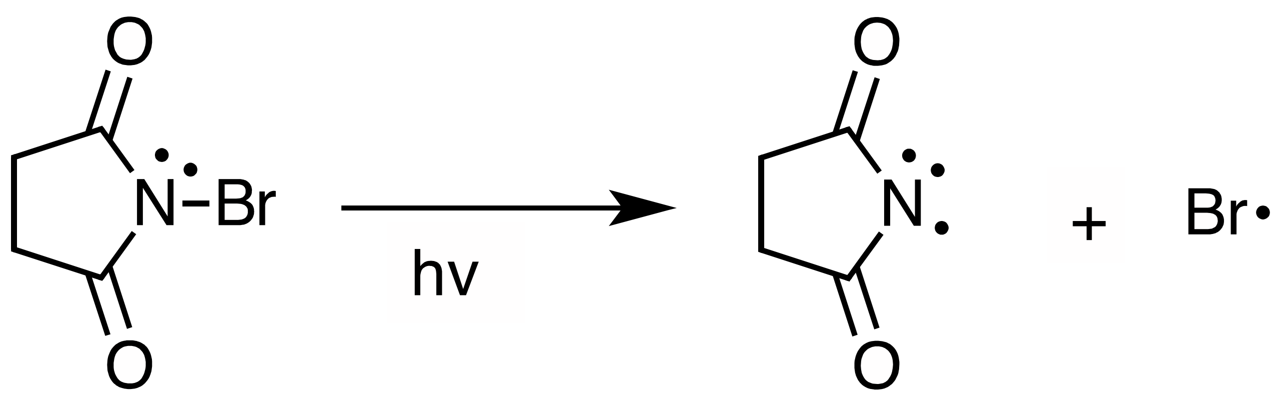


NBS = N-bromosuccinimide = source of Br radical

Allylic Bromination

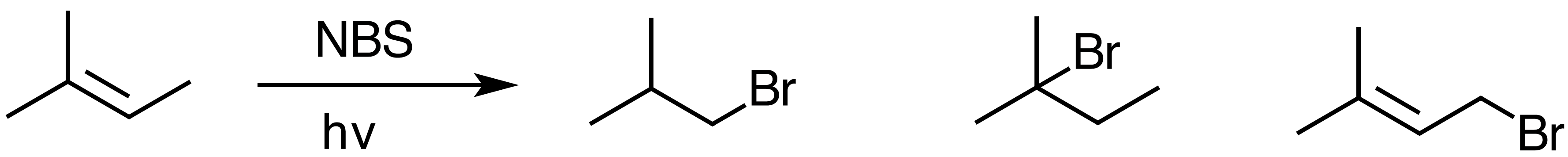
Br_2 or NBS (preferred) are sources of Br radical

<u>Initiation</u>: non-radical ---> radical



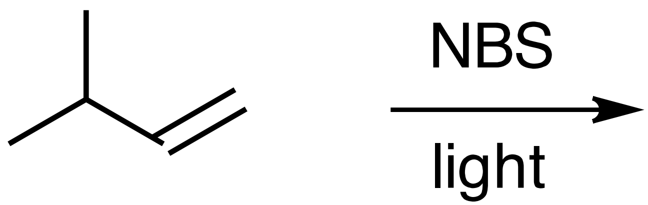
NBS = N-bromosuccinimde

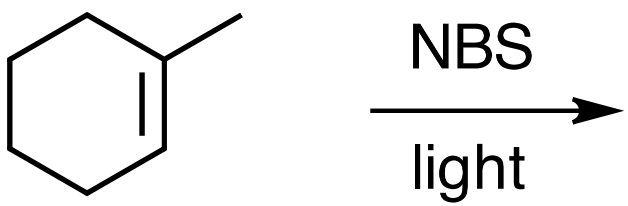
Which C is the allylic carbon?
Predict the product of the reaction:



(iv) (v) (vi)

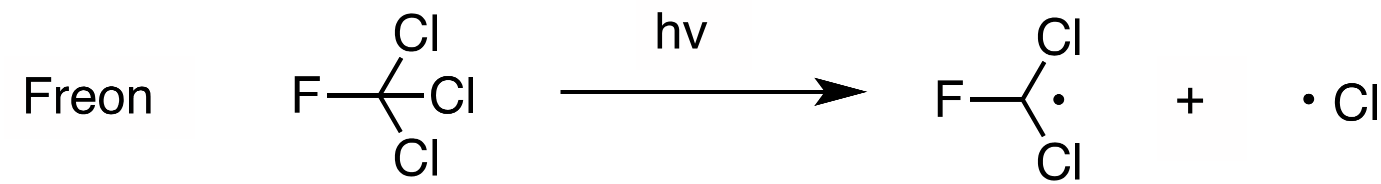
Where’s the allylic C in each reactant?
Predict the major product(s) for each reaction:



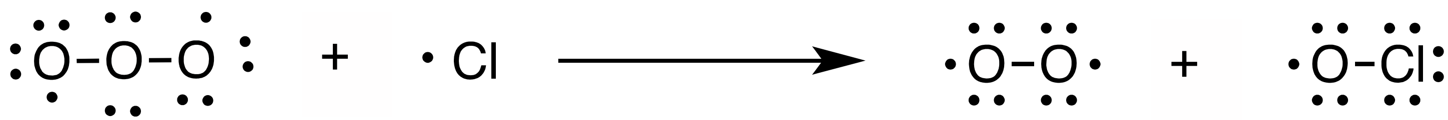


Radicals formed in the Earth's Atmosphere React with Ozone (Klein, p. 514)

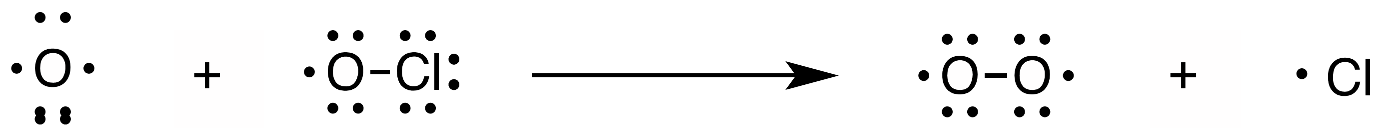
initiation



propagation



propagation



from O_3 -- hv
--> O_2 + O

Does it take a lot or a little Freon to deplete O_3?

Use curved arrows to show how each step occurs.

Note: termination step stops reaction.

Give an example of a termination step.

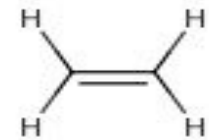
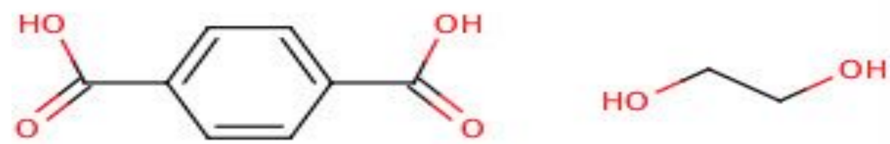
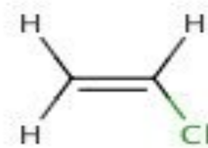
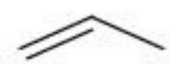
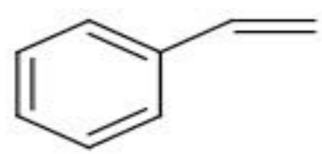
Plastics Are Polymers From Alkenes

Symbol	Acronym	Full name and uses
1	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
2	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
3	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
4	LDPE	Low density polyethylene - Carrier bags and bin liners.
5	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
6	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

Plastic	Recycling symbol	Properties	Major uses
HDPE	2	Good barrier properties, rough surface	Milk, water, and juice containers; grocery bags; toys; liquid-detergent bottles
LDPE	4	Flexible, tough, low melting point	Bread bags, frozen food bags, grocery bags
Polypro pylene	5	Excellent chemical resistance high melting point	Ketchup bottles, yogurt containers, margarine and deli tubs, flexible caps
Polysty rene	6	Stiff, transparent, glossy; can be foamed	Videocassettes, compact disc jackets, cafeteria trays
Polyvin yl chloride	3	Excellent chemical resistance, good weatherability, very glossy	Pipe, siding, clear food packaging, shampoo bottles

Source: CEN, 5/24/99, p. 13

Polymers are Long Chains of Repeating Units called Monomers

<u>Polymer</u>	<u>Monomer</u>
Polyethylene	
PET (Polyethylene terephthalate)	
PVC (polyvinyl chloride)	
Polypropylene	
Polystyrene	

All of the above plastics, except for PET (<u>condensation</u> polymer), are <u>addition</u> polymers. May use ROOR as initiator (radical reaction).

Cationic Polymerization Involves a Carbocation (see Klein, p. 405)

Radical Polymerization Mechanism involves Many Propagation Steps

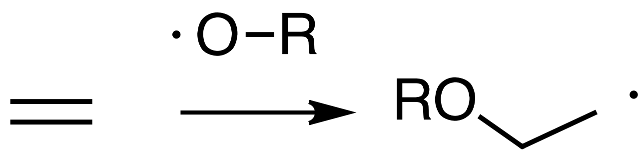
Initiation: RO-OR ⟶ 2 · OR

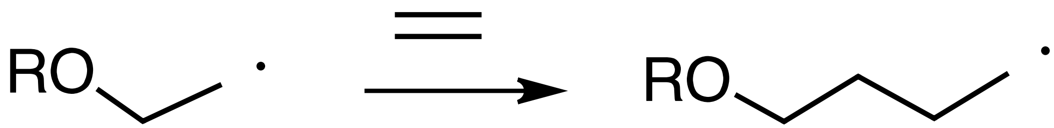
Propagation: $=$ + · OR ⟶

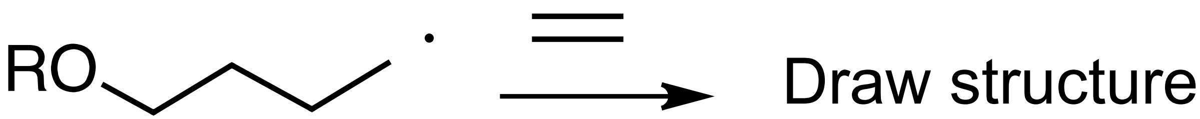
What is the product of the propagation step?
What is the next propagation step?

See Practice Problem 4.

Radical Polymerization Mechanism involves Many Propagation Steps







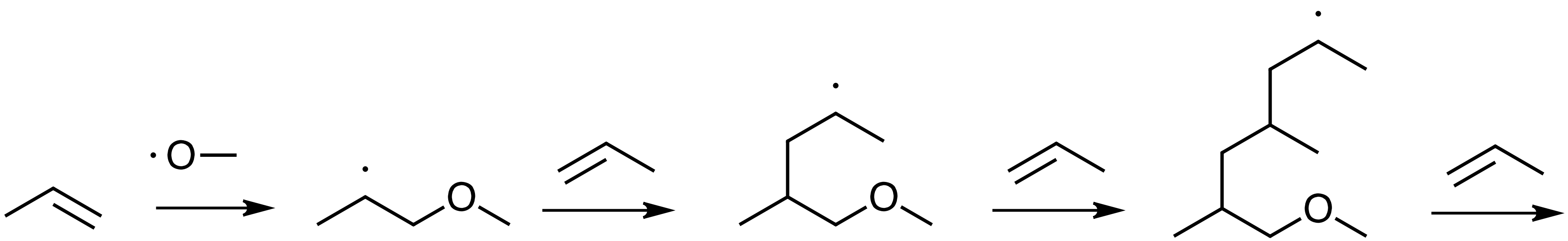
Polymer chain grows …. *(living, growing)*

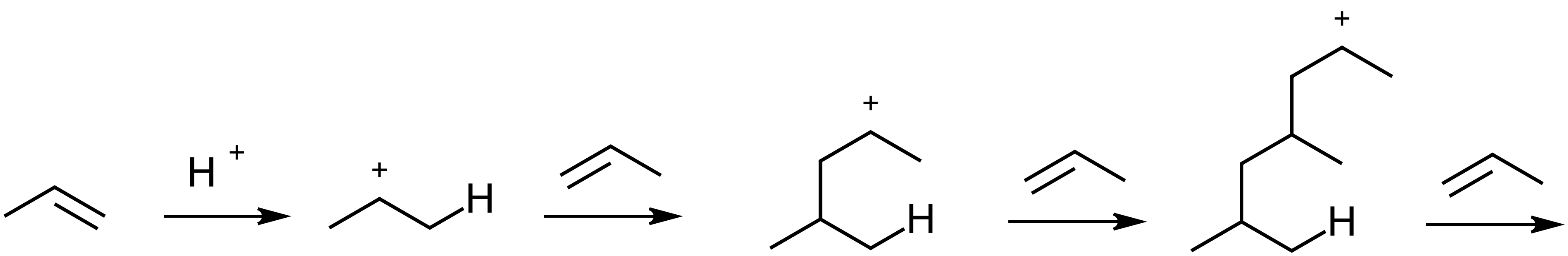
Do you want a high or low concentration of RO• present?

Polymerization Mechanisms
– Radical

- ***Cationic*** *(*Polymerization Involves a Carbocation (see Klein, p. 405)*)*

Propylene → Polypropylene





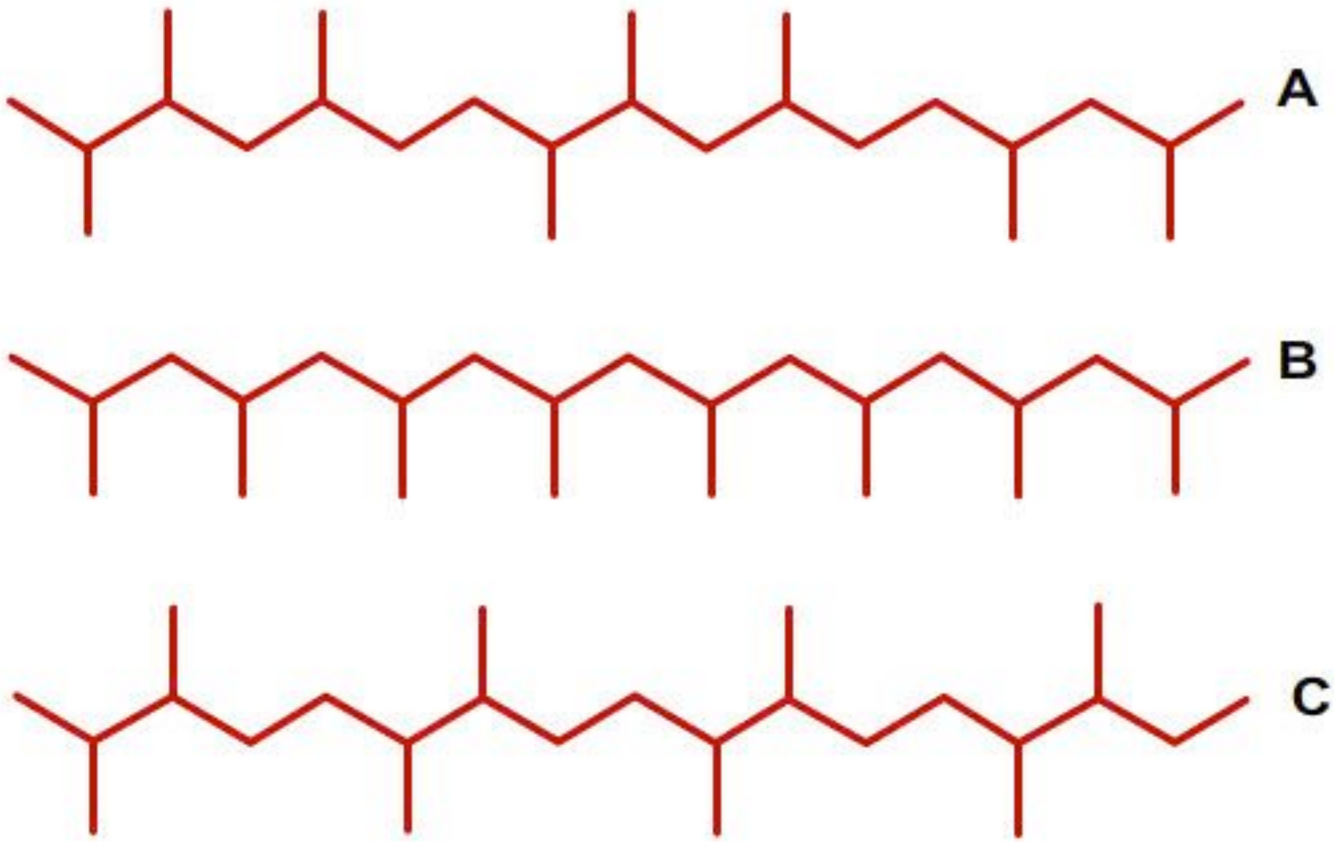
Polymer chain grows …. *(living, growing)*

Plastics Have Different Properties
Properties are Determined by Structure

HDPE is hard whereas LDPE is soft and flexible.
What is the difference between HDPE and LDPE?
HDPE: no branching, chains pack close together
LDPE: branches, chains can't pack close together

There are three types of polypropylene: atactic, isotactic, syndiotactic.
Which type is used in clothing?
Which type is used in hard toys?

There are three types of polypropylene: atactic, isotactic, syndiotactic. *Which one is which?*



http://www.keyword-suggestions.com/emllZ2xlciBuYXR0YSBwb2x5bWVyaXphdGlvbg/

Which type is used in clothing?
Which type is used in hard toys?

http://cen.acs.org/articles/89/i38/Breaking-New.html

9/19/11, CEN, p. 10 New Polymers

WORLDS TO CONQUER

Makers of new polymers have their sights set on major applications

POLYMER	COMPANY	APPLICATIONS
Ingeo polylactic acid	NatureWorks	Thermoformed containers, injection molding, fibers
Mirel polyhydroxyalkanoate	Metabolix/Telles	Film and other agricultural applications, plastic bags
Polyethylene furanoate	Avantium	Bottles, containers
Polypropylene/polyethylene carbonate	Novomer	Packaging, industrial coatings, specialty polymers
Stanyl ForTii high-temperature polyamide	DSM	Electronics, automotive uses
Topas cyclic olefin polymers	Topas Advanced Polymers	Protective packaging, shrink-wrap, optical components
Tritan polyester copolymer	Eastman Chemical	Housewares, baby bottles, medical applications

Tritan replaced polycarbonate (made from BPA) in water bottles

Tritan is a polyester copolymer made from:

dimethyl terephthalate,

1,4-cyclohexanedimethanol,

2,2,4,4-tetramethyl-1,3-cyclobutanediol

Properties: toughness, clarity, and temperature resistance

Tritan is more dishwasher-durable than polycarbonate, which tends to develop cracks, called crazing, at molded-in stress points.