CHEM1201: Section 2

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Contents

1 Alkanes

1.1 Preamble

Rings, double bons and other atoms in organic molecules introduce degrees of unsaturation or double bond equivalents. The formula for working out the degrees of unsaturation is:

$$DBE = \frac{(2 + (2 \times \#Carbons) + \#Nitrogens - \#Hydrogens - \#Halogens)}{2}$$
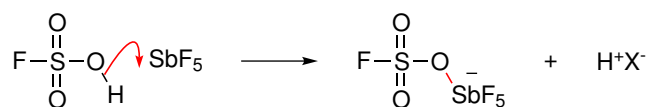
1.2 Reactions of Alkanes

The simplest saturated hydrocarbon is methane, CH_4, which has bon angles of 109°28'. Alkenes are made up of tetrahedral sp^3 hybridised carbon atoms covalently bonded with hydrogen. They undergo two elementary reactions:

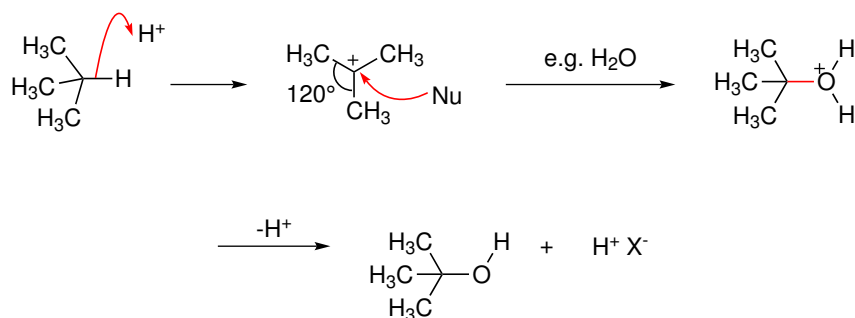### 1.2.1 Heterolytic Fission
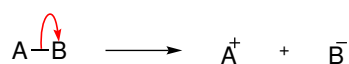
a)

"Superacid" mixture

b)

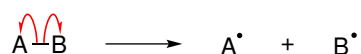A trigonal planar, carbocation is formed as the reactive intermediate

Note that charge is conserved and only the tertiary methane hydrogen is removed. This is because of the stabilisation effect from R groups. Primary carbocations ($R-C^+H_2$) are higher in energy than secondary (R_2C^+H) which are in turn higher than tertiary (R_3C^+) where R is an inductively

electron releasing alkyl group (e.g. $CH_3CH_2CH_3$ etc). This effect can be explained by hyperconjugation, as in a carbocation there will be a sp^2 hybridised vacant p orbital that can accept electrons coming out of the plane of the trigonal planar molecule. Electron donation occurs from the $C-H$ bond, in the same plane as the sp^2 orbital, into the empty p orbital.
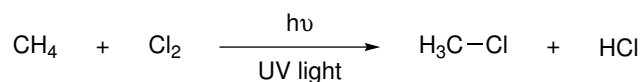
Some electron density is shared with this orbital

sp^2 hybridised
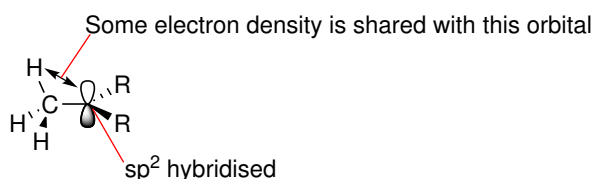
1.2.2 Homolytic Fission

For example free radical chain reactions which are of preparative value.

$$A-B \longrightarrow A^{\bullet} + B^{\bullet}$$

E.g. Free radical halogenation of methane:

$$CH_4 + Cl_2 \xrightarrow[\text{UV light}]{h\upsilon} H_3C-Cl + HCl$$

Initiation

$$Cl-Cl \xrightarrow{h\nu} Cl^{\bullet} + Cl^{\bullet}$$

Propagation

(a) $\quad Cl^{\bullet} \quad H-Cl \longrightarrow H-Cl + {}^{\bullet}CH_3$

(b) $\quad H_3C^{\bullet} \quad H-Cl \longrightarrow H_3C-Cl + {}^{\bullet}Cl$

Termination

$$Cl^{\bullet} \quad {}^{\bullet}Cl \longrightarrow Cl-Cl$$

$$H_3C^{\bullet} \quad {}^{\bullet}Cl \longrightarrow H_3C-Cl$$

$$H_3C^{\bullet} \quad {}^{\bullet}CH_3 \longrightarrow H_3C-CH_3$$
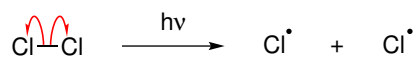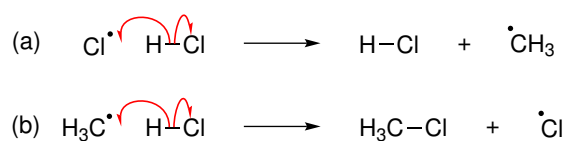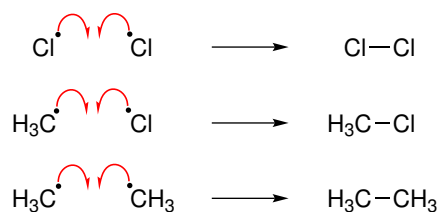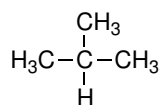
Termination reactions require another photon and account for less than 2% of the product.

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In the free radical halogenation of methane, the propagation steps take place 10^6 times for each initiation step. Additionally, other products are formed when more H's are replaced.

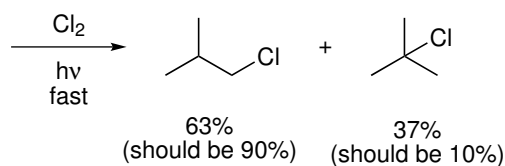When using isobutane (2-methylpropane) we see interesting selectivity.

$$H_3C-\underset{\underset{H}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$$

Isobutane

With Br_2 the reaction is regiospecific - a single regioisomer is formed.

$$\xrightarrow[\substack{\Delta H\ to\\split\ Br_2}]{Br_2} \quad H_3C-\underset{\underset{Br}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$$

> 99%
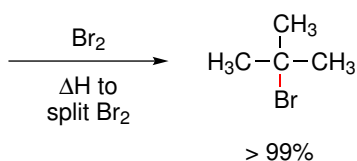
With Cl_2 the reaction is regioselective meaning that there is a preference for one regiosomer rather than the others.

$$\xrightarrow[\substack{h\nu\\fast}]{Cl_2}$$

63%
(should be 90%)   37%
(should be 10%)

These regio effects occur because the chlorine is much more reactive and hence less discriminating in hydrogen abstraction than the brome atom (more electronegative). One $H-Cl$ bond formed for Cl is -431 kJmol^{-1} and for Br is -366 kJmol^{-1} and the tertiary C-H bond requires +397 kJmol^{-1} to break. Hence with Cl the reaction is exothermic and with Br it is endothermic meaning the bromine reaction requires energy, this in turn makes the reaction more discriminating.
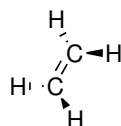
Breaking one primary bond needs +423 kJmol^{-1} and therefore, as reactions follow the path of least energy and the order of radical stability is $3° > 2° > 1°$, the reaction proceeds above.

2 Alkenes

2.1 General

General formula: C_nH_{2n}
Ethene has a planar framework of atoms

Tye carbon atoms have 3 sp³ hybrid atom orbitals using the 2s and only 2 of the 2p orbitals) which lie in the xy plane orientated at 120° relative to each other. The C−H σ bonds are formed by overlap of the sp² hybrids on carbon and the 1s on hydrogen, the C−C σ bond is then constructed using the remaining sp² orbitals. The weaker π bond is constructed using sideways overlap of the reaming 2pz on each carbon atom.

The chemistry of alkenes is dominated by the ability of the 2π electrons to donate themselves, i.e. function as a nucleophile. Geometrical isomerism occurs due to restricted rotation about the C=C. The Z isomer is when the larger products are on the same side (cis) and E is when they are on opposite sides (trans).

2.2 Reactions of Alkenes

Due to the ability of the π cloud to donate 2 electrons, electrophilic addition to alkenes is a wide ranging and general series of reactions. For a reagent of the form $E^{\delta+}-Y^{\delta-}$ the following mechanism can be written.
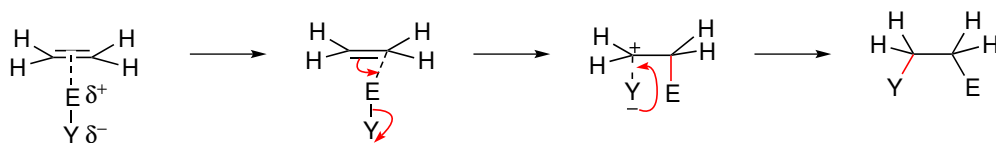
First the there is complex formation with the polarization and lengthening of the E−Y bond followed by the formation of the C−E bond and breakage of the E−Y bond. Finally nucleophilic capture occurs with the reactive carbocation intermediate.
Some useful reagents are:

- Br_2

- H−Cl, H−Br. H−X etc.

- H_3O - acid

- $Br-OH$ - hypobromous acid (or from fromation of borohydrin via H_2O/Br_2)

- $Ph-S^{\delta+}-Cl^{\delta-}$ - sulfenylation

Electrophilic additions to unsymmetrical alkenes are regiospecific (only one regioisomer formed). This method of addition was first noted in 1870 by Markovnikov and is stated as an empirical rule – markovnikov's rule. This is because addition always occurs via the lower energy carbocation.
E.g.

not formed
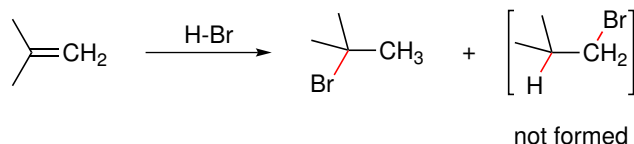
When the component E of the reagent $E^{\delta+}-Y^{\delta-}$ posseses lone pairs of electrons, reactions are also sterospecific (only one sterioisomer formed).
E.g. Addition of bromine to Z and E-but-2-ene.
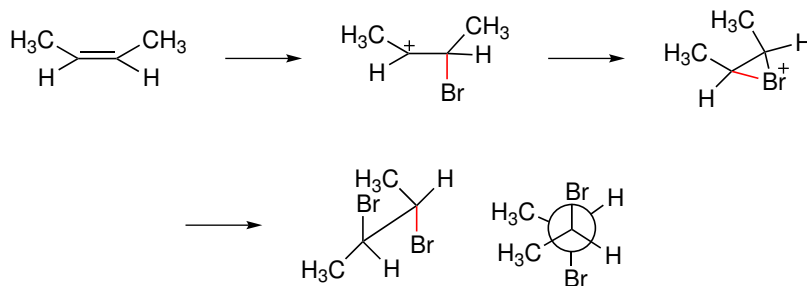
The opening of the bromonium cation occurs by nucleophilic attack from the least hindered opposite face (antiperiplanar position). Overall the reaction is a trans (or anti) electrophilic addition. Similarly the reaction of E-but-2-ene gives a different diasteroisomer.
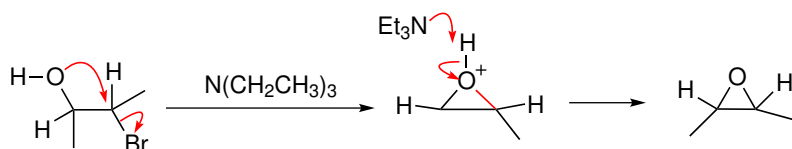Other examples of bridged intermediates that form stereospecific compounds are:

Some reactions are both regio and stereospecific. E.g. BrOH
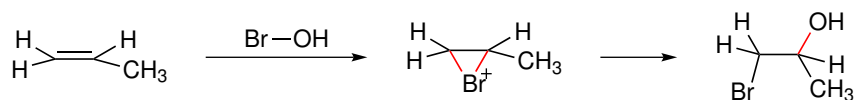
Bromohydrins are used in the preparation of epoxides. E.g.

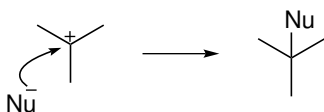Hydration can also occur via acetomercuration to form an alcohol (see section 1) and either $NaBH_4$ or NaOH can be used as bases to remove the final Hg$-$OAc.
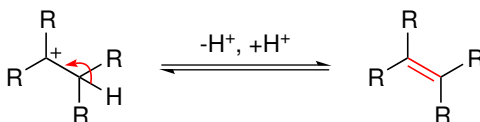
2.2.1   Reactions of Carbocations

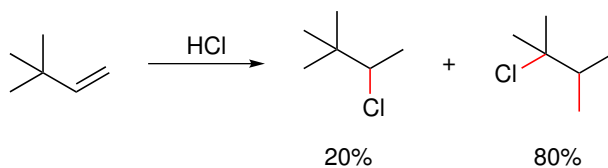Carbocations undergo 3 types of reaction:

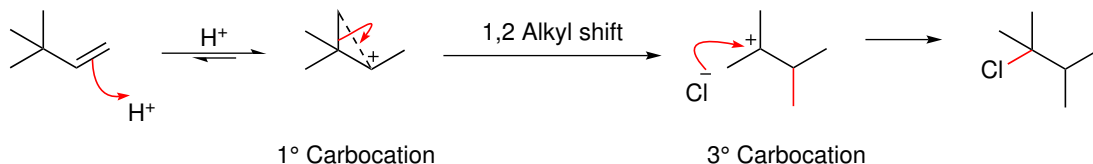a) Capture by a nucleophile

b) Proton loss to give an alkene

c) Carbocation Rearrangement Rearrangement will always occur to give a lower energy carbocation. Examples of rearrangement during electrophilic addition to an alkene are:

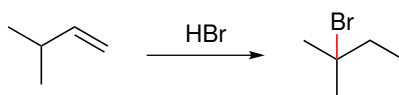   i) Wagner–Meerwein rearrangement involving a 1,2-Alkyl shift

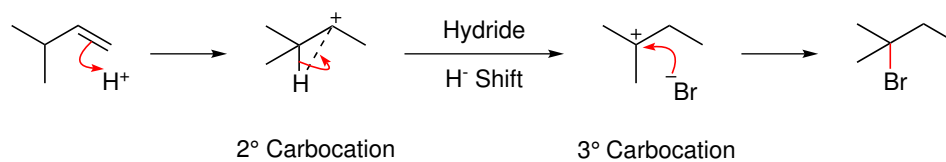20%   80%

Mechanism

1° Carbocation   3° Carbocation

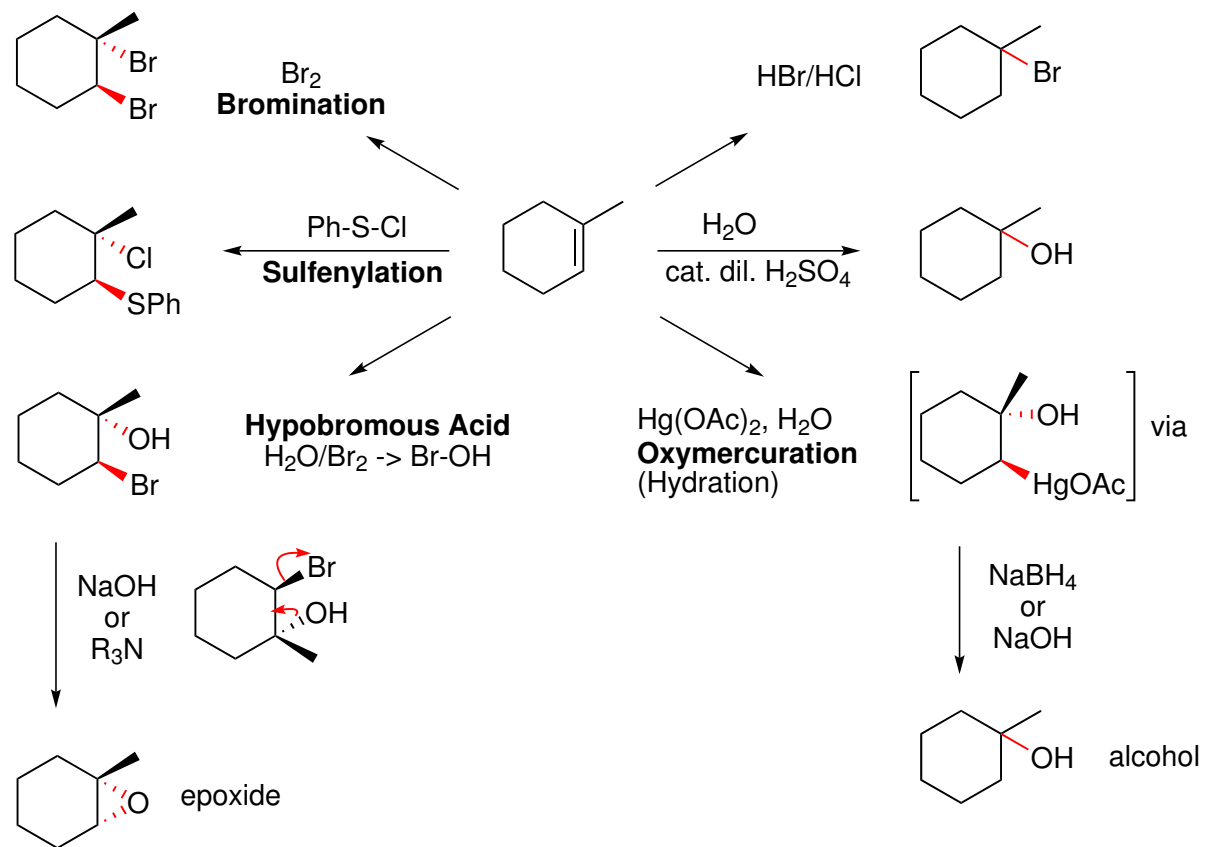ii) Hydride Shift

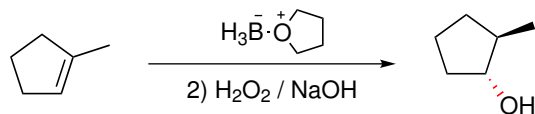Mechanism

2° Carbocation   3° Carbocation

The 1,2 alkyl shift would give the same 2° carbocation and therefore would not be lower in energy.

2.2.2 Summary of all Electrophilic Additions to Alkenes

Br₂
Bromination

Ph-S-Cl
Sulfenylation

HBr/HCl

H₂O
cat. dil. H₂SO₄

Hypobromous Acid
H₂O/Br₂ -> Br-OH

Hg(OAc)₂, H₂O
Oxymercuration
(Hydration)

via

NaOH
or
R₃N

NaBH₄
or
NaOH

epoxide
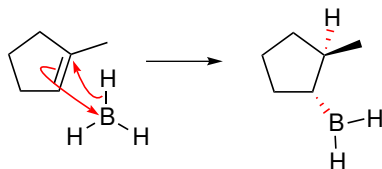
alcohol

2.2.3 Other Alkene Reactions

a) Hydroboration (followed by oxidation) - useful for anti-markovnikov hydration.

Mechanism

Is electron deficient but commercially available as a complex with the ether THF.

This takes place in a syn addition in a concerted way (both bonds are made in the same step). The bond to B is made slightly faster since it is the electrophilic center and the electron deficient atom. This results in the observed regiochemistry.

Each of the remaining B−H bonds also adds across an alkene to give
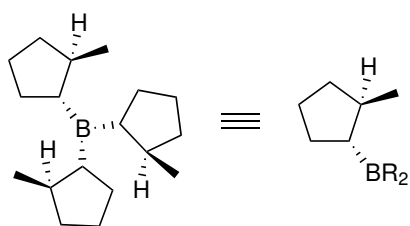
The carbon–boron bond is then replaced by a hydroxyl group with retention of configuration.
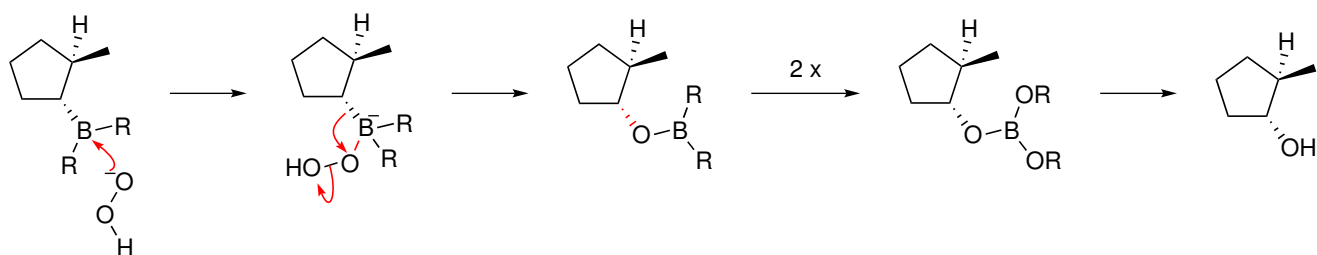
The final step occurs via borate ester hydrolysis