

Preliminaries:

Remember to pick up your quizzes

Oscient: Yawning, gaping from drowsiness; inattentive, dull, negligent

Visual brain power: Human brain is very good at processing pictures

Novel:

Fully developed characters

Motivation for characters

Foreshadowing (for mystery novels; and *all* novels are mysteries

Question everything: Helps you stay engaged as a reader/student
“Is this statement consistent with that statement, or that data?”

To see a world in a grain of sand,
And a heaven in a wild flower,
Hold infinity in the palm of your hand,
And eternity in an hour.

William Blake, *Auguries of Innocence*

You can see all of O-Chem by studying a single type of reaction

Kinetics, thermodynamics, stereochemistry, isotope effect, ...

Miscellaneous

Motivation: No reaction is spontaneous unless it lowers the free energy of the system

Enthalpy: Usually the most important energy term

Gibbs free energy: Sometimes the entropy term becomes very important

Magnitude of entropy term changes with temperature

Arrhenius acid/base: H⁺ and OH⁻

Lowry-Bronsted: proton donor/proton acceptor

Lewis: Electron pair donor/acceptor

Arrhenius equation: $k = A \exp(-E_a/RT)$; or $\ln(k) = -E_a/RT + \ln(A)$

$RT = 592$ calories at room temp (0.6 kcal)

Thermodynamic control implies a dynamic equilibrium, which can only happen if ΔG is not too large.

Beginning with E-Z notation (Cahn-Ingold-Prelog)

First: cis: Mnemonic device: “Z” like Frenchman saying “zis” (zis/cis)

Priority rules for substituents:

Work out from point of attachment till a difference is found;
then evaluate

If an atom with higher atomic number is attached, it wins:
 $\text{Br} > \text{Cl} > \text{S} > \text{O} > \text{N} > \text{C} > \text{H}$

Also, $\text{T} > \text{D} > \text{H}$ (Heavier isotope wins)

Note that a single O will beat even *two* carbons

Otherwise, if more atoms of the same element are *directly* attached to one atom than the other, the more highly substituted atom wins.
E.g., t-butyl > isopropyl > propyl > ethyl.

Only the directly attached atoms count; a long, unbranched alkyl chain will lose to a short, branched one.

Alkene Polarity

Question: Should alkenes have a dipole moment? I.e., should an alkene molecule have partial electrical charges?

Answer: ethylene, no. Symmetric.

Propene: Yes, 0.3 Debye.

Why?

Which way does the dipole point?

How to figure this out?

Answer:

Vinyl chloride: Chlorine is very electronegative;

We expect this molecule to have a dipole moment, with Cl at the negative end of the dipole.

Found: vinyl chloride has dipole moment of 1.4 Debye.

Now, prepare *trans*-1-chloropropene:

Found: dipole moment of 1.7 Debye.

Conclusion: the two dipoles add, so they point in same direction

What can we conclude:

S orbitals are lower energy than p orbitals, which means the energy of the system is lowered more by putting electrons into s orbitals than into p orbitals.

This effectively means that s orbitals are more electronegative than p orbitals.

An sp² orbital has 1/3 s character, and 2/3 p whereas an sp³ orbital has only 1/4 s character and 3/4 p.

Result: sp² orbitals are more electronegative than sp³.

Result: sp² carbons bonded to sp³ carbons will withdraw some electron density from the sp³ atoms.

Alkenes are sp² hybridized: The sp³ carbons contribute electron density by induction and hyperconjugation.

Hyperconjugation is important for carbocations, but less important for alkenes, because for the latter, it requires *sacrificial hyperconjugation*. (“Sacrificial” because a sigma bond is sacrificed.)

Stability of alkenes (lower energy is more stable)

Considering the isomers of butane (four in all):

Which would we expect to be lower energy, and why?

(Also, how can we measure stability?)

(A: Heat of combustion)

(A: Heat of hydrogenation)

The problem:

Electronegativity of sp^2 carbons: how to satisfy this?

Also, steric considerations can affect stability (steric interference).

Heat of combustion data

Starting with several isomers, combusting them with O₂ produces the same products in each case, so differences in heat (energy) released reflect differences in the energy content of the isomers being combusted. This is assumed to be mostly due to differences in stability of the double bond, but in fact includes small differences due to differences in the alkyl chains.

Heat of Hydrogenation data

Since the only change that occurs is at the site of the double bond, this method should not include contributions due to differences at other parts of the isomers being compared.

Also, heats of hydrogenation are smaller than heats of combustion, so we are subtracting small numbers to look for small differences, rather than subtracting large numbers to look for small differences, as in heat of combustion data.

Still, the methods show remarkably good agreement.

From bond strength data, we can make a good estimate of what to expect for heat of hydrogenation of one double bond: about 30 kcal/mol

Bond	Strength (kcal/mol)	
C—H	-98	
H—H	-104	
C=C	-145	sigma plus pi
C—C	-83	sigma
Subtract to get		
C~C	-62	pi

We give up $-(62+104) = -166$ in broken bonds

We gain $-(2 \times 98) = -196$ kcal in newly formed bonds

Net effect: system is 30 kcal more stable after hydrogenation

Steric effects of more bulky substituents

Cycloalkenes

Elimination reactions of alkanes (and substituted alkanes)
("Beta elimination reactions", or "1,2 elimination reactions")
Dehydrogenation (at high T, 750C)
Enthalpy is bad; entropy drives this

Dehydration of alcohols (acid catalyzed) (first look)

Dehydrohalogenation (consumes base) (first look)

Called E1 and E2 reactions: E for elimination; 1 or 2 for reaction order

Dehydration of alcohols (acid catalyzed) (closer look)

Mechanism(s): (E1)

Surprise results from E1 dehydration of alcohols

How can alkyl shifts and hydride shifts occur?

Carbocation stability

Regioselectivity: The Zaitsev rule

Regioselective: Reaction can make more than one different constitutional isomers (connectedness order of atoms), but is observed to favor certain isomers. I.e., the product mix does not appear to be the result of chance.

Regioselectivity: The Zaitsev rule (continued)

Zaitsev: “Predominant product is formed by removing an H from the beta carbon having the fewest H’s.”

Descriptive and predictive, but not very illuminating as to *why*.

Now: “Predominant product will be the most highly substituted” or “most stable.”

Why? More substitution → greater stability, so this makes sense.

But there’s a catch: That is a thermodynamic argument.

To be valid, it would require that the system be a dynamic thermodynamic equilibrium, which requires that ΔG be small enough that any product that “took the wrong path” can back up and “try again”.

But for this reaction, ΔG is too large; it is not reversible, so it must be the case that the outcome is under kinetic control.

Kinetic control

Kinetic control means that the outcome (the product ratio) is controlled by $\Delta\Delta G^\ddagger$ for the different paths that involve different TS's.

The difference in the ΔG 's controls the product ratio.
It is a little harder – and less likely – to form the higher energy TS.

Probably the TS resembles the product enough that the TS of the more stable product is also the more stable TS.

This is not always the case:

Sometimes a less stable product dominates because of kinetic control.

Stereoselectivity in E1 dehydration of alcohols

Stereoselective means that more than one stereoisomer (orientation in space, with significant energy barrier to interconversion – not just conformers) could result from a reaction, but one or more appear to be favored. (Non-random results.)

Dehydration of alcohols tends to favor the more stable stereoisomer. This is not surprising, but again we'd better be careful to not oversimplify our analysis of why.

The answer in this case appears to be that the more stable conformer in the reactants leads to the more stable product.

Dehydrohalogenation (closer look)

Mechanism(s): (E2)

Stereoselectivity (E2 dehydrohalogenation)

Using isotope effects to “prove” E2 dehydrohalogenation mechanism

Dehydration of alcohols (acid catalyzed) (closer look)

Mechanism(s): (E2)

Dehydrohalogenation (closer look)

Mechanism(s): (E1)