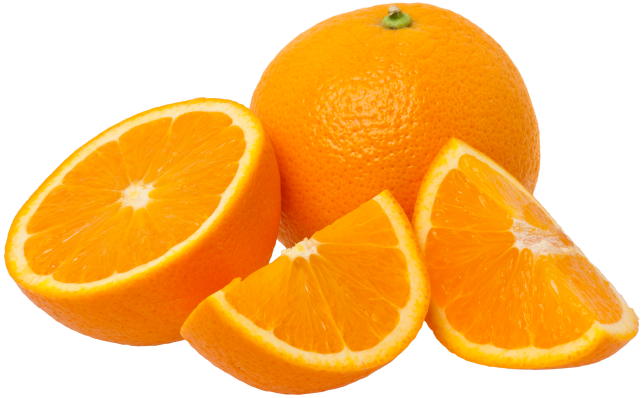
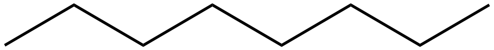
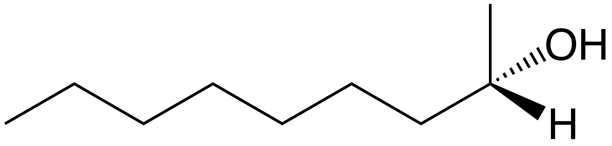
Chapter 3: Alkane Properties, Introduction to Organic Functional Groups and Stereochemistry





octane



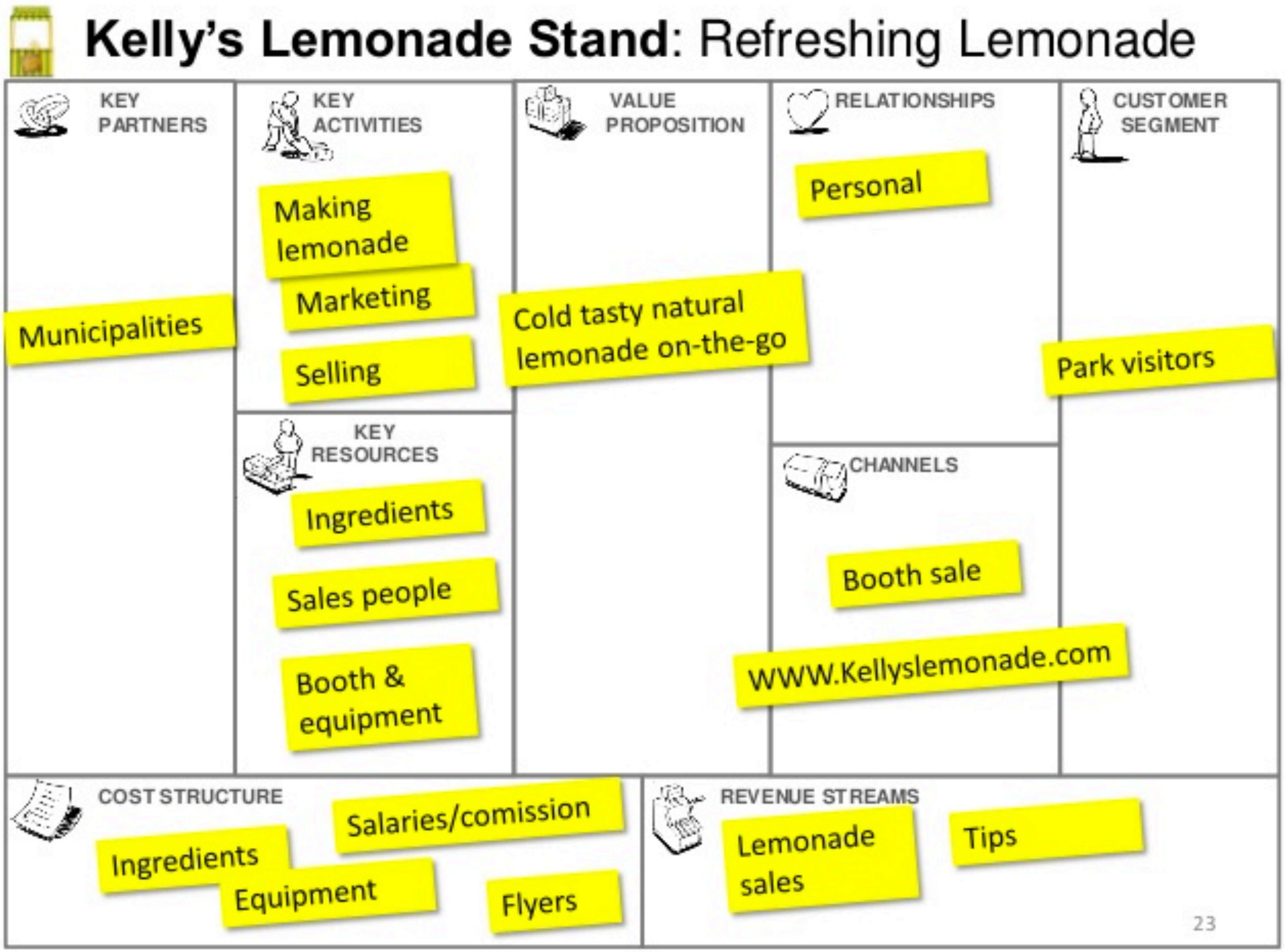
(*S*)-nonan-2-ol

Outline

- The Language of Chemistry
- Common Functional Groups in Organic Chemistry
- Physical properties and trends of alkanes
- Nomenclature of alkanes and cycloalkanes
- Stereochemistry and Isomers
  - Constitutional isomers, cis-trans isomers
- Conformational analysis
- Newman Projections

“Knowing the Lingo”

…when talking business, among experts, or clients



Kelly’s Lemonade Stand: Refreshing Lemonade

KEY PARTNERS
- Municipalities

KEY ACTIVITIES
- Making lemonade
- Marketing
- Selling

KEY RESOURCES
- Ingredients
- Sales people
- Booth & equipment

VALUE PROPOSITION
- Cold tasty natural lemonade on-the-go

RELATIONSHIPS
- Personal

CHANNELS
- Booth sale
- WWW.Kellyslemonade.com

CUSTOMER SEGMENT
- Park visitors

COST STRUCTURE
- Ingredients
- Equipment
- Salaries/comission
- Flyers

REVENUE STREAMS
- Lemonade sales
- Tips

23

Business Model Canvas - Alexander Osterwalder

Specialized Language – practice makes perfect

B2B or (Business-to-Business)
Companies doing business with each other such as manufacturers selling to distributors and wholesalers selling to retailers. Pricing is based on quantity of order and is often negotiable.

B2C or (Business-to-Consumer)
Businesses selling to the general public typically through catalogs utilizing shopping cart software.

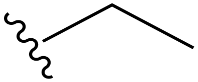
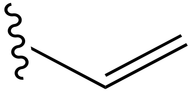
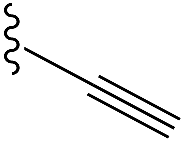
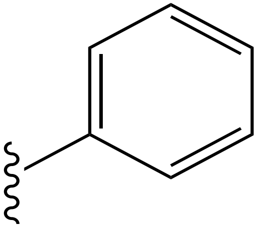
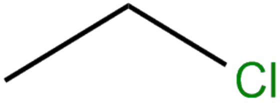
C2B or (Consumer-to-Business)
A consumer posts his project with a set budget online and within hours companies review the consumer's requirements and bid on the project. The consumer reviews the bids and selects the company that will complete the project.

C2C or (Consumer-to-Consumer)
There are many sites offering free classifieds, auctions, and forums where individuals can buy and sell thanks to online payment systems like PayPal where people can send and receive money online with ease.

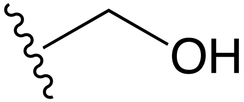
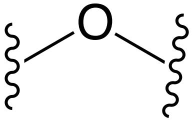
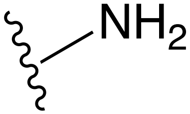
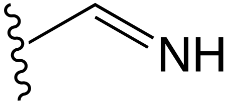
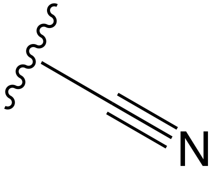
G2G or (Government-to-Government)
G2E or (Government-to-Employee)
G2B or (Government-to-Business)
B2G or (Business-to-Government)
C2G or (Citizen-to-Government)
The last five acronyms represent other forms of e-commerce that involve transactions with the government. Other acronyms have a high degree of specialization; non specialists cannot decode them. For example:

SEO- Search Engine Optimization
EDI- Electronic Data Interchange
PPA- Pay per Action
PPC- Pay per Click

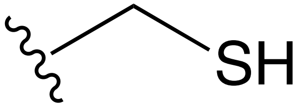
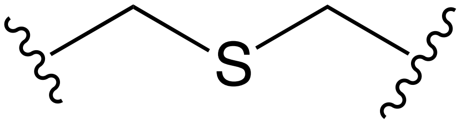
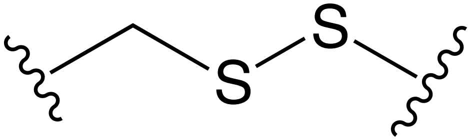
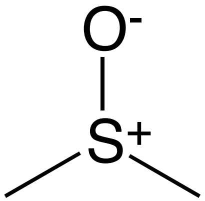
Organic Functional Group I

Structure	**Functional Group**	**Name ending**
	alkane	*none*
	alkene	*-ene*
	alkyne	*-yne*
	arene	*none*
	halide	alkane name e.g. chloroethane

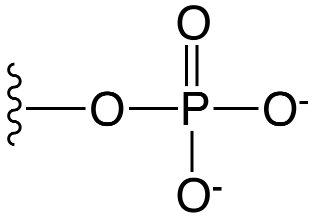
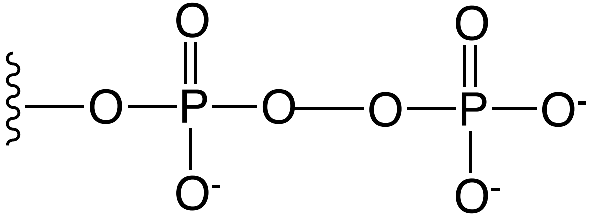
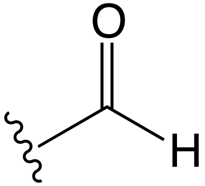
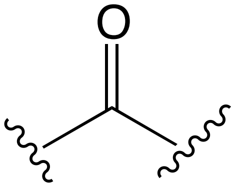
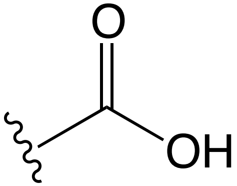
Organic Functional Group II

Structure	**Functional Group**	**Name ending**
	alcohol	*-ol*
	ether	*ether*
	amine	*-amine*
	imine (aka Schiff base)	*none*
	nitrile	*-nitrile*

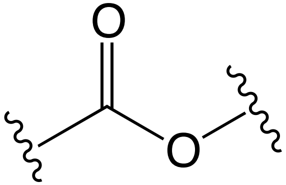
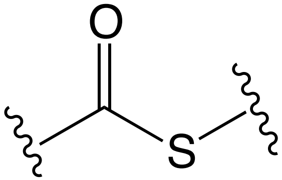
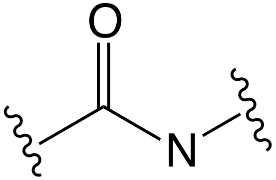
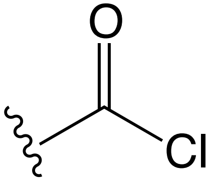
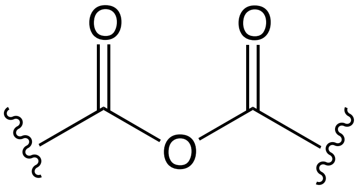
Organic Functional Group III

Structure	**Functional Group**	**Name ending**
	thiol	*-thiol*
	sulfide	*sulfide*
	disulfide	*-disulfide*
	sulfoxide	*sulfoxide*

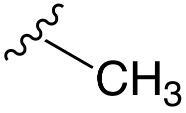
Organic Functional Group IV

Structure	**Functional Group**	**Name ending**
	monophosphate	*phosphate*
	diphosphate	*diphosphate*
	aldehyde	*-al*
	ketone	*-one*
	carboxylic acid	*-oic acid*

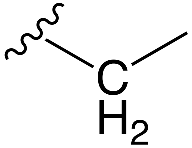
Organic Functional Group V

Structure	**Functional Group**	**Name ending**
	ester	*-oate*
	thioester	*-thioate*
	amide	*-amide*
	acid chloride	*-oyl chloride*
	carboxylic acid anhydride	*-oic anhydride*

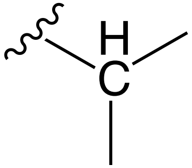
Hydrocarbon Connectivity



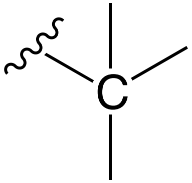
Primary (1°) carbon atom (methyl)



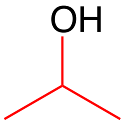
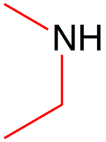
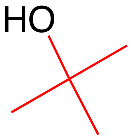
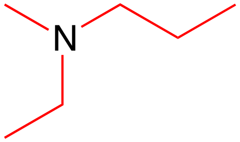
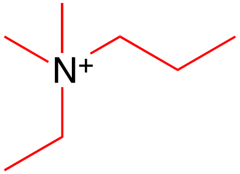
Secondary (2°) carbon atom (methylene)



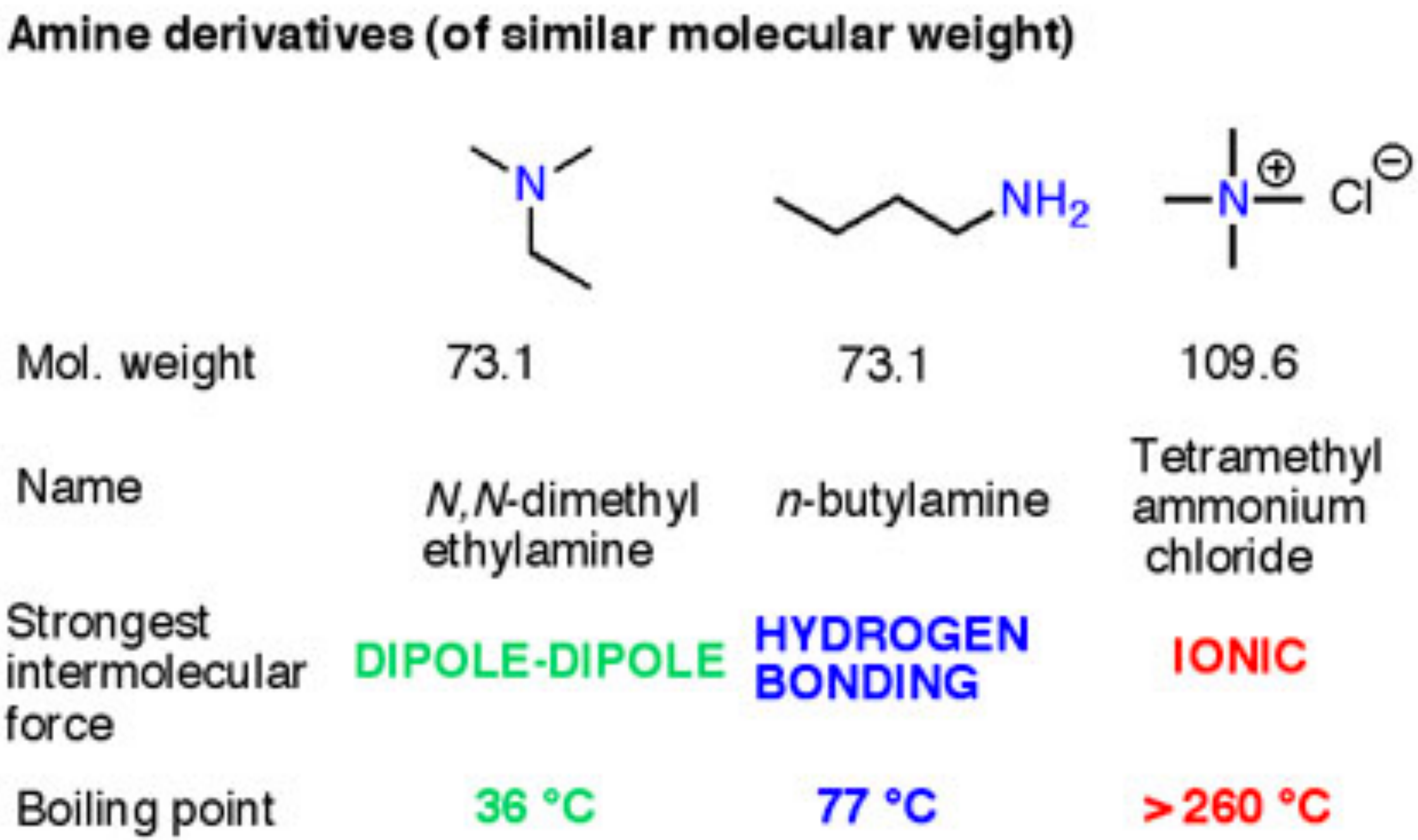
Tertiary (3°) carbon atom (methine)



Quaternary (4°) carbon atom

	Alcohols	**Amines**
Primary		
common name	butanol	*N*-butylamine
IUPAC name	butan-1-ol	butan-1-amine
Secondary		
common name	isopropanol	*N*-methylethylamine
IUPAC name	(propan-2-ol)	*N*-methylethylamine
Tertiary		
common name	isobutanol	*N*-ethylmethylpropylamine
IUPAC name	2-methylpropan-2-ol	*N*-ethyl-*N*-methylpropan-1-amine
Quaternary	Cannot have quaternary alcohols	
common name		*N*-ethyldimethylpropylammonium
IUPAC name		*N*-ethyl-*N*,*N*-dimethylpropan-1-aminium

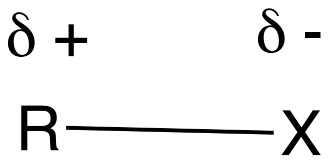
Intermolecular forces of alkyl amines



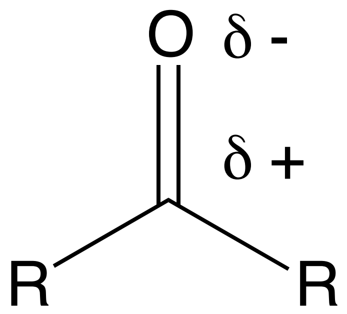
Amine derivatives (of similar molecular weight)

Mol. weight	73.1	73.1	109.6
Name	*N,N*-dimethyl ethylamine	*n*-butylamine	Tetramethyl ammonium chloride
Strongest intermolecular force	DIPOLE-DIPOLE	HYDROGEN BONDING	IONIC
Boiling point	36 °C	77 °C	> 260 °C
Additional intermolecular forces	Van Der Waals	Van Der Waals Dipole-Dipole	Van Der Waals Dipole-Dipole

Functional Group Polarity

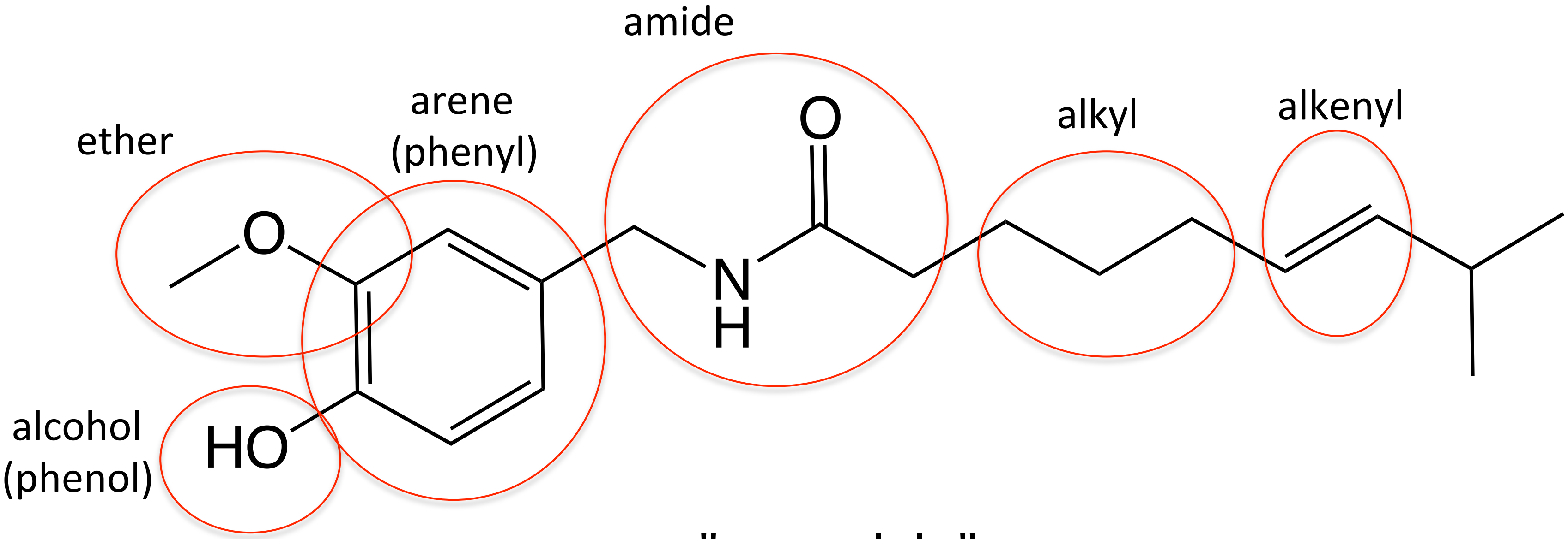


R = alkyl
X = halogen, O, N, S, P



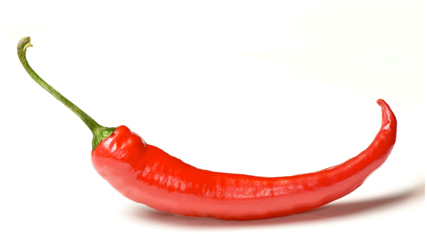
- Polarized bonds
- Carbonyls found in most biomolecules

Multiple functional groups on the same molecule



"capsaicin"

(*E*)-*N*-(4-hydroxy-3-methoxybenzyl)-8-methylnon-6-enamide



Alkanes

- Simplest family of organic compounds (C and H only)
- "Alkyl" prefix (e.g. alkyl halide, alkyl group)
- Fully ***saturated*** (C_nH_{2n+2}), Free rotation around C-C bonds
- aka paraffins/waxes: From the Latin "parum affinis" meaning "little affinity" [for other substances]. "Aliphatic" Greek = "fat"
- Relatively unreactive - not involved in biochemistry of living organisms
- Useful for introductory topics such as ***nomenclature*** and ***stereochemistry***
- Physical properties are often functions of "carbon chain length" (i.e. boiling point, melting point, density, number of ***isomers***)
- No dipole moment in "straight chain" alkane molecules
- Thus, the only intermolecular forces present are Van Der Waals forces (London Dispersion Forces)
- Often used as heating and transportation fuels (e.g. propane, gasoline, diesel) *via* exothermic ***combustion reactions*** with oxygen
- Have different energetic value depending on density, chain length, degree of oxidation

The “alkyl group”

Remove H from alkane, then name the group

(e.g. CH_4 – H = CH_3 - a “methyl” group)

Other common examples:

Ethyl (CH_3CH_2-) = ethyl alcohol (aka ethanol)

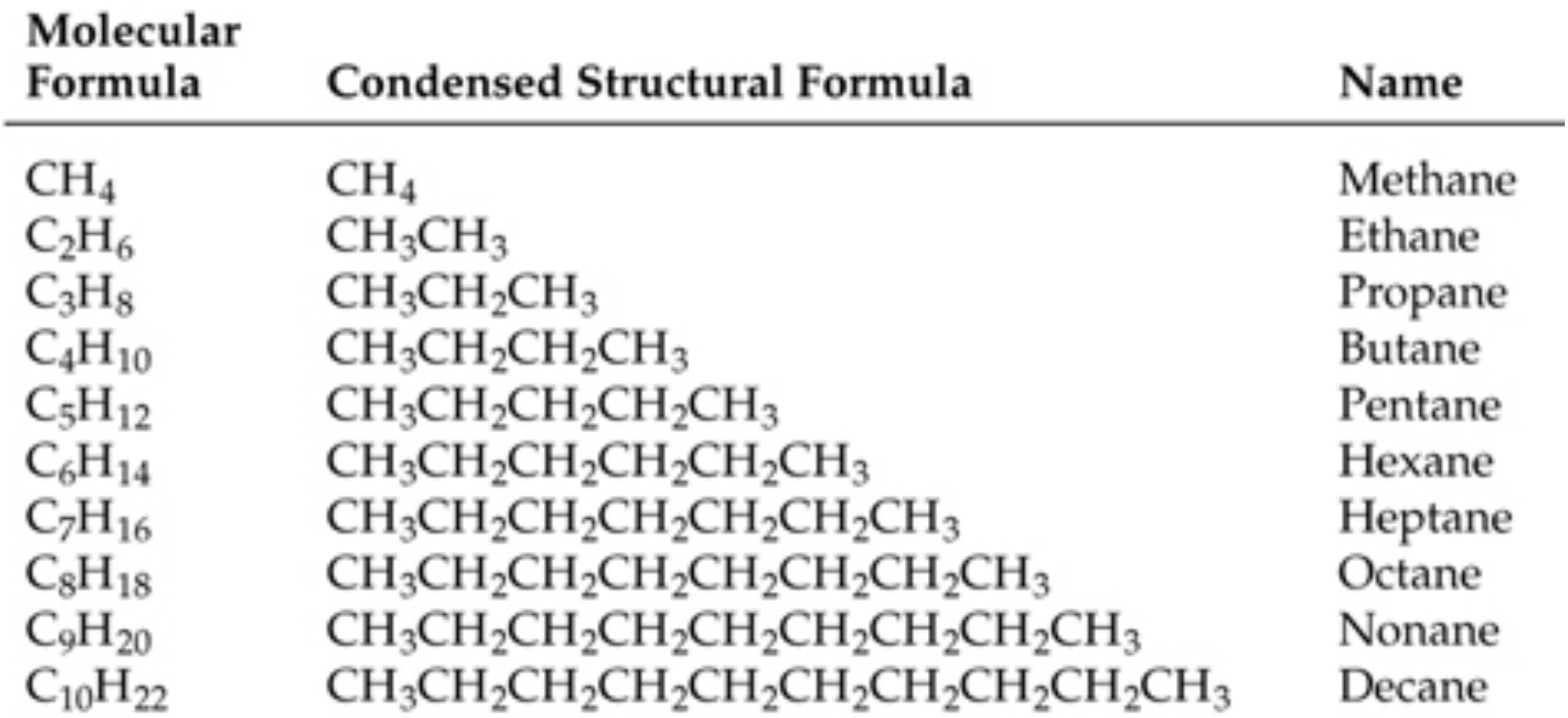
= ethylamine, ethyl ester…

Propyl: $CH_3CH_2CH_2$

Butyl: $CH_3CH_2CH_2CH_2$

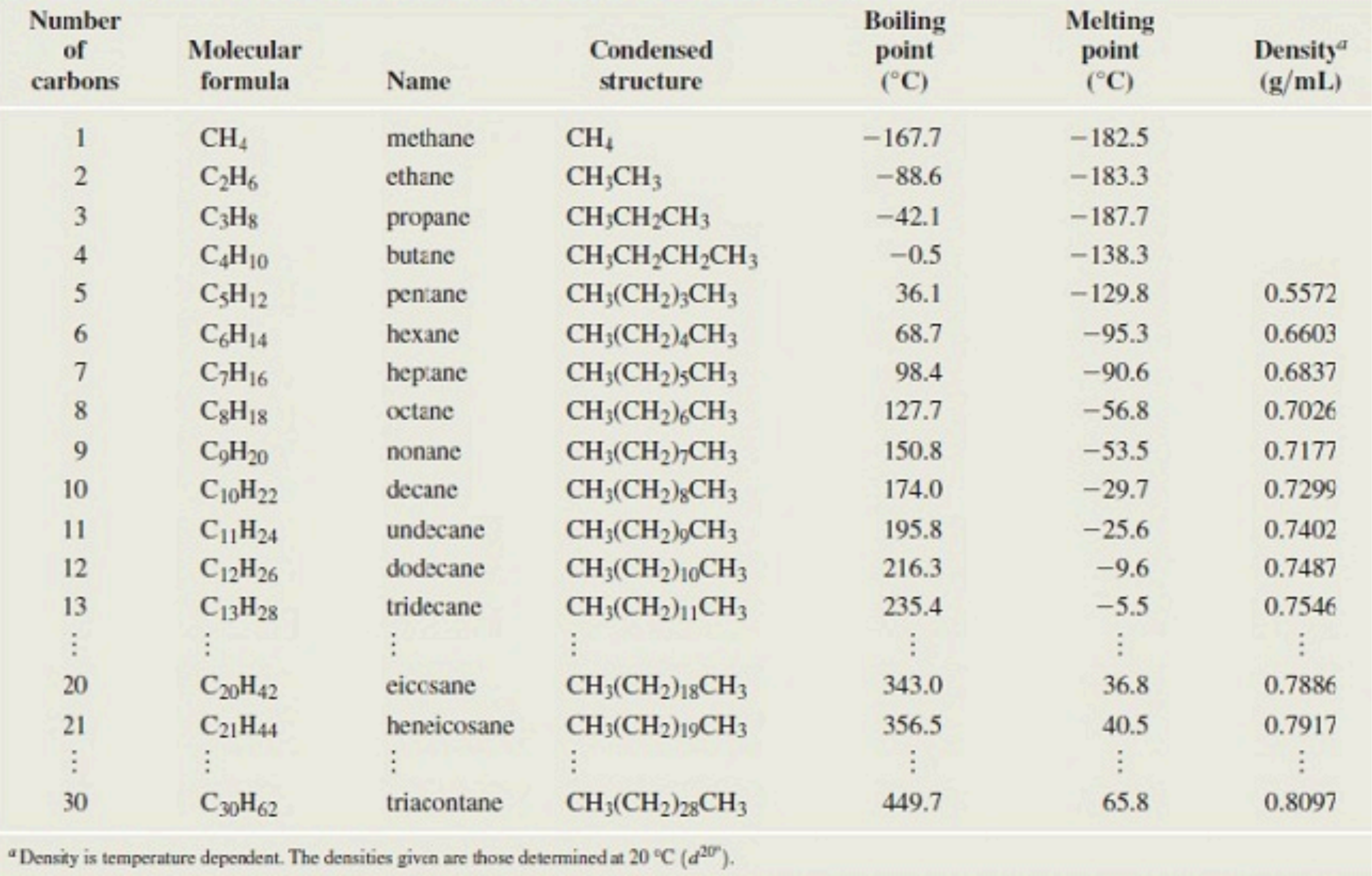
Pentyl (or “amyl”): $CH_3CH_2CH_2CH_2CH_2$

First 10 straight chain alkanes



Molecular Formula	Condensed Structural Formula	Name
CH_4	CH_4	Methane
C_2H_6	CH_3CH_3	Ethane
C_3H_8	$CH_3CH_2CH_3$	Propane
C_4H_{10}	$CH_3CH_2CH_2CH_3$	Butane
C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$	Pentane
C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$	Hexane
C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	Heptane
C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Octane
C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Nonane
$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Decane

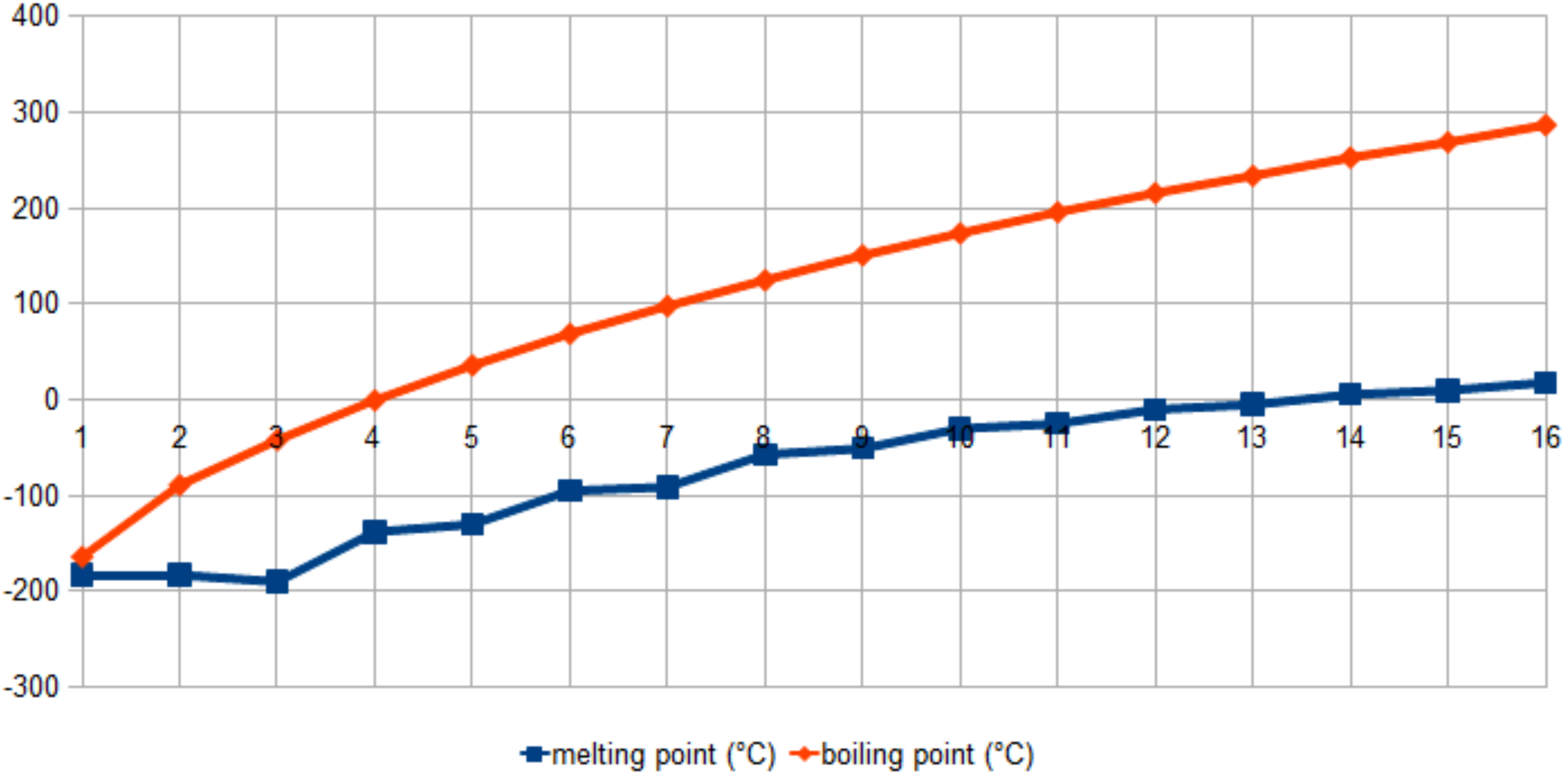
Physical properties of alkanes as a function of carbon chain length



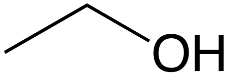
Number of carbons	Molecular formula	Name	Condensed structure	Boiling point (°C)	Melting point (°C)	Density[a] (g/mL)
1	CH_4	methane	CH_4	−167.7	−182.5	
2	C_2H_6	ethane	CH_3CH_3	−88.6	−183.3	
3	C_3H_8	propane	$CH_3CH_2CH_3$	−42.1	−187.7	
4	C_4H_{10}	butane	$CH_3CH_2CH_2CH_3$	−0.5	−138.3	
5	C_5H_{12}	pentane	$CH_3(CH_2)_3CH_3$	36.1	−129.8	0.5572
6	C_6H_{14}	hexane	$CH_3(CH_2)_4CH_3$	68.7	−95.3	0.6603
7	C_7H_{16}	heptane	$CH_3(CH_2)_5CH_3$	98.4	−90.6	0.6837
8	C_8H_{18}	octane	$CH_3(CH_2)_6CH_3$	127.7	−56.8	0.7026
9	C_9H_{20}	nonane	$CH_3(CH_2)_7CH_3$	150.8	−53.5	0.7177
10	$C_{10}H_{22}$	decane	$CH_3(CH_2)_8CH_3$	174.0	−29.7	0.7299
11	$C_{11}H_{24}$	undecane	$CH_3(CH_2)_9CH_3$	195.8	−25.6	0.7402
12	$C_{12}H_{26}$	dodecane	$CH_3(CH_2)_{10}CH_3$	216.3	−9.6	0.7487
13	$C_{13}H_{28}$	tridecane	$CH_3(CH_2)_{11}CH_3$	235.4	−5.5	0.7546
⋮	⋮	⋮	⋮	⋮	⋮	⋮
20	$C_{20}H_{42}$	eicosane	$CH_3(CH_2)_{18}CH_3$	343.0	36.8	0.7886
21	$C_{21}H_{44}$	heneicosane	$CH_3(CH_2)_{19}CH_3$	356.5	40.5	0.7917
⋮	⋮	⋮	⋮	⋮	⋮	⋮
30	$C_{30}H_{62}$	triacontane	$CH_3(CH_2)_{28}CH_3$	449.7	65.8	0.8097

[a] Density is temperature dependent. The densities given are those determined at 20 °C ($d^{20°}$).

MP and BP of alkanes



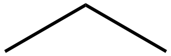
Comparison of Combustion Fuels



$+ \ 3O_2 \longrightarrow 2CO_2 + 3H_2O$

ethanol
(C_2H_6O)

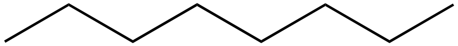
$\Delta H^o = 1368$ kJ/mol = 12,800 BTU/lb



$+ \ 5O_2 \longrightarrow 3CO_2 + 4H_2O$

propane
(C_3H_8)

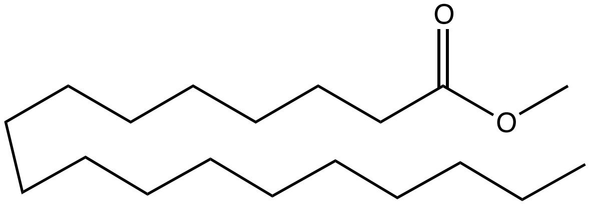
$\Delta H^o = 2220$ kJ/mol = 22,400 BTU/lb



$+ \ 12.5\ O_2 \longrightarrow 8CO_2 + 9H_2O$

octane
(C_8H_{18})

$\Delta H^o = 5460$ kJ/mol = 19,104 BTU/lb (Gasoline = 20,400 BTU/lb)



$+ \ 27.5\ O_2 \longrightarrow 19CO_2 + 19H_2O$

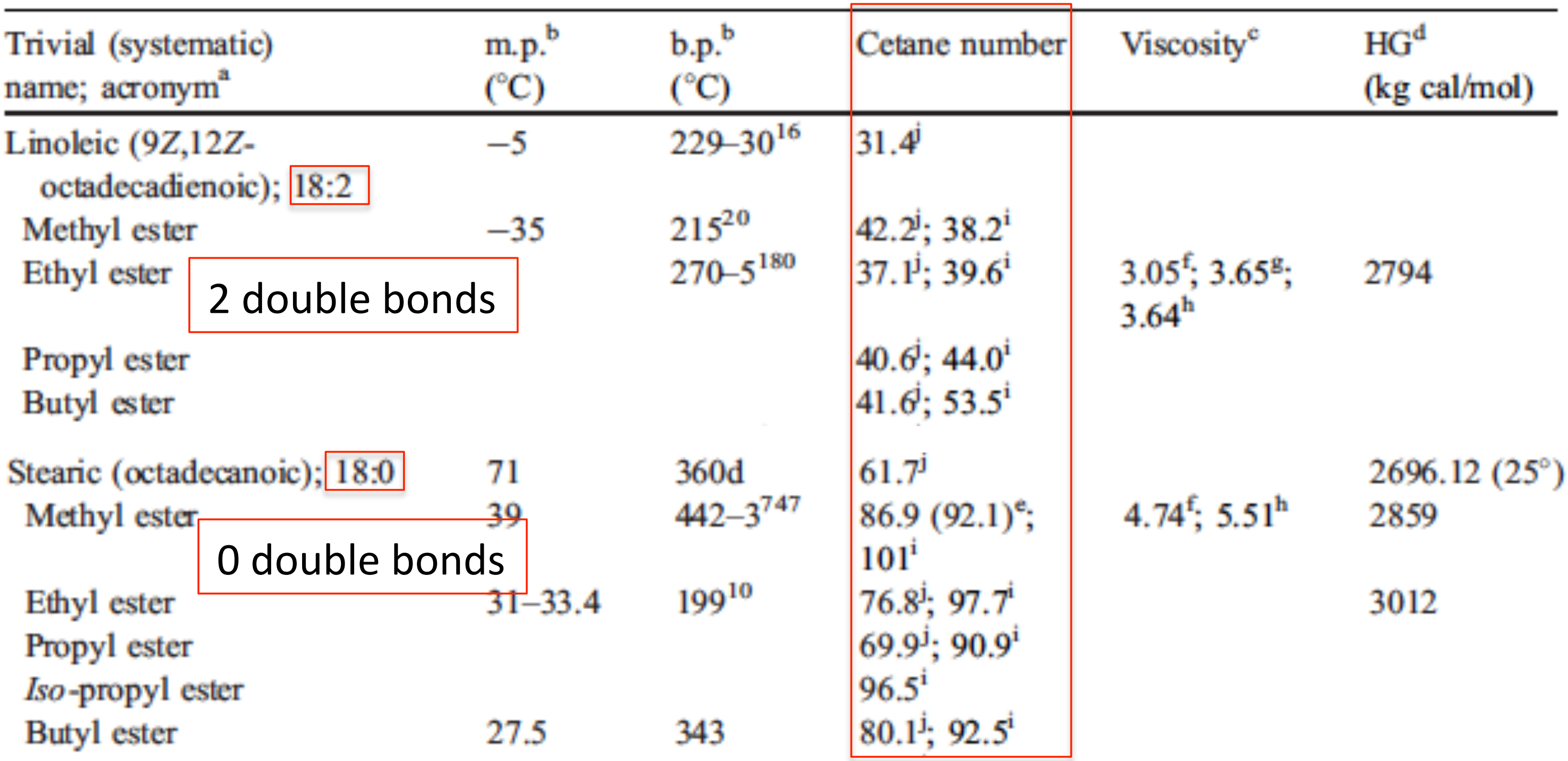
methyl stearate (biodiesel)
($C_{19}H_{38}O_2$)

$\Delta H^o = 9140$ kJ/mol = 19,300 BTU/lb

ΔH^o = Ultra Low Sulfur Diesel = 20,888 BTU/lb

http://www.engineeringtoolbox.com/liquids-densities-d_743.html

Fuel and Emissions Values as Functions of Oxidation (unsaturation) (e.g. VW Diesel and Biodiesel Fuel)



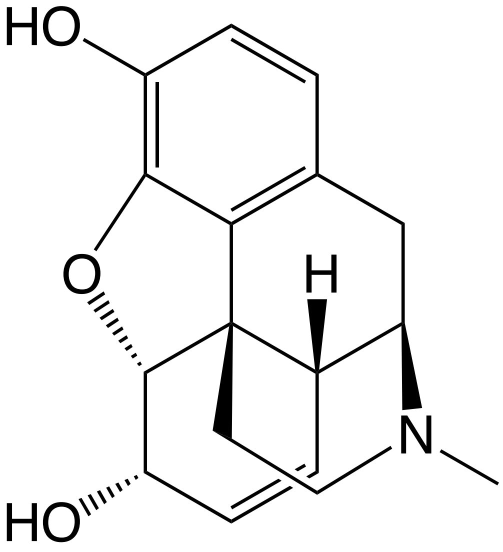
Trivial (systematic) name; acronym[a]	m.p.[b] (°C)	b.p.[b] (°C)	Cetane number	Viscosity[c]	HG[d] (kg cal/mol)
Linoleic (9Z,12Z-octadecadienoic); 18:2	−5	229–30^{16}	31.4[j]		
Methyl ester	−35	215^{20}	42.2[j]; 38.2[i]		
Ethyl ester		270–5^{180}	37.1[j]; 39.6[i]	3.05[f]; 3.65[g]; 3.64[h]	2794
Propyl ester			40.6[j]; 44.0[i]		
Butyl ester			41.6[j]; 53.5[i]		
Stearic (octadecanoic); 18:0	71	360d	61.7[j]		2696.12 (25°)
Methyl ester	39	442–3^{747}	86.9 (92.1)[e]; 101[i]	4.74[f]; 5.51[h]	2859
Ethyl ester	31–33.4	199^{10}	76.8[j]; 97.7[i]		3012
Propyl ester			69.9[j]; 90.9[i]		
Iso-propyl ester			96.5[i]		
Butyl ester	27.5	343	80.1[j]; 92.5[i]		

2 double bonds

0 double bonds

More saturation = higher cetane numbers = Lower NOx emissions
More unsaturation = lower melting point = better “cold start” properties

Naming Organic Compounds



(4*R*,4a*R*,7*S*,7a*R*,12b*S*)-3-methyl-2,3,4,4a,7,7a-hexahydro-1*H*-4,12-methanobenzofuro[3,2-*e*]isoquinoline-7,9-diol

“morphine”

Naming Chemicals with the International Union of Pure and Applied Chemistry (IUPAC) Naming System

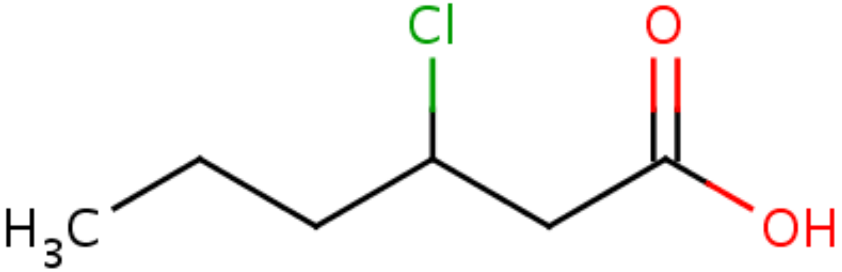
Locant — Prefix — Parent — Suffix

Where are the substituents and ***what*** are the *functional groups*?

What are the substituents?

How many carbons?

What is the primary functional group?



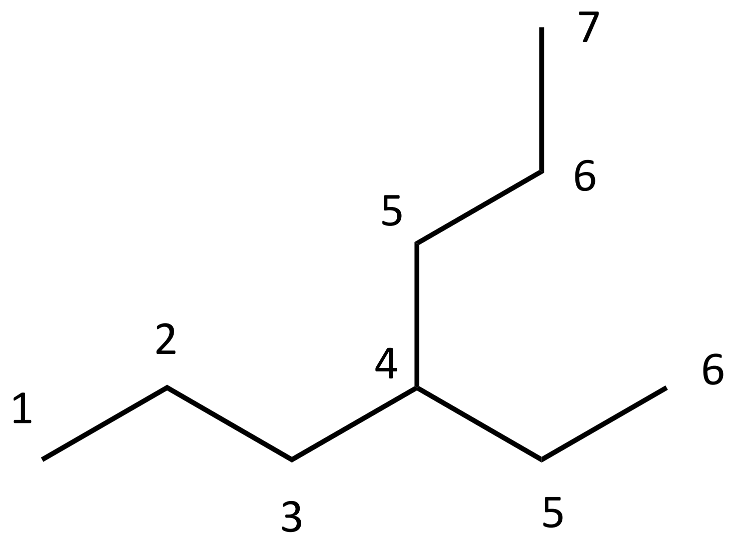
e.g. 3-chlorohexanoic acid

Naming alkanes: The 5 step process

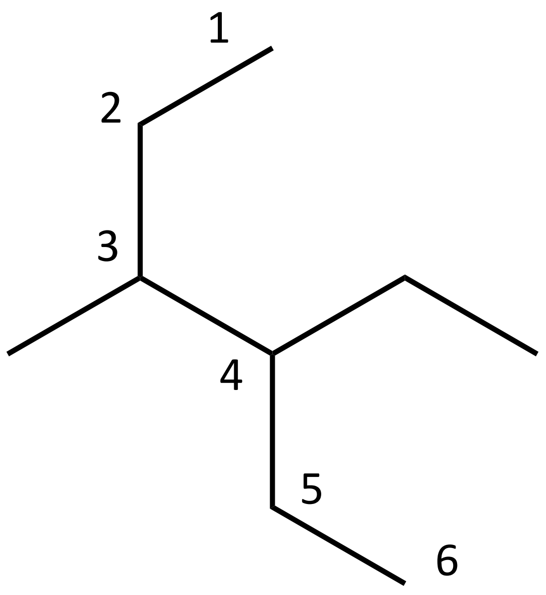
1. Find longest carbon chain
2. Number atoms starting at the end nearest the closest branch point
3. Identify and number the substituents
4. Write name as a single word. Be mindful of hyphens, commas and alphabetization
5. Name complex substituents as if they were individual compounds

1) Find the longest continuous carbon chain

- Don’t be afraid to “turn corners”



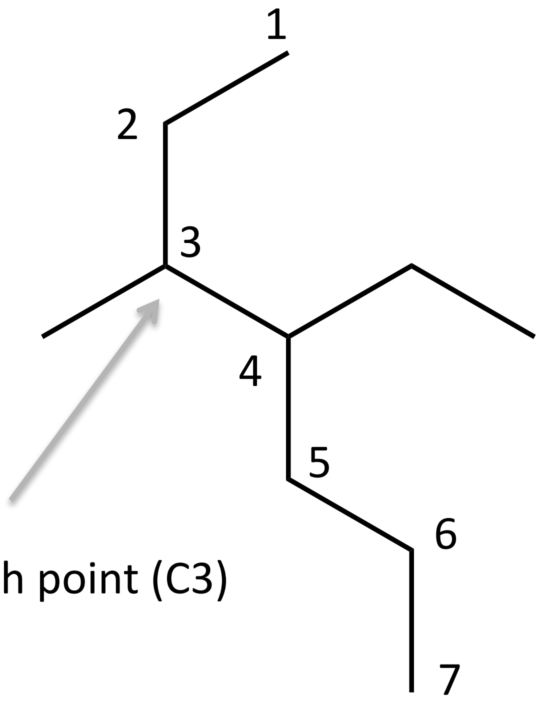
Name as a substituted heptane (C7)



Name as a substituted hexane (C6)

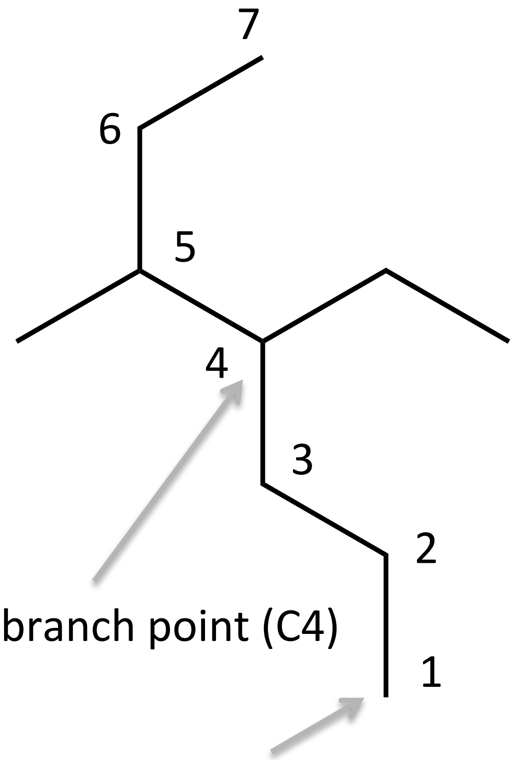
2a) Number the atoms in the longest continuous carbon chain

- Begin at end nearest the first “branch point”



First branch point (C3)

not

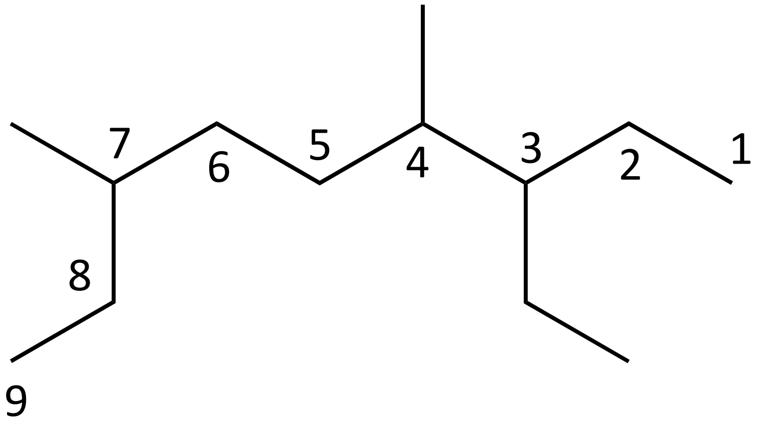


Not first branch point (C4)

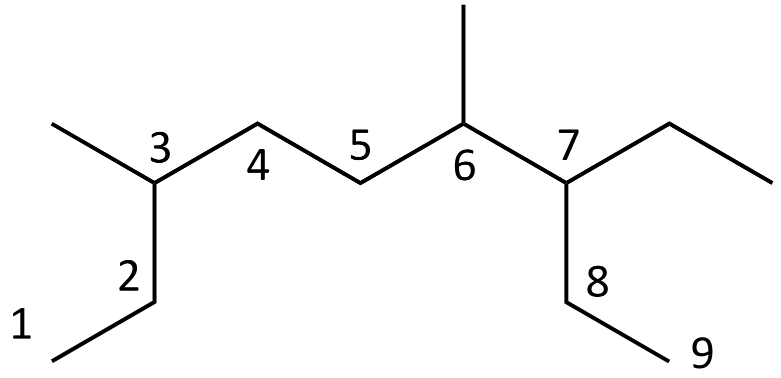
This end not nearest first branch point

2b

- If the branching is equidistant from both ends of the parent chain, begin numbering at the end nearest the second branch point



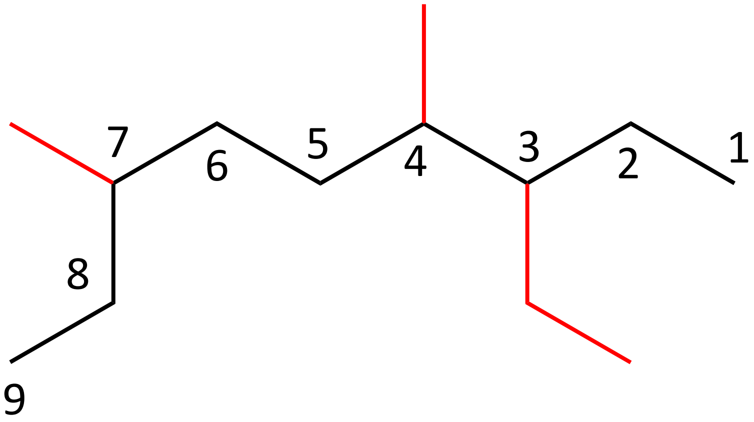
not



3) Identify and number the substituents

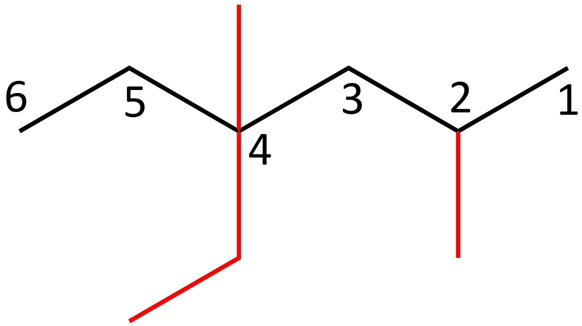
- Assign a number (locant) to each substituent to locate its point of attachment to the parent chain
- If there are two substituents on the same carbon, give them both the same number.
- There must be as many numbers in the name as there are substituents

Examples of substituent numbering



3-ethyl
4-methyl
7-methyl

Name as nonane (C9)

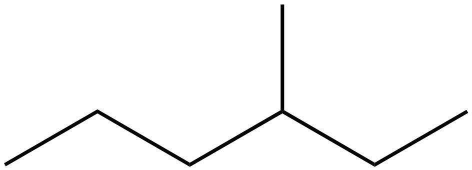


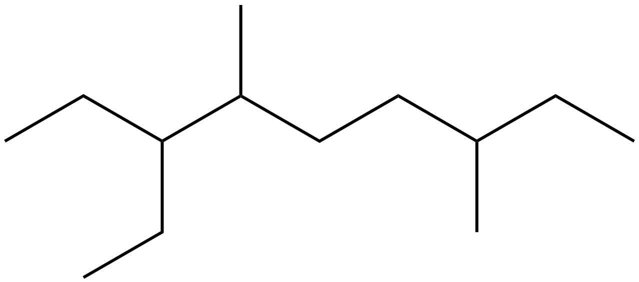
2-methyl
4-methyl
4-ethyl

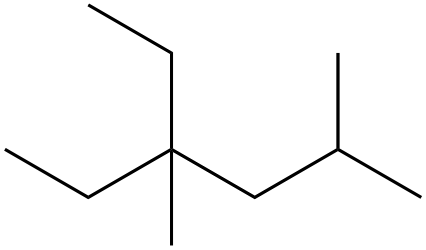
Name as hexane (C6)

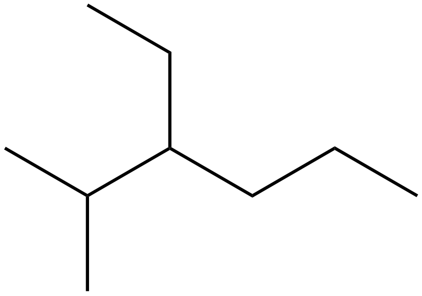
4) Write the name as a single word

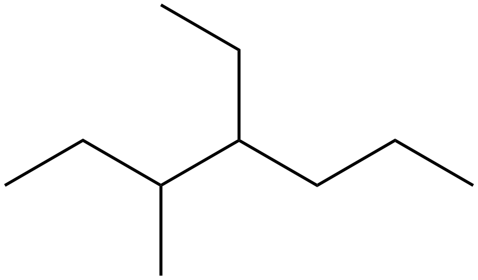
- Use *hyphens* (-) to separate *prefixes*
- Use *commas* (,) to separate *numbers*
- If 2+ different substituents are present, cite them in *alphabetic order*
- If 2+ are present on the parent chain, use one of the multiplier prefixes (di-, tri-, tetra-), but do *not* consider these when alphabetizing.

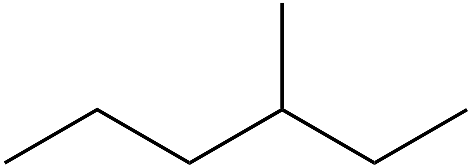




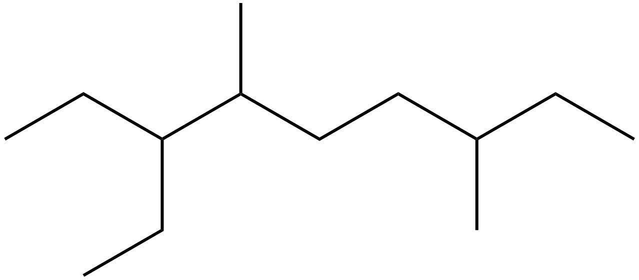






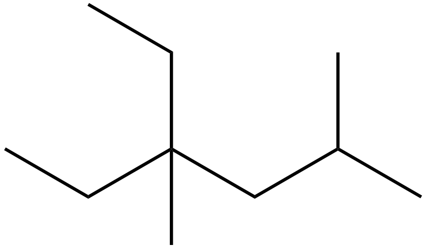


3-methylhexane



3-ethyl-4,7-dimethylnonane

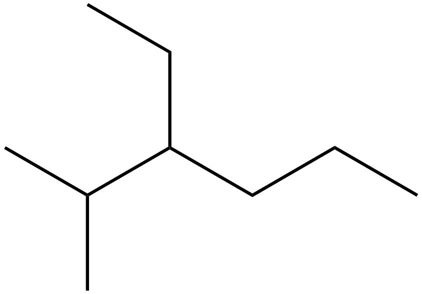
Prefix is *not* prioritized in alphabetization



4-ethyl-2,4-dimethylhexane

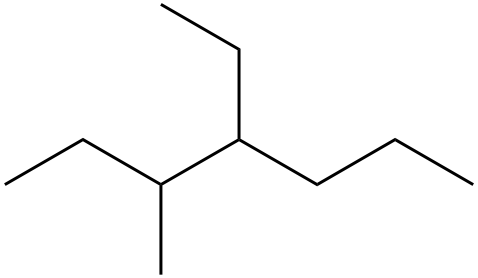
Alphabetization gives naming priority

Prefix is *not* prioritized in alphabetization



3-ethyl-2-methylhexane

Alphabetization gives naming priority



4-ethyl-3-methylheptane

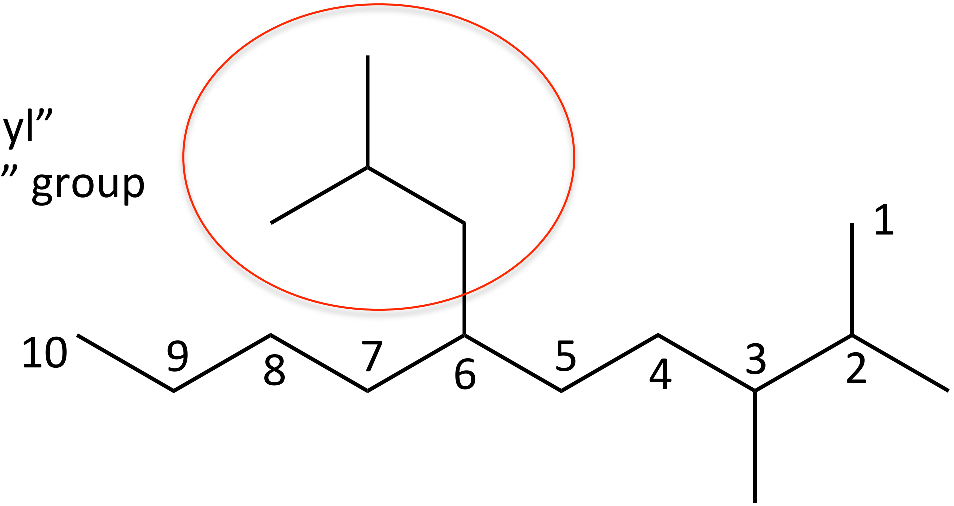
Alphabetization gives naming priority

5) Name a complex substituent as if it were a compound itself

- Name branched substituent beginning at its point of attachment to the main chain and identify it (e.g. “2-methylpropyl” group or an “isobutyl” group)
- Substituents are treated as a whole and alphabetized according to first letter of complete name (including any numerical prefix)
- Set off in parentheses when naming as a whole

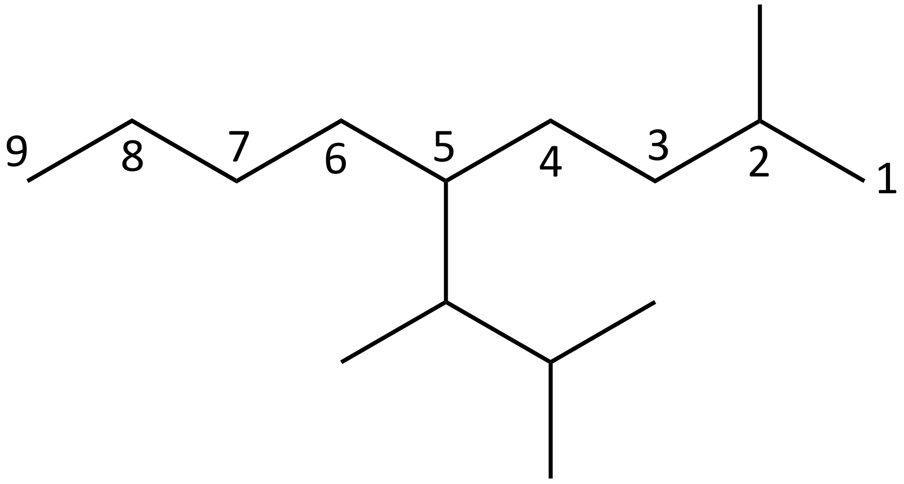
Complex Example 1

“2-methylpropyl”
or an “isobutyl” group



Complex Example 2

1) Find longest carbon chain
2) Number atoms at end nearest to first branch point
3) Identify and number the substituents
   2-methyl and 1,2-dimethylpropyl
4) Write name as single word being mindful of punctuation and alphabetization



5-(1,2-dimethylpropyl)-2-methylnonane

Reminders:

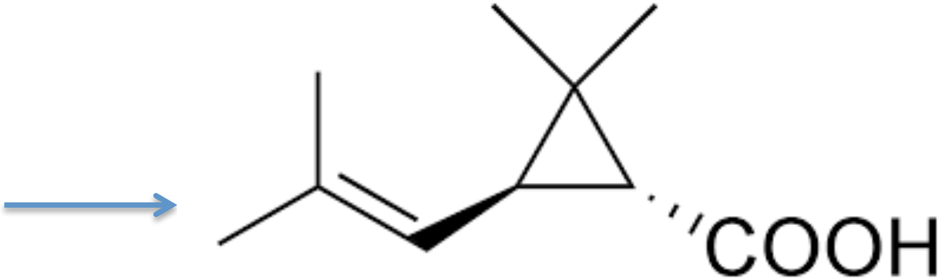
1. Topics and 1 paragraph abstracts for ***Flash-Presentations*** due in 2 weeks (Oct 21). You may consult with me if questions on either. Presentations will be *in class* on Nov 18.
2. Registration (as student) for SED Conference on Nov 20 is <u>mandatory</u>. Visit csebcc.org and follow link
3. Extra Credit opportunity. Chemistry Haiku

w/ English Professor Cross. Publish in "Thesis". Examples.

4. Registration for SEGE – Bucket E Pathways Course. Learning Community with HIS10 Mon/Weds AM Spring 2016

Cycloalkanes

Chrysanthemums (aka “mums”) Kiku Exhibit, NYBG - 2014



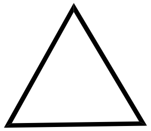
Chrysanthemic acid a natural insecticide containing a “cyclopropane” group

IUPAC Name:

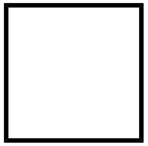
2,2-dimethyl-3-(2-methylprop-1-enyl)cyclopropane-1-carboxylic acid

Cycloalkane chemistry

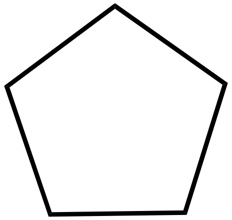
- Saturated cyclic hydrocarbons
- No free rotation around C-C bond
- “alicyclic” = “aliphatic + cyclic”
- $(CH_2)_n$ not C_2H_{2n+2} because 2H lost in cyclization



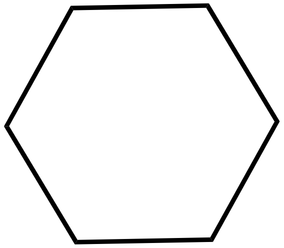
cyclopropane



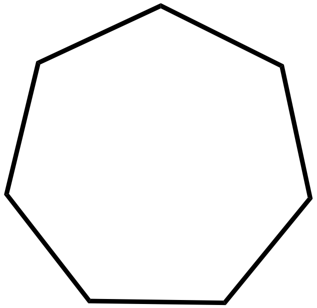
cyclobutane



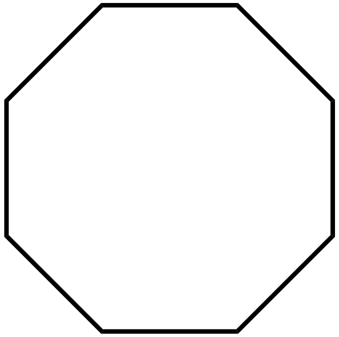
cyclopentane



cyclohexane



cycloheptane

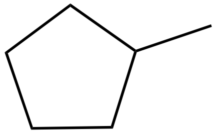


cyclooctane

Nomenclature of Cycloalkanes

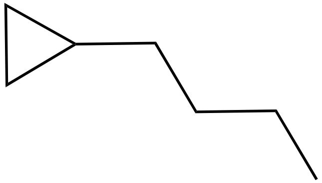
1) Count the number of carbon atoms in the ring and the number of carbon atoms in the largest substituent:

If the # of C atoms in the ring ≥ # atoms in the substituent, then name as alkyl substituted cycloalkane



methylcyclopentane

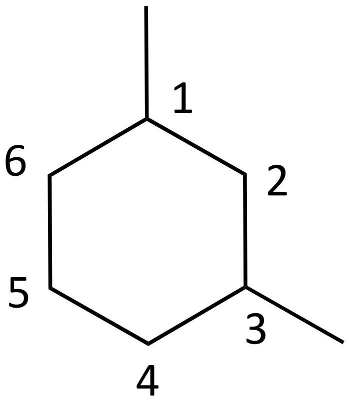
If the # of C atoms in the substituent ≥ # atoms in the ring, then name as cyclo-alkyl substituted alkane



1-cyclopropylbutane

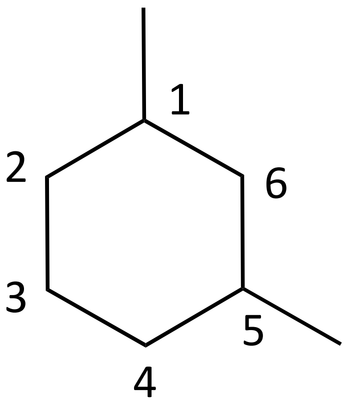
2) Name the Substituents and Write Name

- For alkyl or halo substituted cycloalkanes, choose a point of attachment at carbon #1 and number substituents on the ring so that the second substituent has as low # as possible. Then continue with 3rd, 4th… substituent



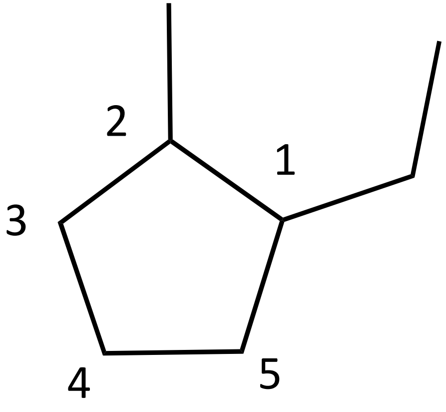
1,3-dimethylcyclohexane

not



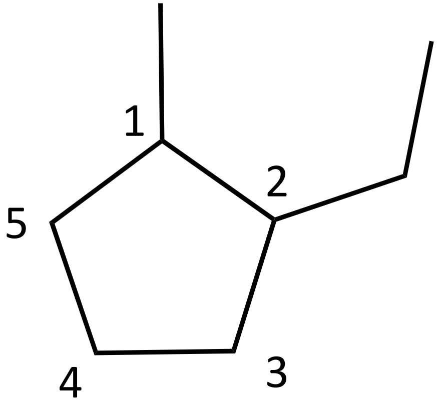
1,5-dimethylcyclohexane

- *Number* alkyl groups alphabetically, omitting prefixes



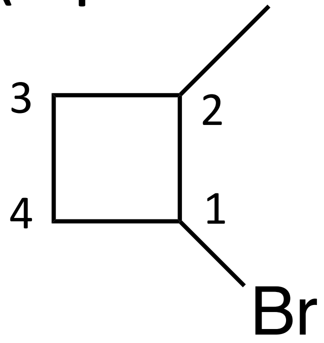
1-ethyl-2-methylcyclopentane

not



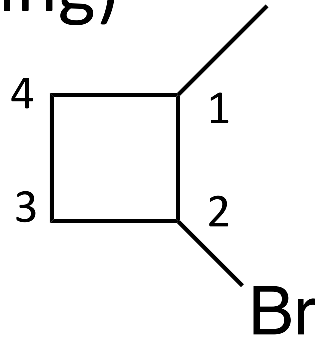
2-ethyl-1-methylcyclopentane

- If halogens are present, treat them like alkyl groups (alphabetically speaking)



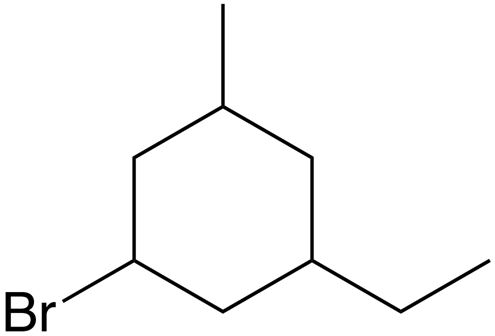
1-bromo-2-methylcyclobutane

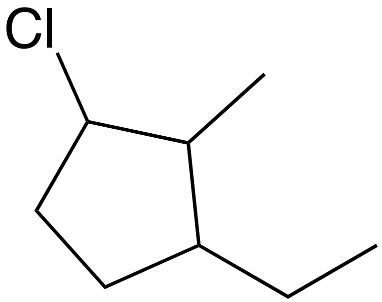
not

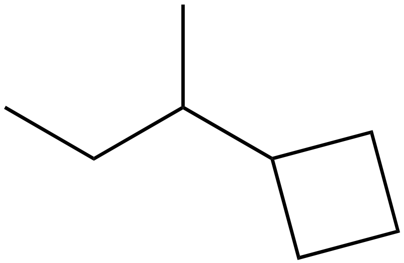


2-bromo-1-methylcyclobutane

Example of Substituted Cycloalkanes



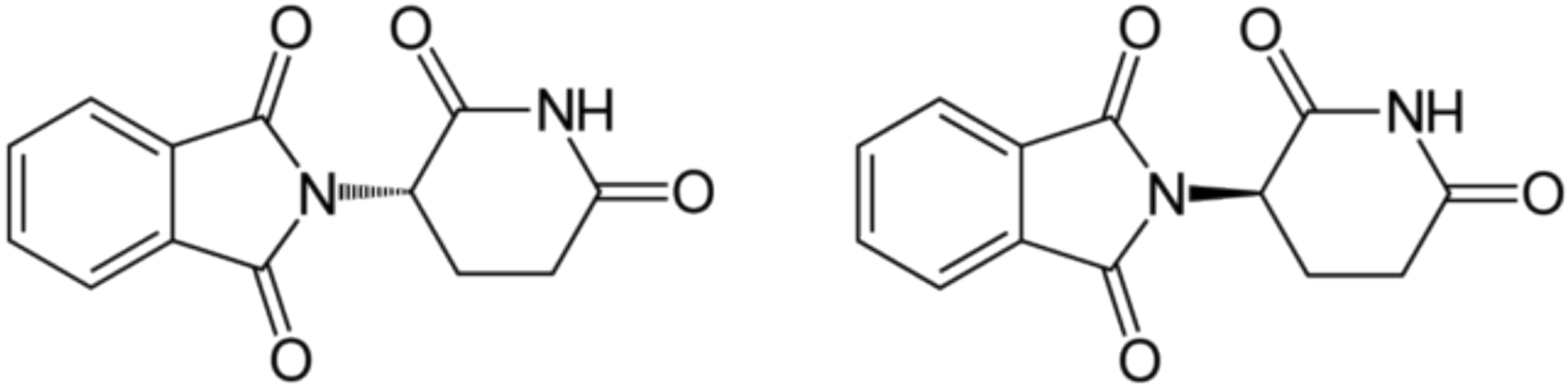




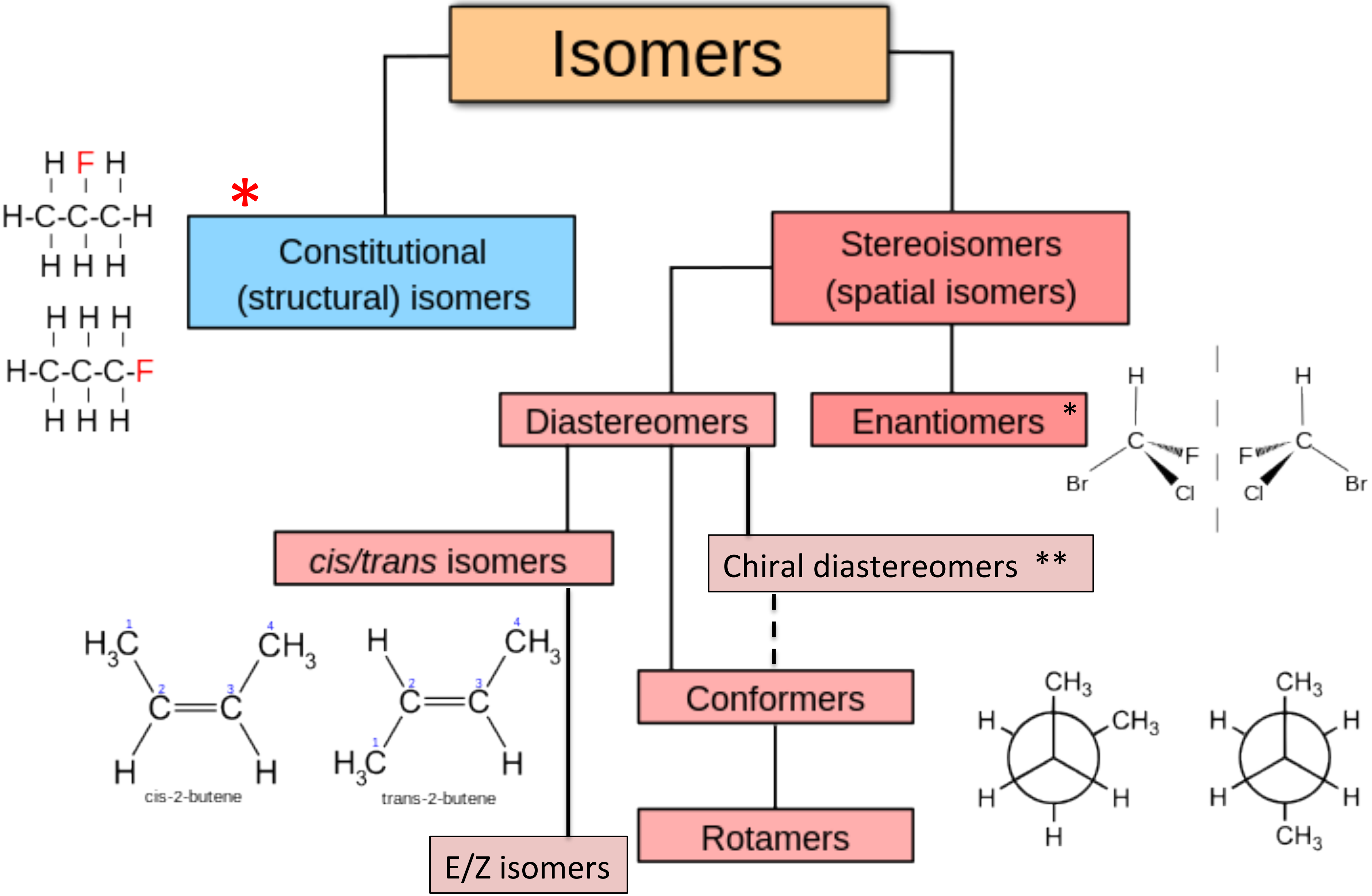
Stereochemistry and Isomers

- **Stereochemistry** = *The study of chemistry in three dimensions (3D), involving the relative spatial arrangement of atoms that form the structures of molecules.*

- **Isomer** = *compounds with the same number and kinds of atoms - but differ in the manner in which the atoms are connected, or arranged in space*



The (S) and (R) stereoisomers of Thalidomide – a teratogen



Isomers

* Constitutional (structural) isomers

Stereoisomers (spatial isomers)

Diastereomers

Enantiomers *

cis/trans isomers

Chiral diastereomers **

Conformers

Rotamers

E/Z isomers

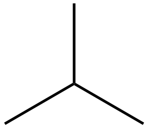
*Enantiomers require least 1 ***chiral*** carbon atom (a carbon bonded to 4 *different* substituents)

** Chiral diastereomers require at least 2 chiral carbon atoms

Constitutional (Structural) Isomers

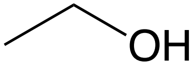
- Atoms in molecules “connected” differently
  - Different carbon skeletons

butane

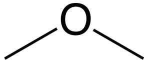


isobutane

  - Different functional groups

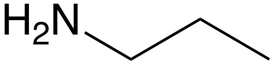


ethanol

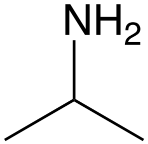


dimethylether

  - Different position of functional groups

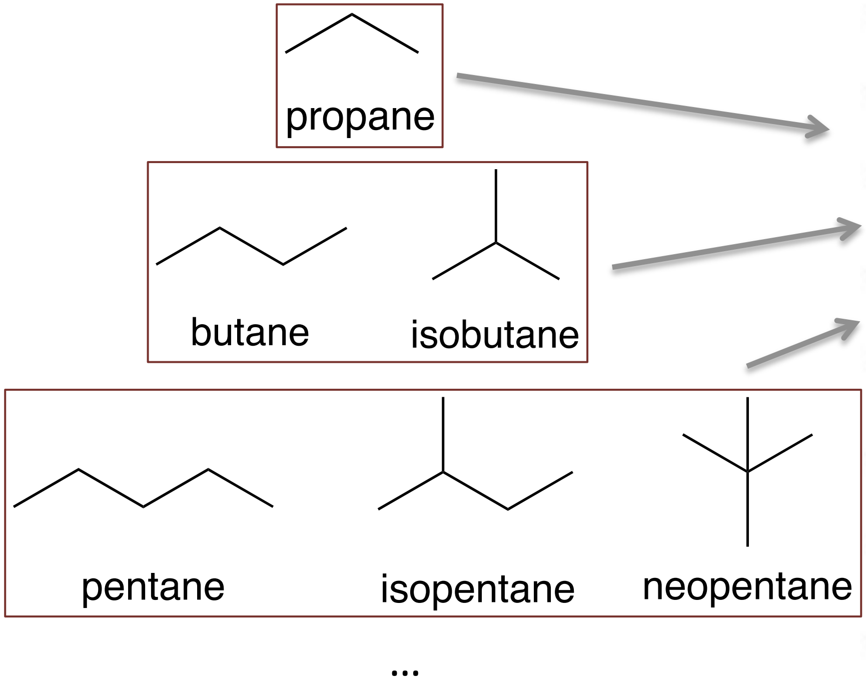


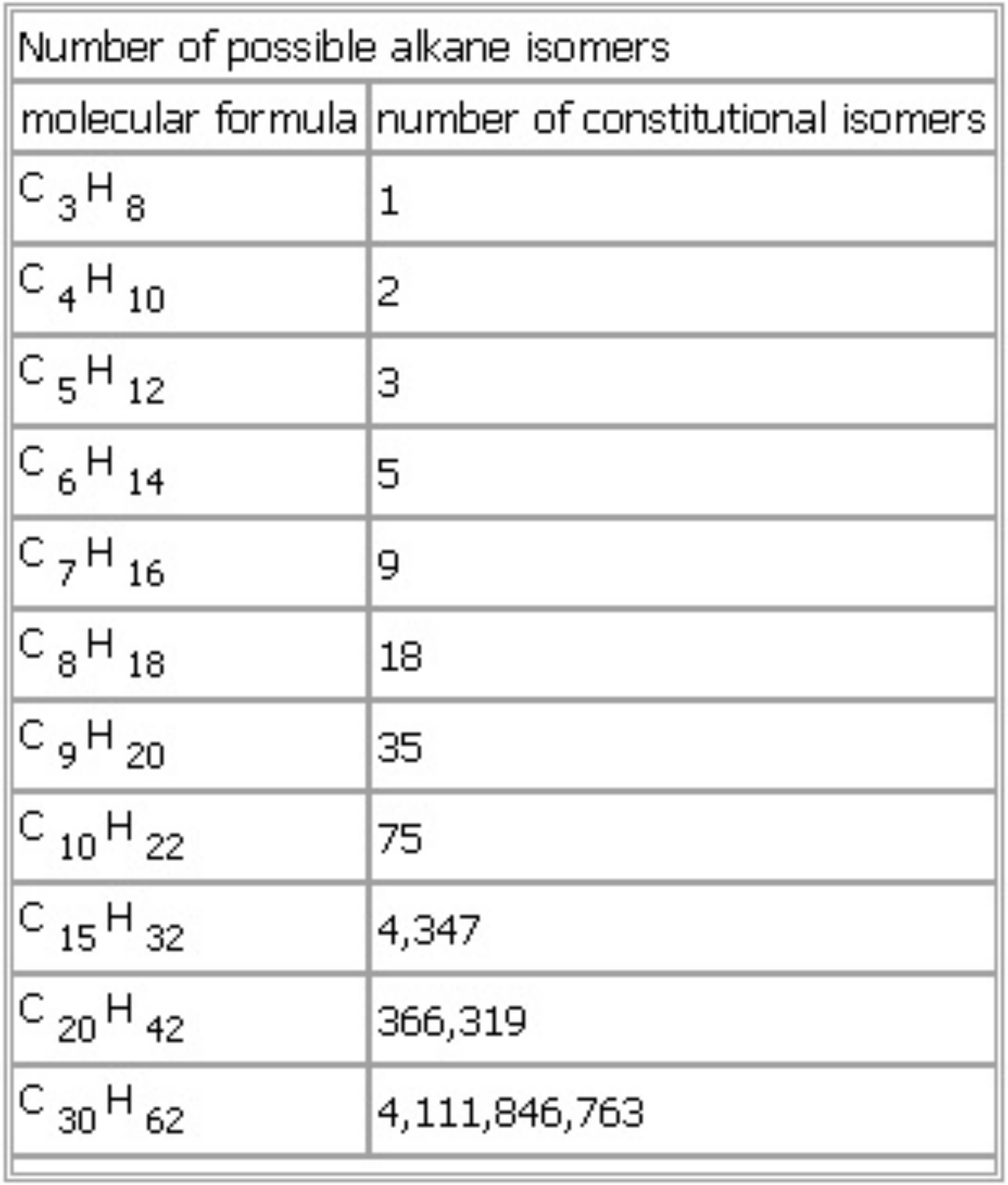
propylamine



isopropylamine

Number of alkane constitutional isomers as a function of carbon chain length

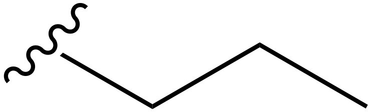




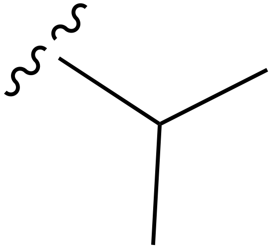
Number of possible alkane isomers

molecular formula	number of constitutional isomers
C_3H_8	1
C_4H_{10}	2
C_5H_{12}	3
C_6H_{14}	5
C_7H_{16}	9
C_8H_{18}	18
C_9H_{20}	35
$C_{10}H_{22}$	75
$C_{15}H_{32}$	4,347
$C_{20}H_{42}$	366,319
$C_{30}H_{62}$	4,111,846,763

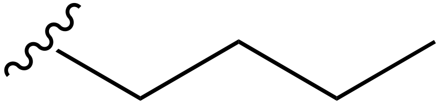
Common isomeric alkyl groups



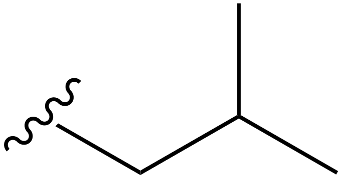
propyl



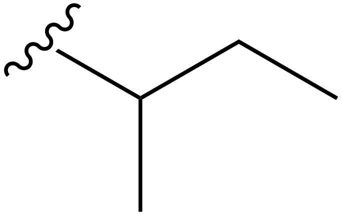
isopropyl



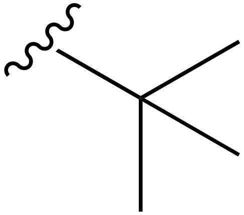
butyl



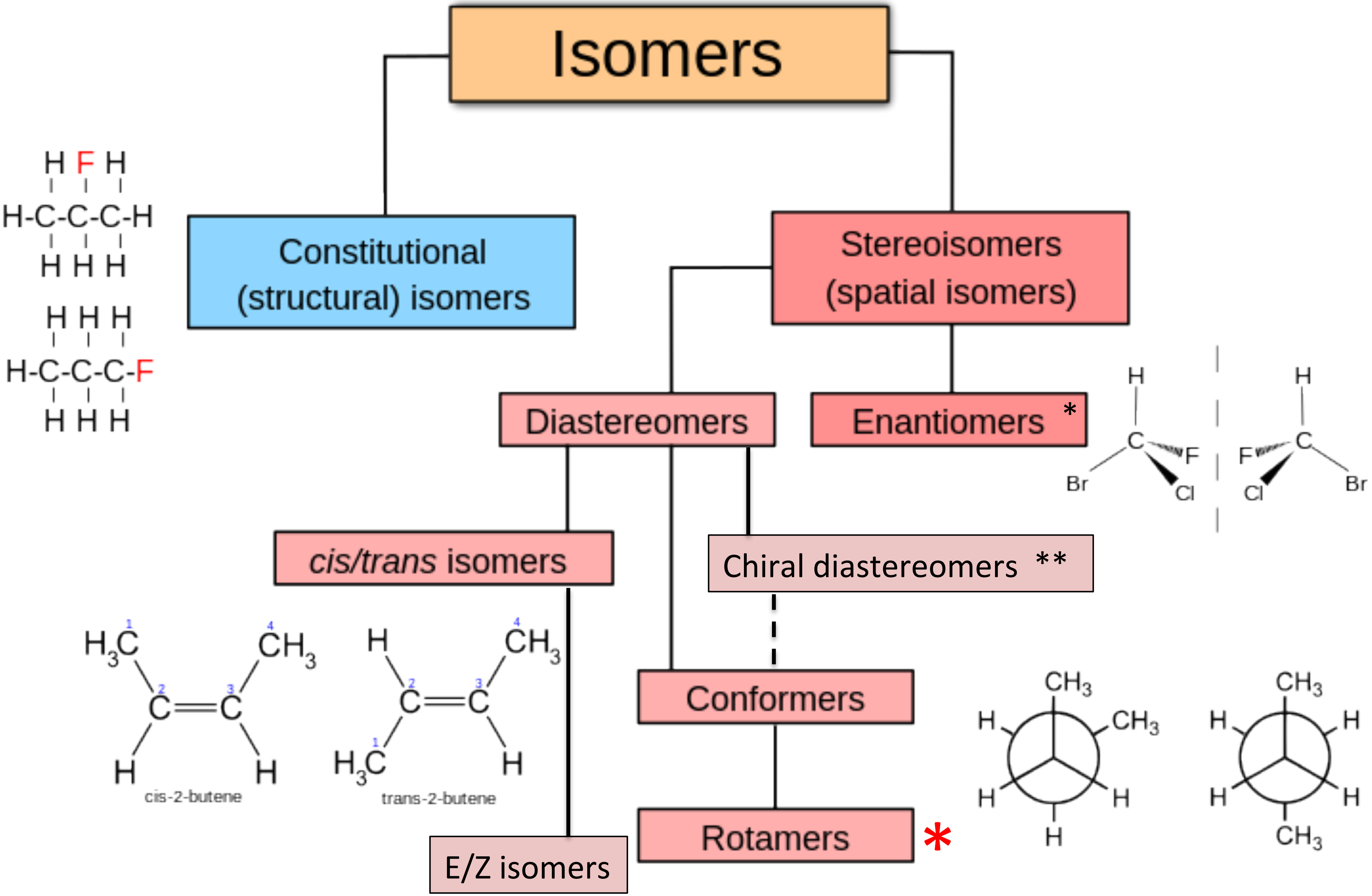
isobutyl



sec-butyl



tert-butyl



Isomers

Constitutional (structural) isomers

Stereoisomers (spatial isomers)

Diastereomers

Enantiomers *

cis/trans isomers

Chiral diastereomers **

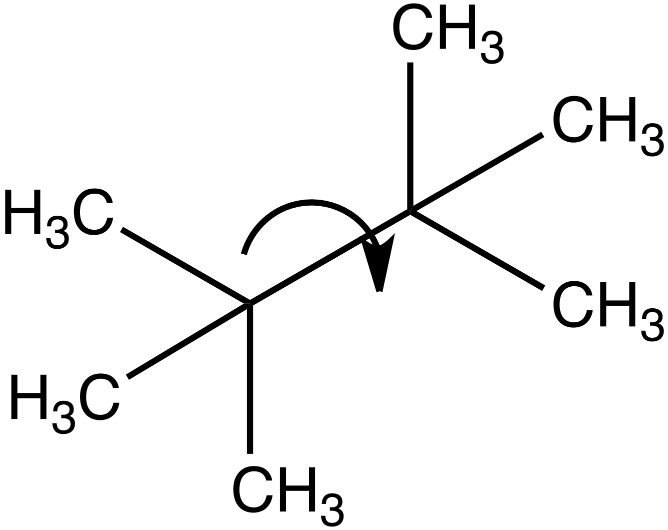
Conformers

Rotamers *

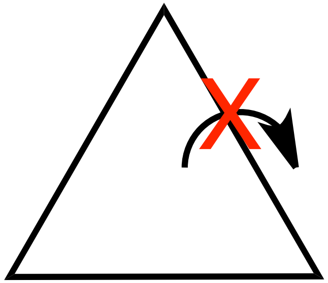
E/Z isomers

“Rotamers” are simply “rotational isomers” and mostly describe bonds in linear systems
* Most importantly, they are energy barriers between rotations *

Rotational Isomers (aka "Rotamers"): Comparing C-C bond rotation



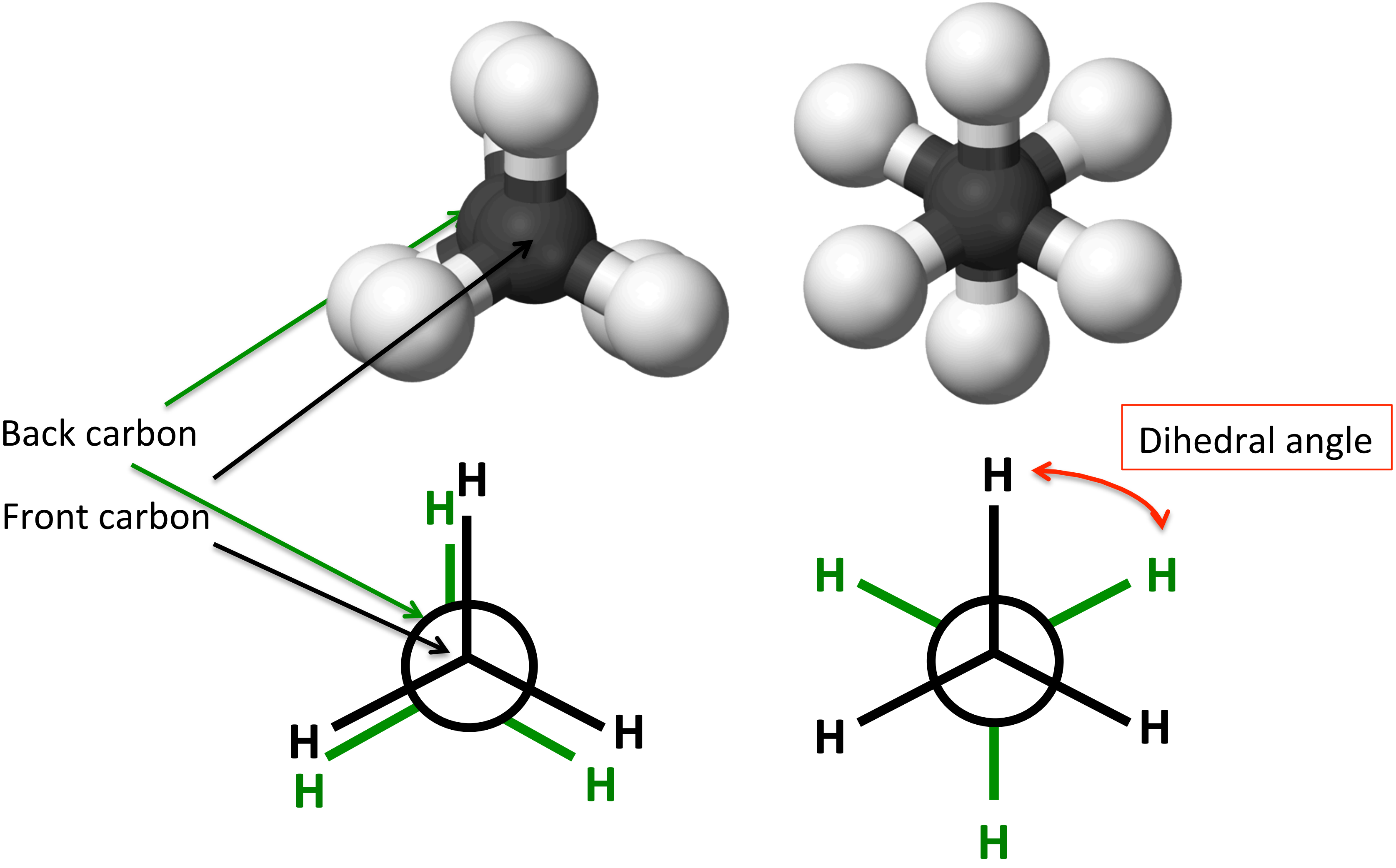
Linear alkanes ***vs.*** ***Cycloalkanes***



- Flexible (free rotation)
- Interconvert too rapidly to isolate
- Rotamers have different energy levels
- Described by Sawhorse Representations and Newman Projections

- Rigid (limited rotation)
- Can not rotate small ring structures (C3-C7) without breaking C-C bonds
- Larger cycloalkanes have more "degrees of freedom" for rotation
- C25 and greater behave almost like open chain alkanes

Newman Projections of a Linear Alkane (Ethane)



Back carbon

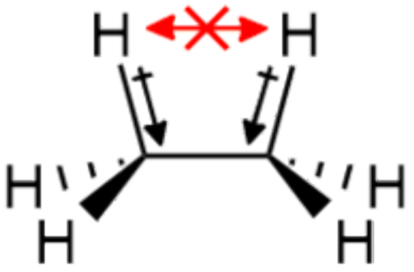
Front carbon

Dihedral angle

"Eclipsed"

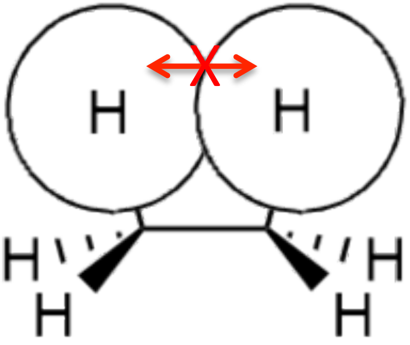
"Staggered"

Energetic factors contributing to rotation of linear systems



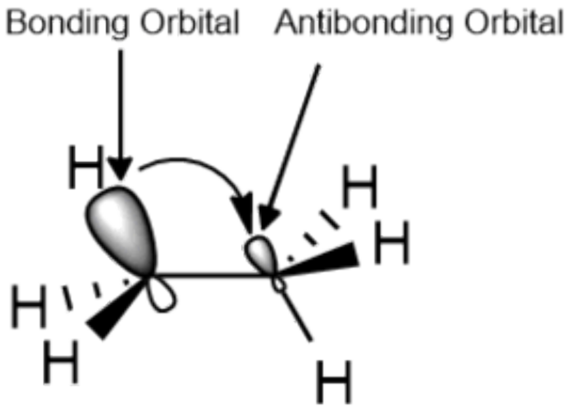
Electrostatic Repulsion

Proton (+ +) repulsion



Steric Repulsion

Electron cloud (- -) repulsion



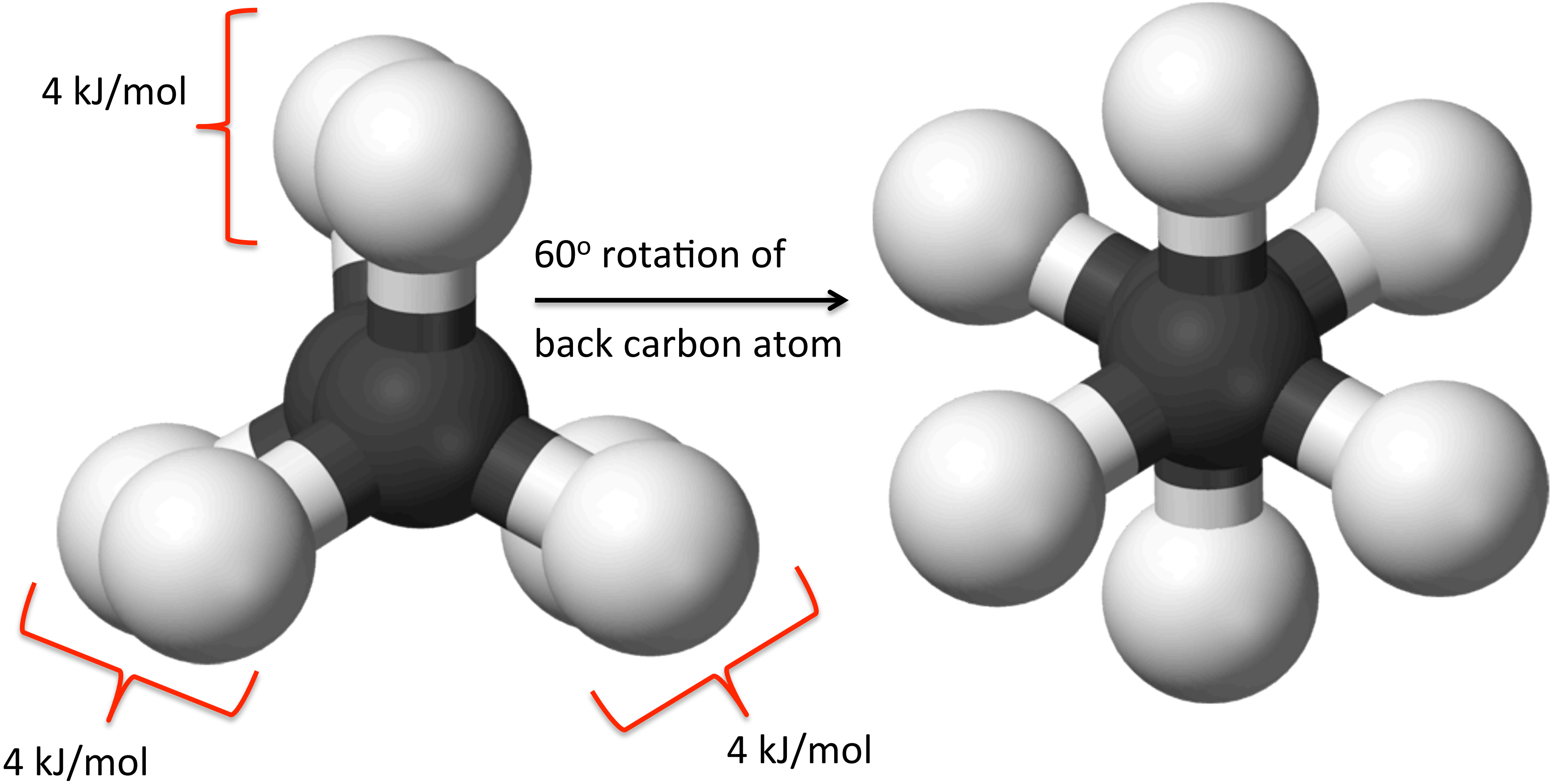
Strengthened Hyperconjugation

σ bonding electrons (C-H or C-C) interact with adjacent, empty/ non-bonding π orbitals, (σ* or π*)to extend (stabilize) the molecular orbital

- Contributions from these factors vary depending on the substituent and can contribute positively or negatively to the energy barrier.
- Can often be observed and measured in the lab, by NMR and IR spectroscopy.

Energetics of Ethane Rotamers

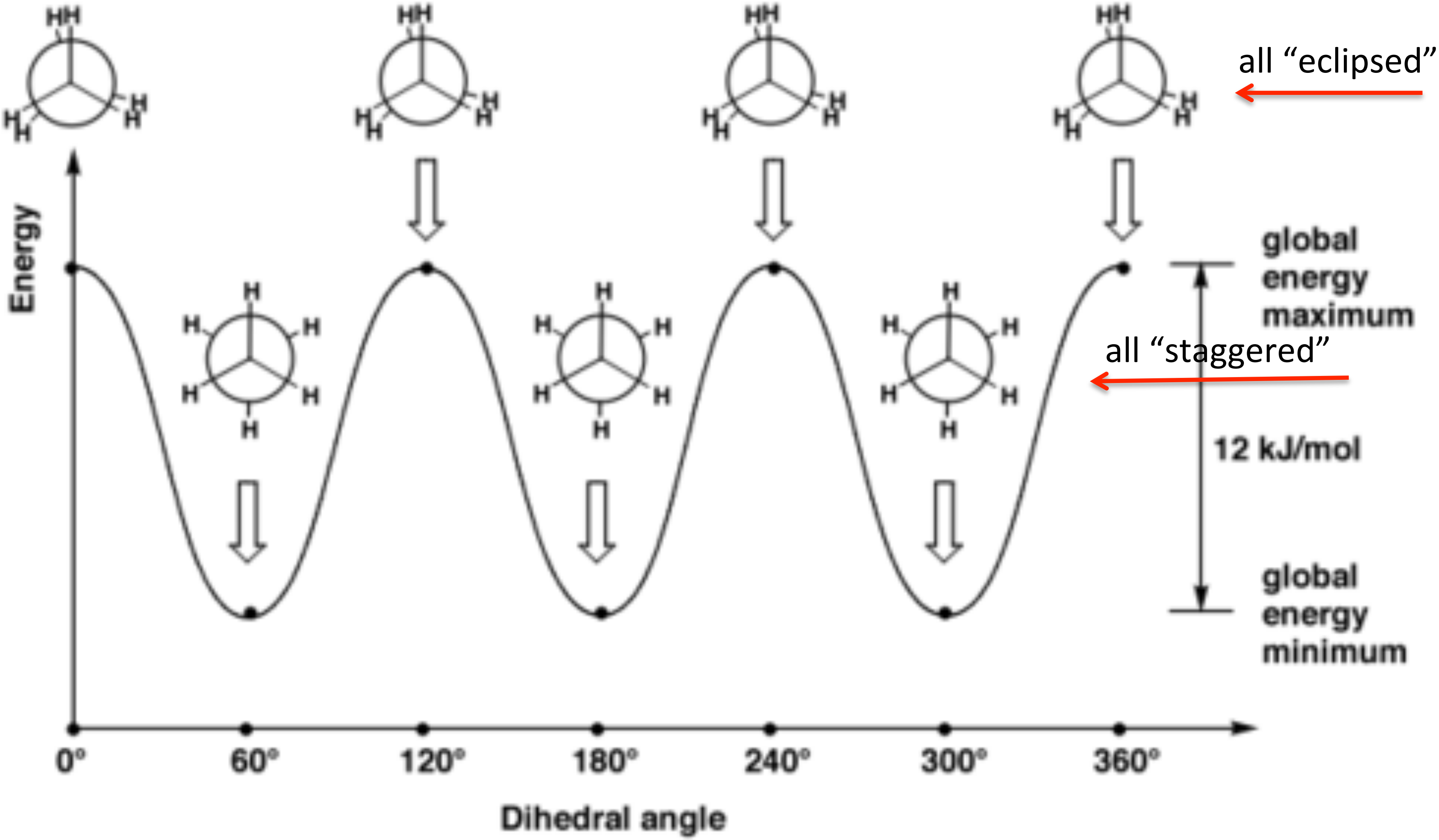
- Sum of interactions



“Eclipsed” conformer

“Staggered” conformer
(4 + 4 + 4 = 12 kJ/mol more stable)

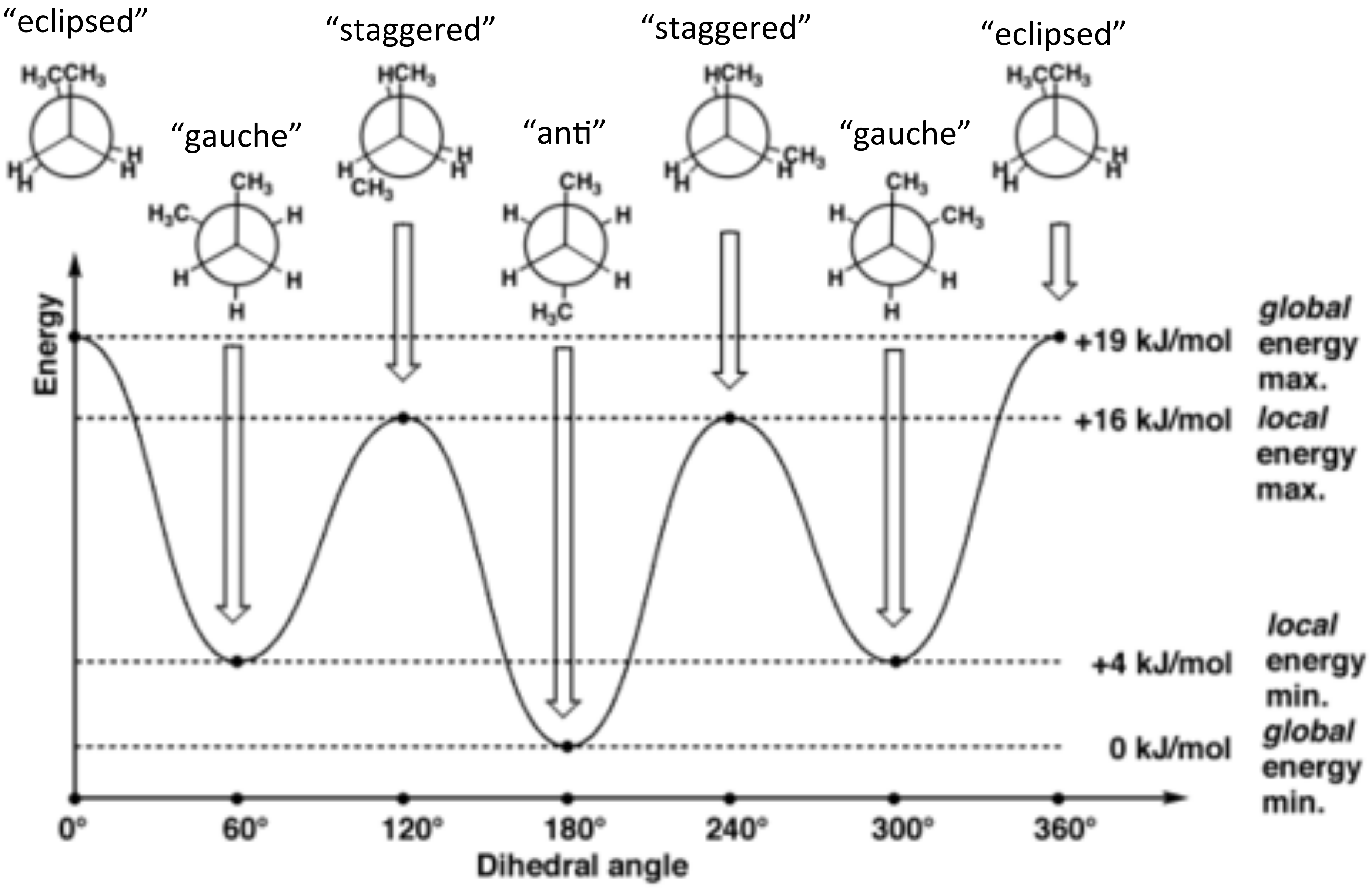
Sum of Rotational Energies for Ethane – ChemDraw 3D can generate these plots very quickly for many simple compounds



all “eclipsed”

all “staggered”

Sum of Rotational Energies for Butane



"eclipsed"

"gauche"

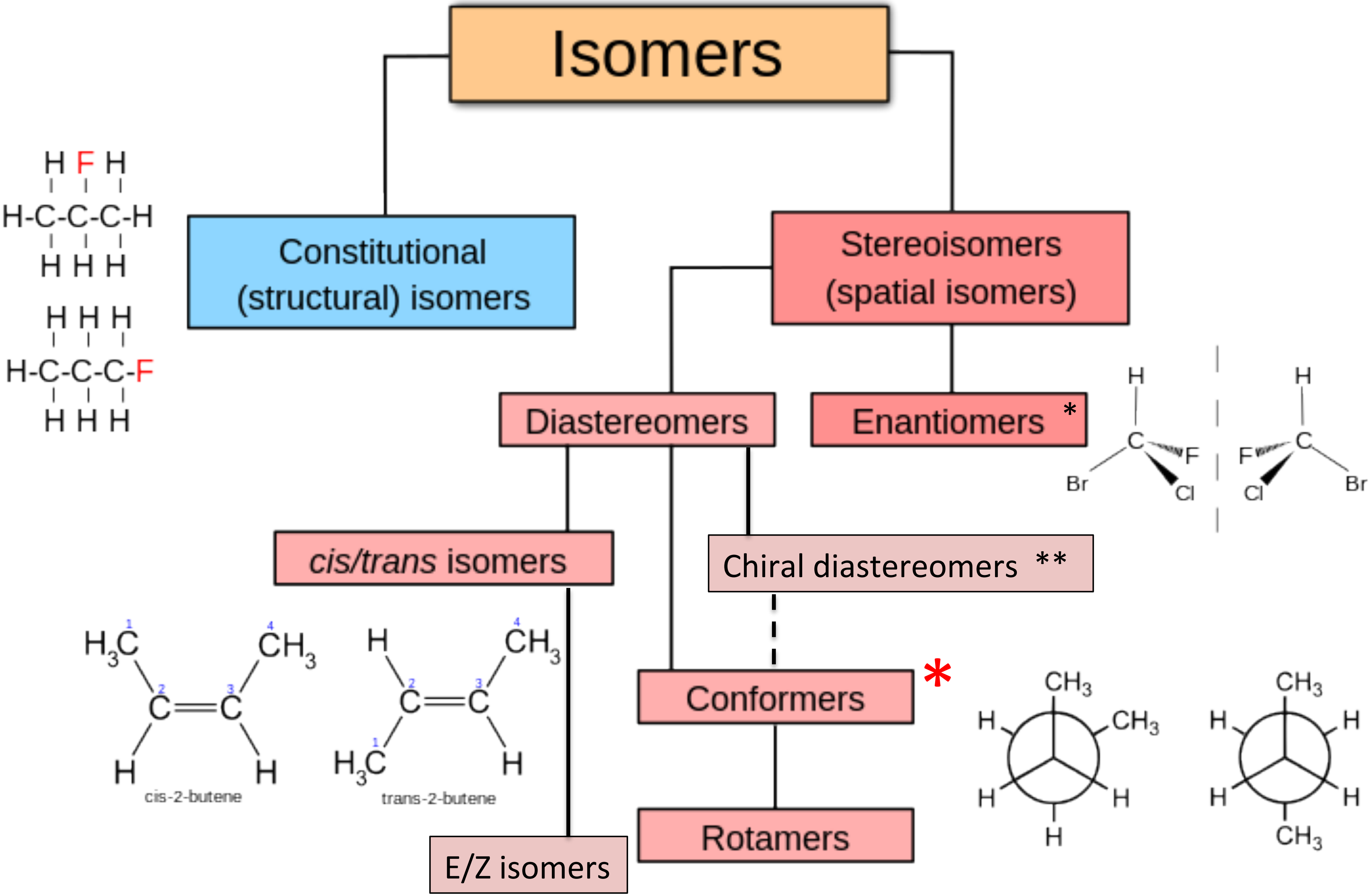
"staggered"

"anti"

"staggered"

"gauche"

"eclipsed"



Isomers

Constitutional (structural) isomers

Stereoisomers (spatial isomers)

Diastereomers

Enantiomers *

cis/trans isomers

Chiral diastereomers **

Conformers *

Rotamers

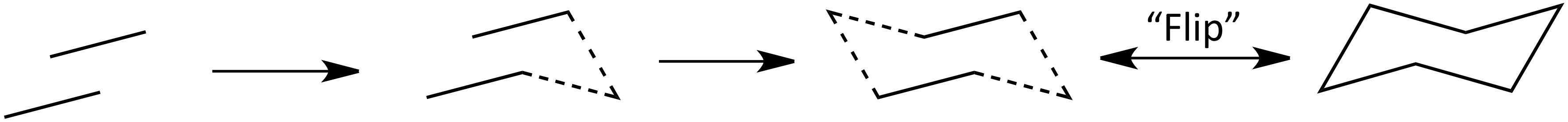
E/Z isomers

Conformers used to describe cyclic systems, e.g. cyclohexane conformers
Careful not to confuse "conformation" with configuration

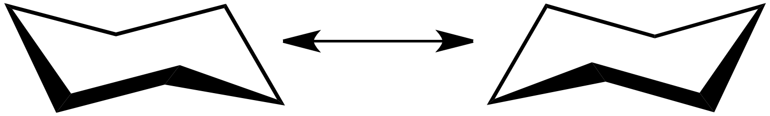
Cyclohexane

- Drawing cyclohexanes and model inter-conversion
- Energetics (e.g. “chair” and “boat” conformations)
- Newman Projection
- Axial vs. equatorial (“chair/chair flip”)
- Conformations of monosubstituted cyclohexanes
- Conformations of disubstituted cyclohexanes
- Polycyclic molecules

Drawing Cyclohexanes as easy as 1, 2, 3



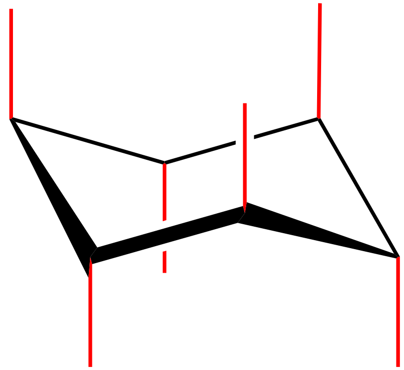
1. Draw offset parallel lines
2. Connect bottom
3. Connect top



3D representation

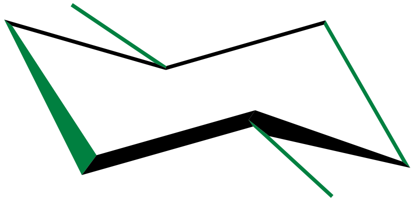
Drawing Axial and Equatorial Substituents of Cyclohexanes

1.

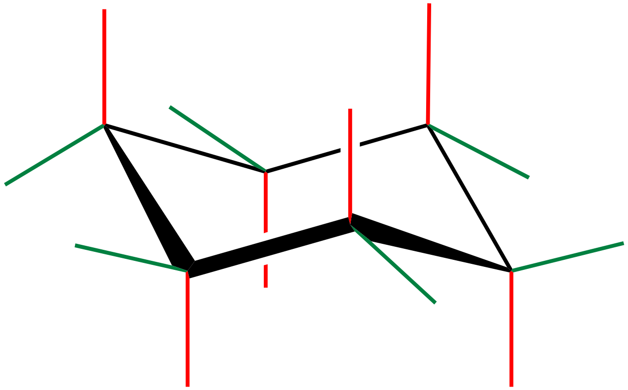


- **Axial** bonds are drawn *straight up and down from carbon at point of attachment* –easy
- **Equatorial** bonds are drawn *parallel to C-C bond two atoms away* – thought required

2.

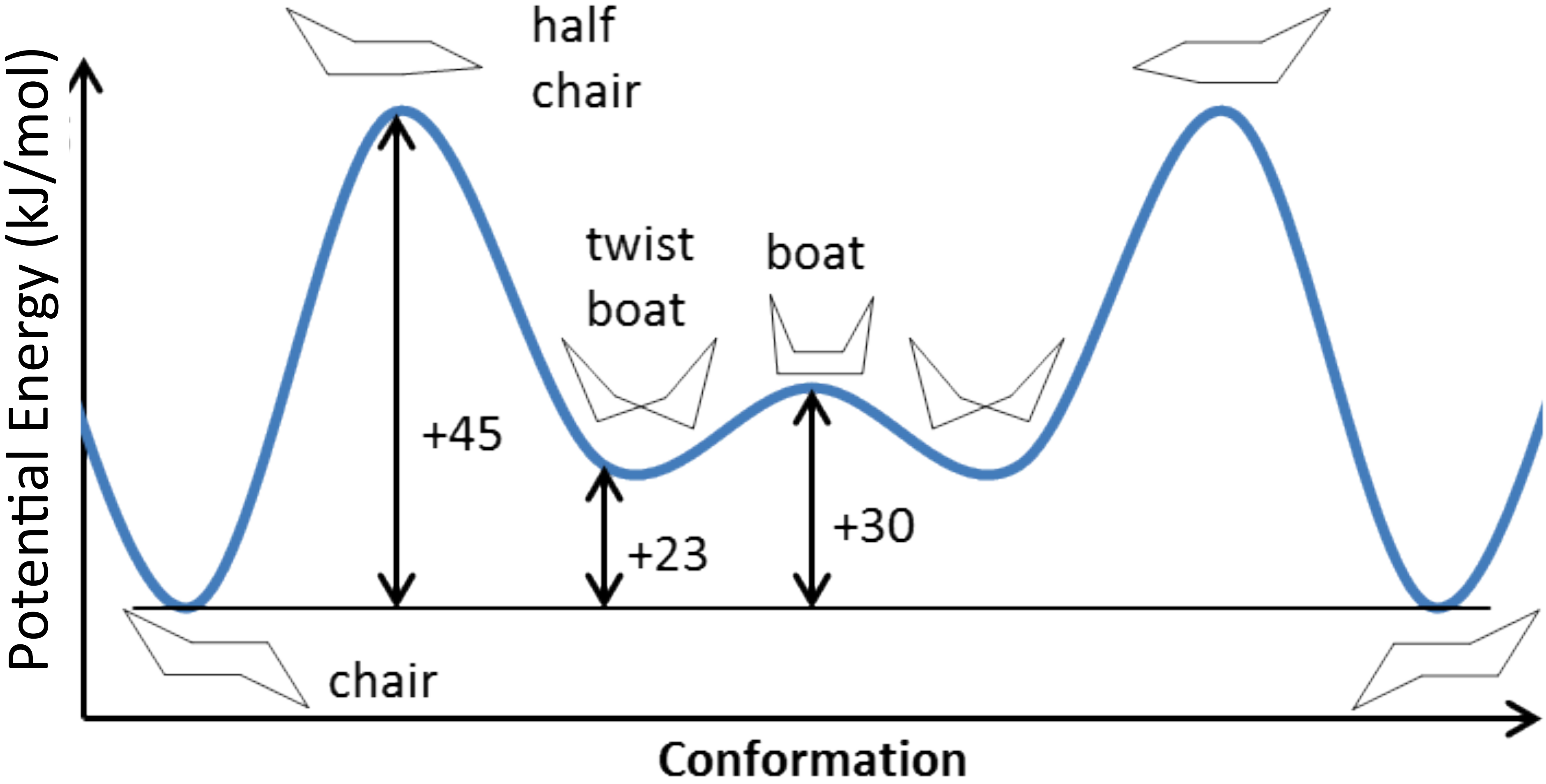


3.

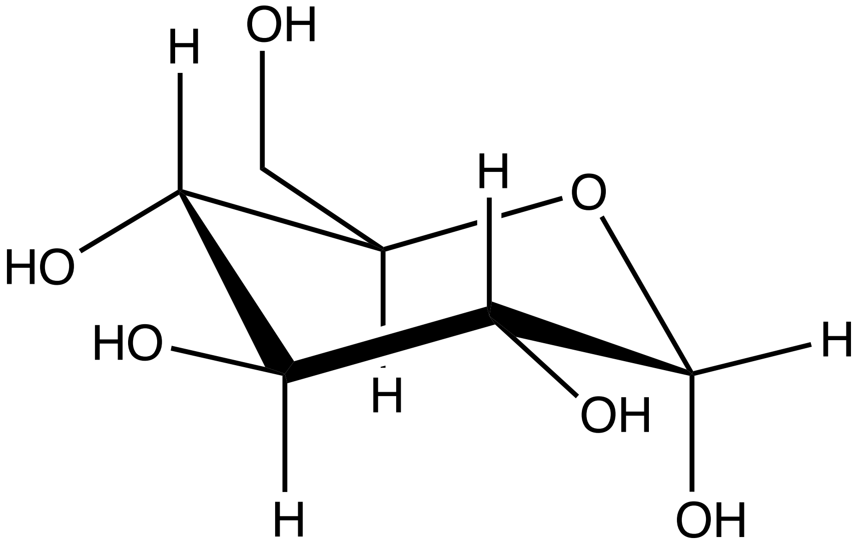


Put it all together!

Energetics of cyclohexane conformational isomers ("conformers")



Biological examples of conformers

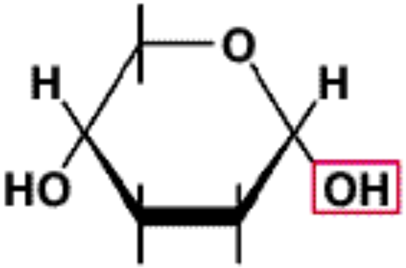


D-glucose (a hexose sugar, 180 g/mol)

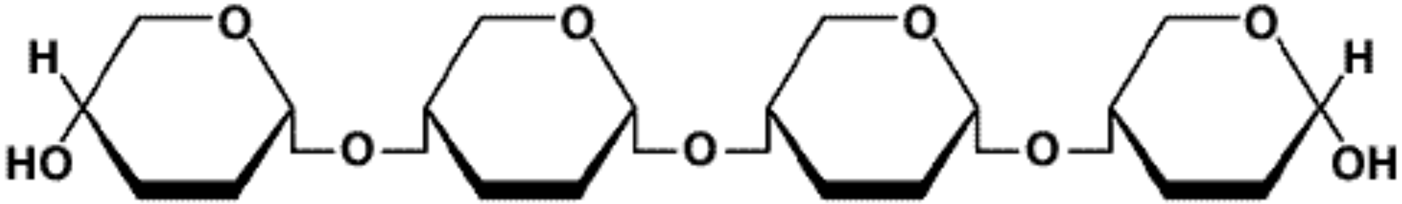
- Hexose = 6 carbon sugar
- Produced by plants during photosynthesis
- Energy source for anaerobic, aerobic respiration, fermentation
- 16 kJ/gram (2880 kJ/mol)
- Solar radiation…
- Starch vs. cellulose…

$C_6H_{12}O_6 + 6O_2 \text{-->} 6CO_2 + 6H_2O$

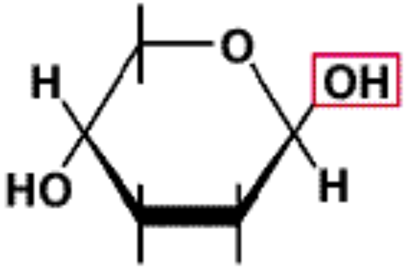
Alpha-glucose and Beta-glucose, Plus Primary Structures of Amylose and Cellulose



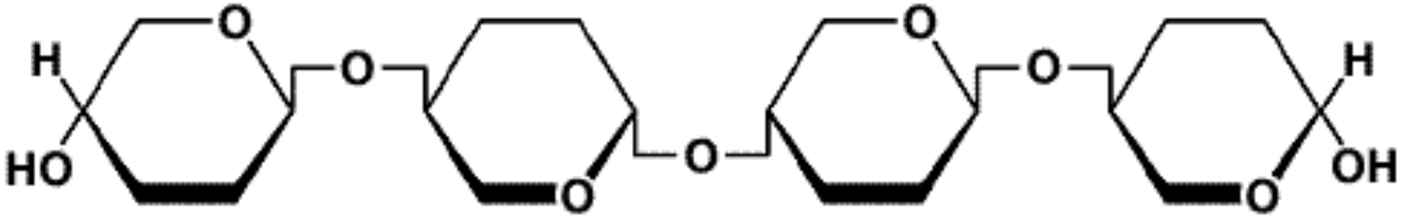
Alpha-glucose



Amylose (a component of "starch")

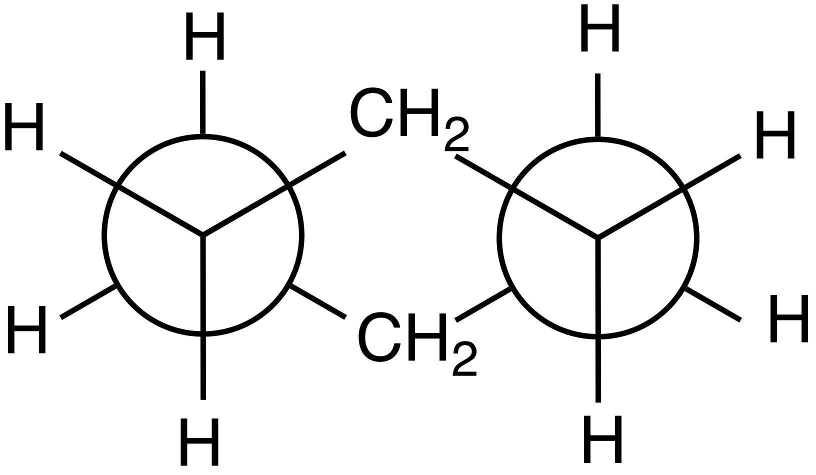


Beta-glucose

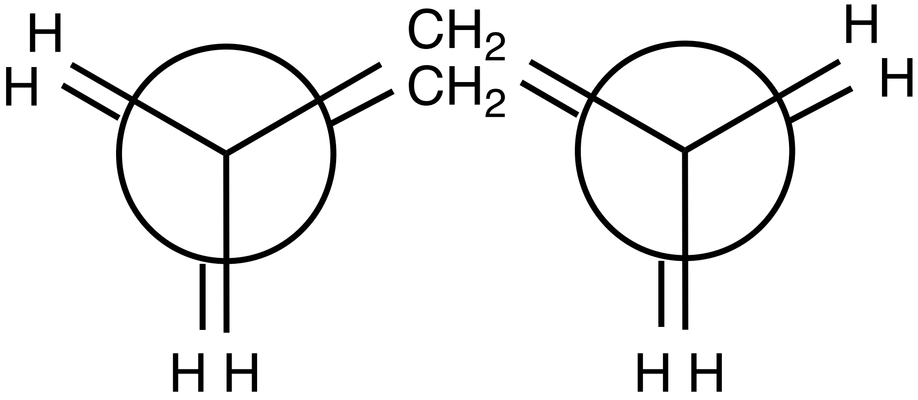


Cellulose

Newman Projections of Cyclohexane

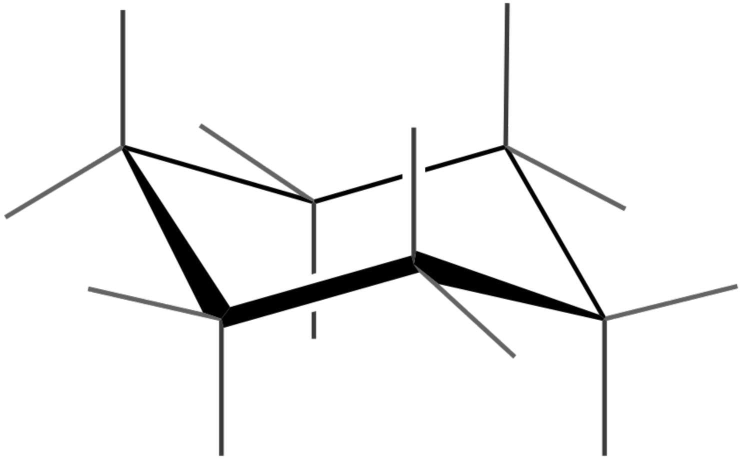


“Chair” Conformation

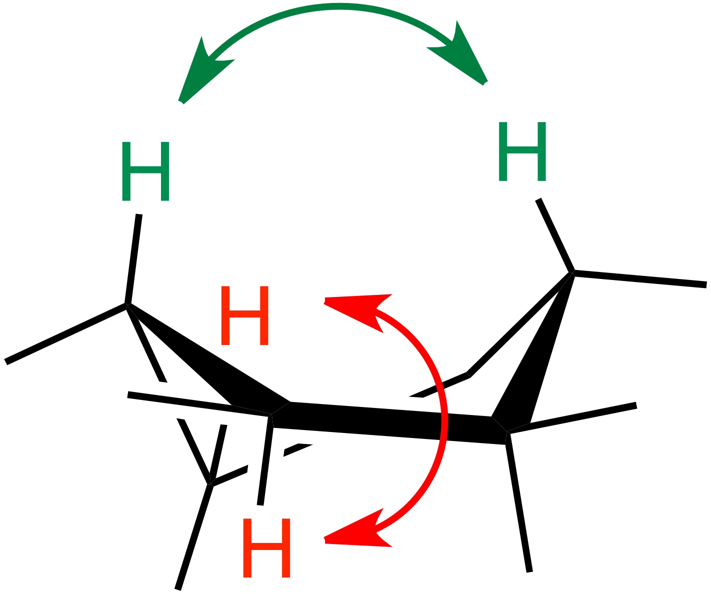


“Twist Boat” Conformation
23 kJ/mol less stable

Ring Strain in “Chair” vs. “Twist Boat” Cyclohexane



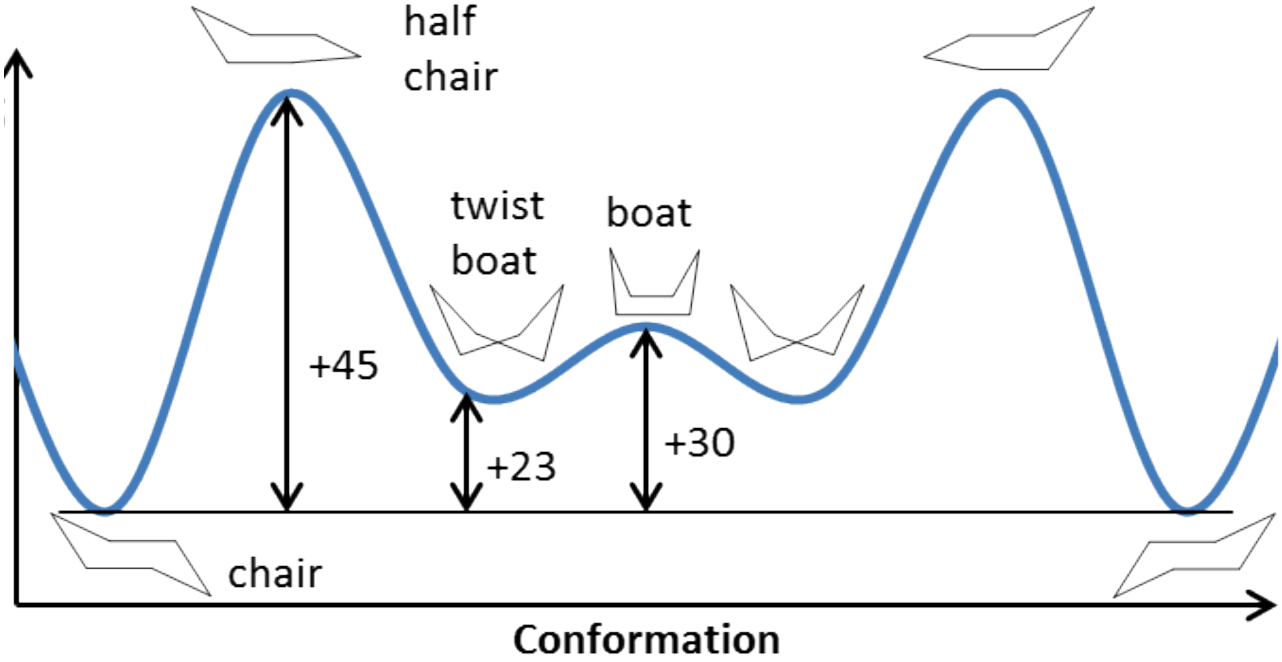
- Minimal repulsion on all Hydrogen atoms



- Steric strain (electron cloud repulsion) between 1, 4 Hydrogen atoms
- electrostatic repulsion(proton proton repulsion) between 1, 3 hydrogens

The “Chair-Chair Flip”

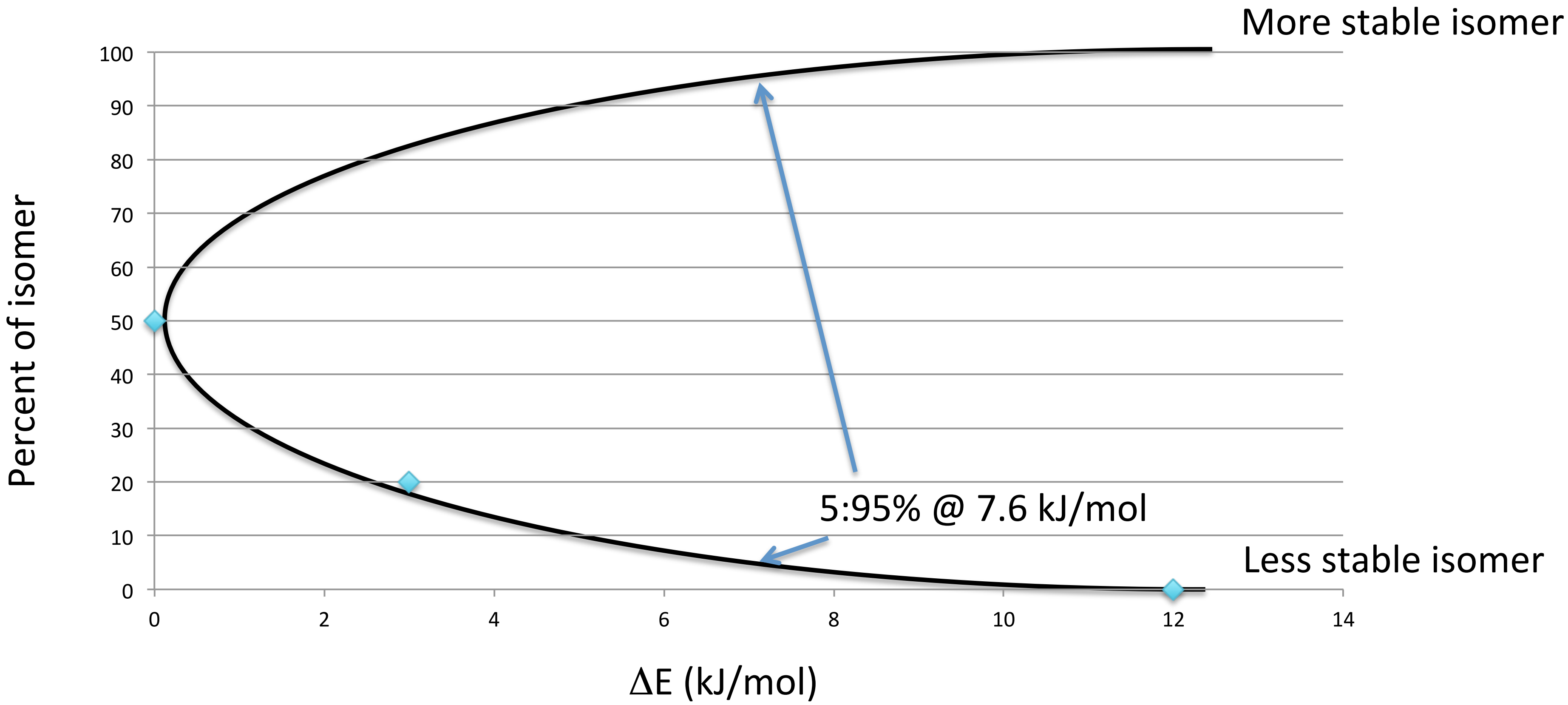
- Passes through half chair, twist boat, boat
- *Allows all axial substituents to become equatorial and vice versa*
- 45 kJ/mol (interconversion occurs readily at RT)



Conformations of Monosubstituted Cyclohexanes

- The substituent is almost always ***more stable*** in the ***equatorial*** position
- Calculate the percentages of two isomers at equilibrium using $\Delta E = -RT \ln K$
  - Where ΔE = energy difference between 2 isomers
  - R = ideal gas constant (8.315 J/k mol)
  - T = Kelvin temperature
  - K = equilibrium constant
  - ln = natural log

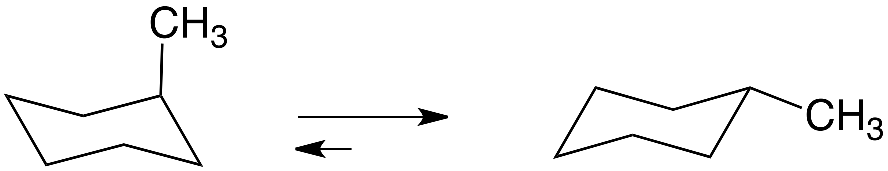
Example with methylcyclohexane



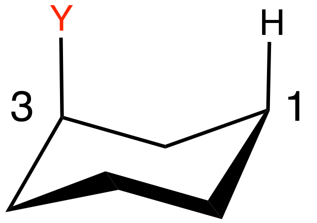
More stable isomer

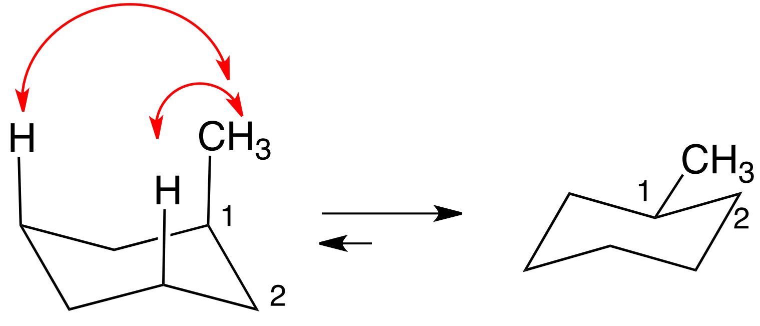
5:95% @ 7.6 kJ/mol

Less stable isomer



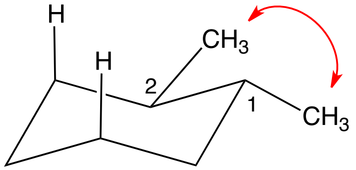
Conformational Analysis of cyclohexane: 1,3-diaxial and Gauche interactions





- Exact amount of 1, 3- diaxial strain depends on the nature and size of substituent
- Steric strain increases as size increases (methyl, ethyl, propyl, etc)

- Gauche interactions (3.8 kJ/mol)

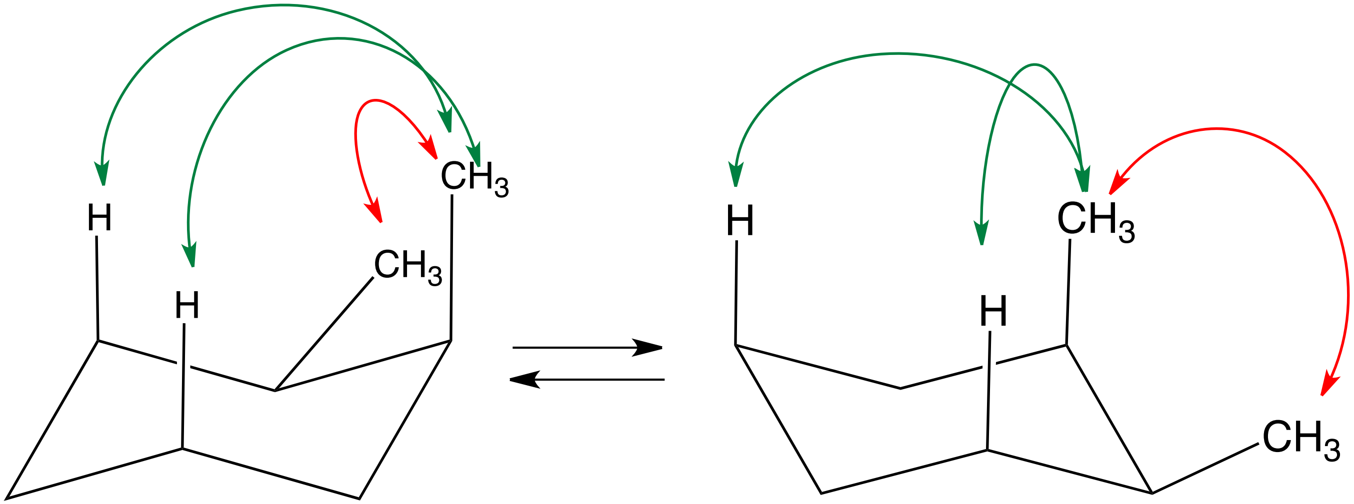


	E per H atom
Y	kJ/mol
F	0.5
Cl, Br	1.0
OH	2.1
CH_3	3.8
CH_2CH_3	4.0
$CH(CH_3)_2$	4.6
$C(CH_3)_3$	11.4
C_6H_5	6.3
CO_2H	2.9
CN	0.4

Conformations of disubstituted cyclohexanes

- More complex analysis (steric effects of ***both*** substituents must be considered)
- ***Both*** chair conformations must be analyzed for steric interactions before deciding which is favored

Cis 1,2-dimethylcyclohexane

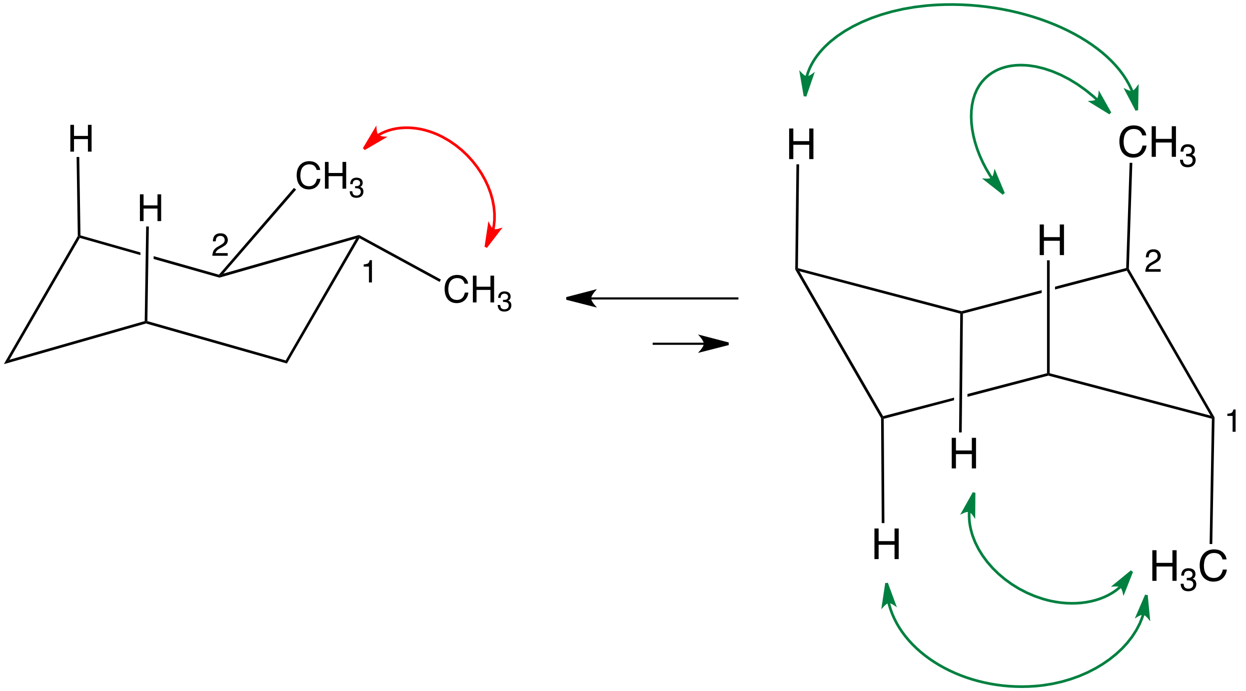


Each Conformer has:

one gauche interaction (3.8 kJ/mol)
two CH3 --- H 1,3- diaxial interactions (7.6 kJ/mol)

Total Energy = 11.4 kJ/mol

Trans 1,2-dimethylcyclohexane



Diequatorial Conformer:

one gauche interaction (3.8 kJ/mol)

Total Energy = 3.8 kJ/mol

More stable

Diaxial Conformer:

Four CH3 --- H 1,3- diaxial interactions (7.6 kJ/mol)

Total Energy = 15.2 kJ/mol

cis- vs *trans*- 1,2-diethylcyclohexane

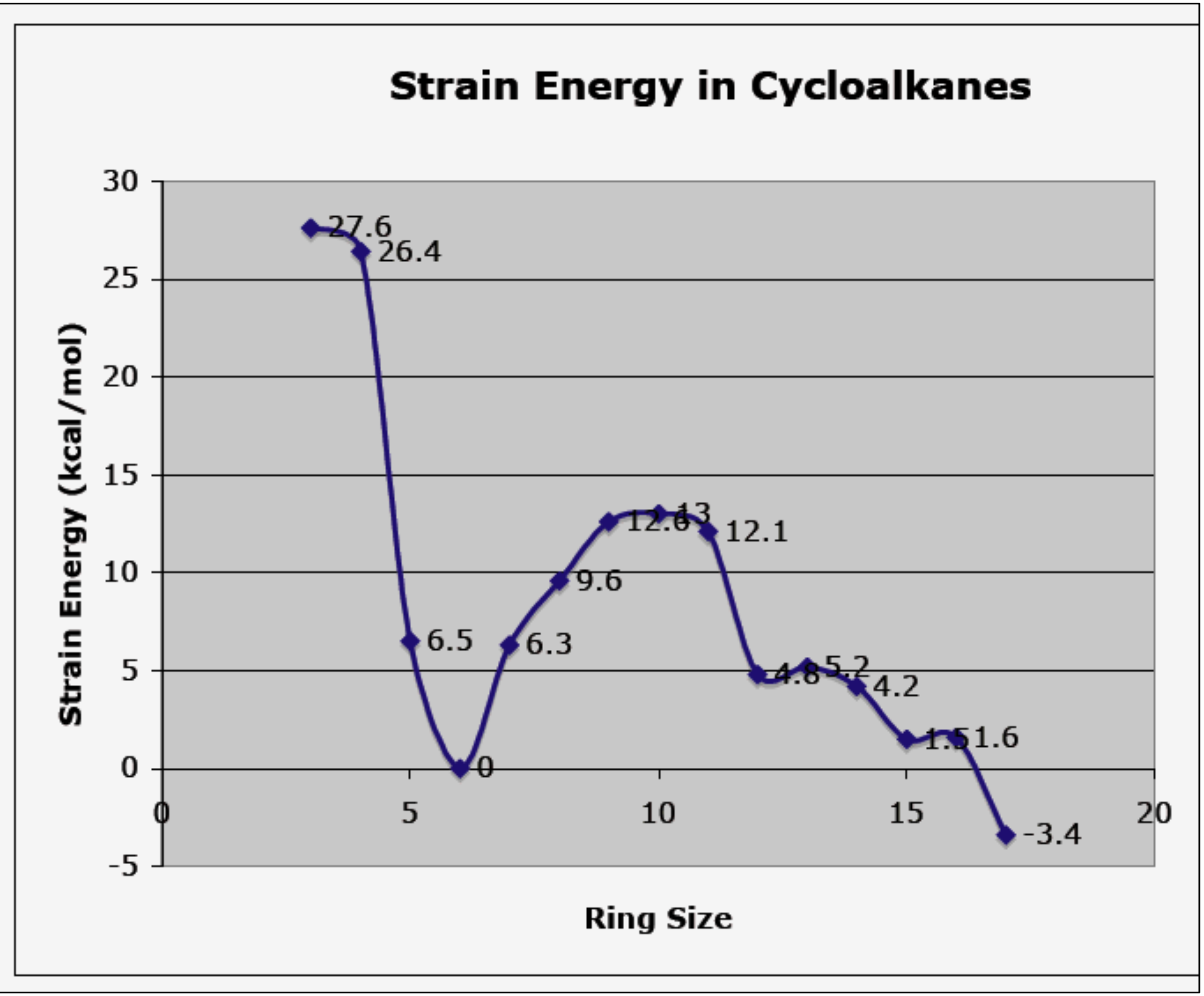
- Draw the two structures using 3 step method
- Perform conformational analysis on each using 1-3 diaxial interactions and gauche interactions
- What are the energy differences between the isomers?
- Which is/are more stable?

- CHEM DRAW 3D - PLOT DIHEDRAL ANGLE VS. ENERGY (KCAL/MOL) FOR ETHANE ROTAMERS

Cycloalkanes and Ring Strain

- ***von Baeyer Theory (1885)***: deviation from ideal angle (109.5^o)
- ***Angle strain***: strain due to expansion or compression of bond angles (C_3-C_5)
- ***Torsional strain***: strain due to eclipsing of bonds on neighboring atoms (C_7-C_{11})
- ***Steric strain***: strain due to repulsive interactions when atoms approach each other too closely (C_7-C_{11})

Sum of Cycloalkane Strain Energies vs. Ring Size



- Measured by difference in heat of combustion vs. linear alkane (per CH_2 unit)

- 1 kcal = 4.184 kJ

Cyclopropane
(27.6 kcal/mol
= 115.4 kJ/mol)

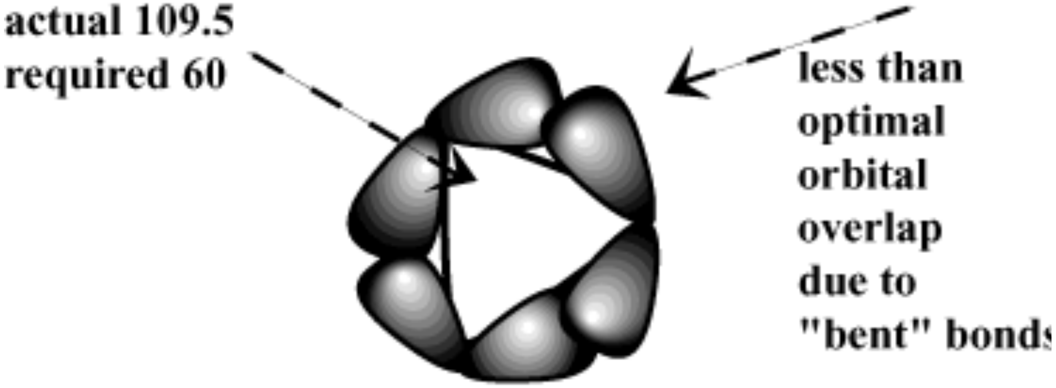
Cyclobutane
(26.4 kcal/mol
= 110.5 kJ/mol)

Cyclopentane
(6.5kcal/mol
= 27.3 kJ/mol)

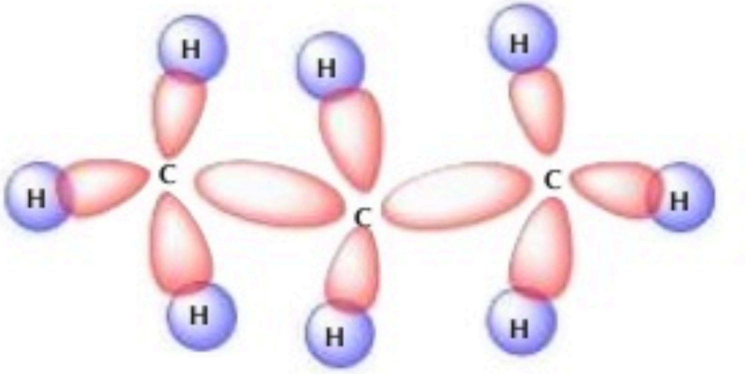
Cyclohexane = 0 kJ/mol!

Consequences of angle ring strain in cyclopropane

- Bonds between *sp^3* hybrid orbitals are bent rather than linear = weaker (and thus more reactive)



carbon frame of cyclopropane



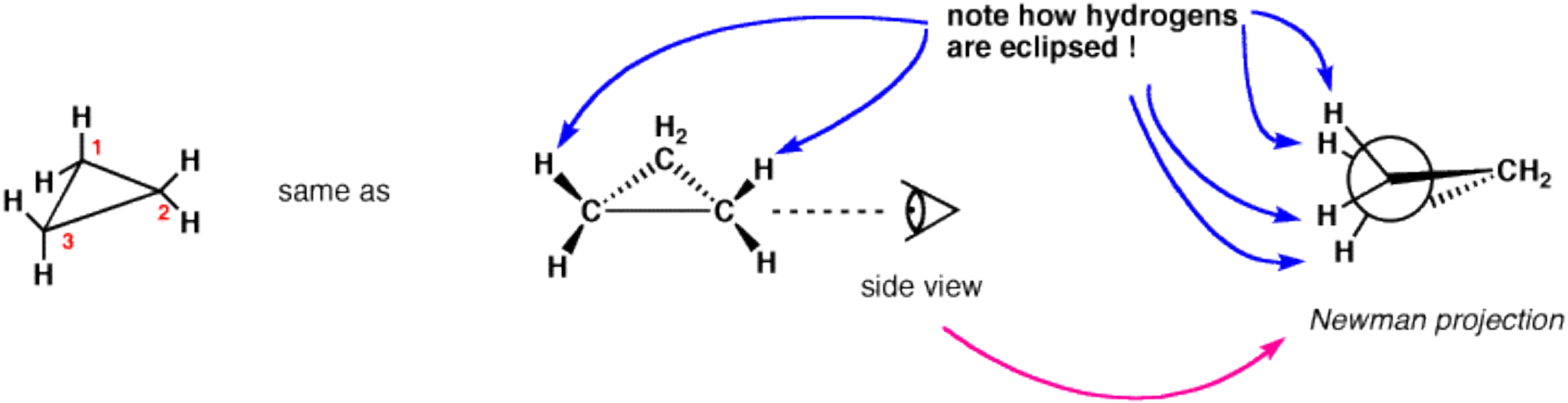
255 kJ/mol = cyclopropane C-C bond ***370 kJ/mol = propane C-C bond***

Difference = 115 kJ/mol (measured by combustion)

$(CH_2)_n + 3n/2\ O_2 \rightarrow n\mathrm{CO2} + nH_2O$ + HEAT

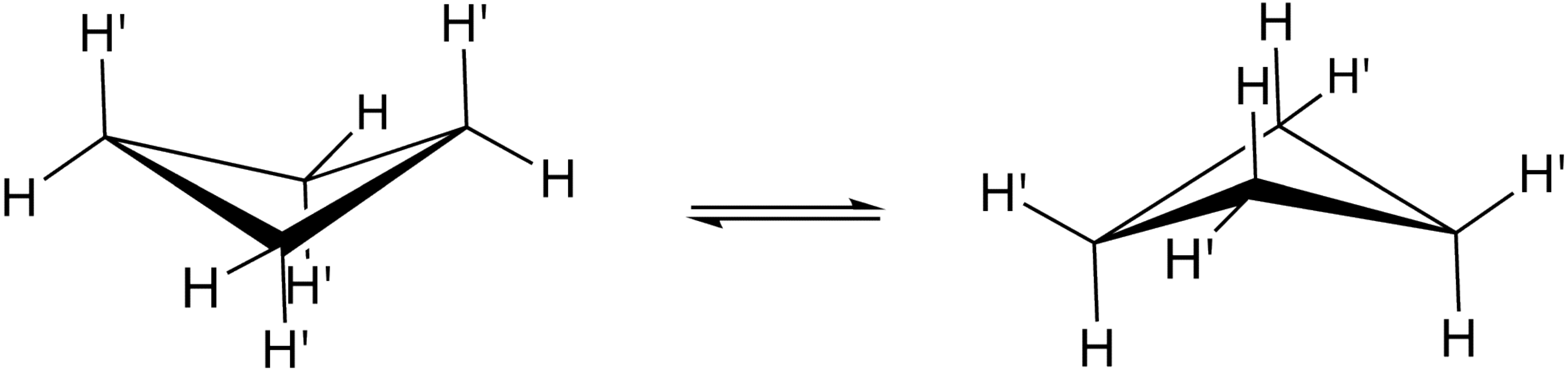
Torsional and Steric Ring Strain in Cyclopropane

- *Torsional strain: Eclipsing C-H bonds between neighboring atoms*
- *Steric strain: H atoms approaching one another too closely*


note how hydrogens are eclipsed !

Cyclobutane

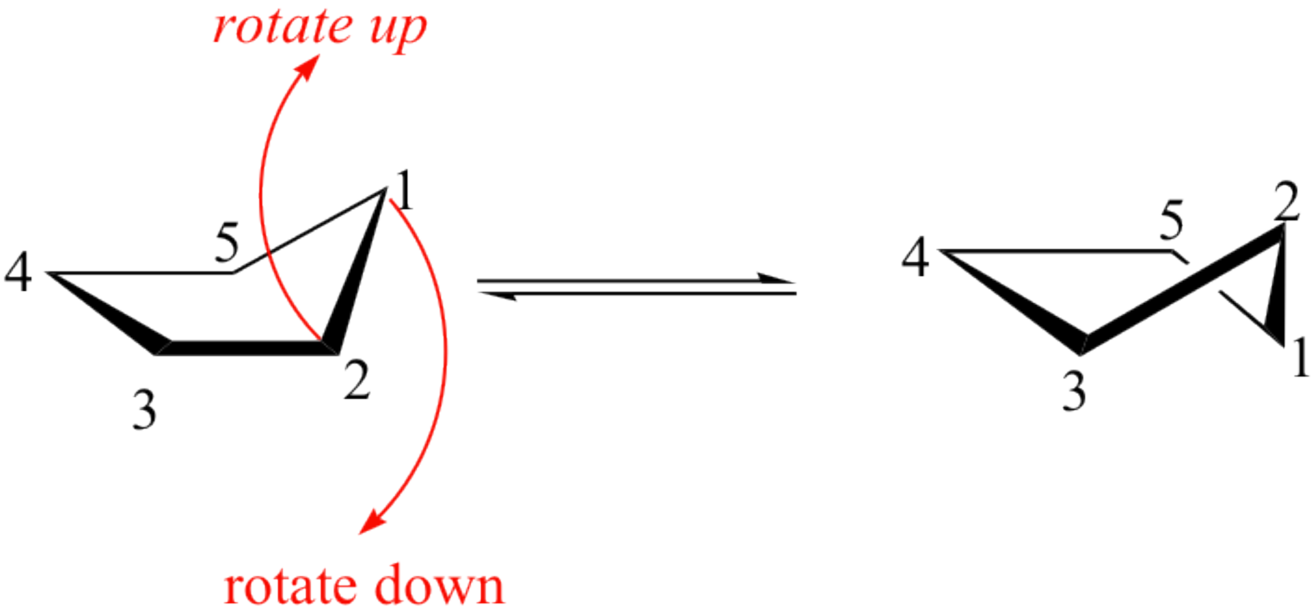
- Less angle strain
- More torsional strain (more H atoms in ring)
- Total strain similar to cyclopropane (CB = 110 vs CP 115 kJ/mol)
- “Bends” to increase angle strain and decrease torsional strain until a minimum energy balance is acheived
- Interconversion between bent structures



Cyclopentane

- Predicted by to be strain free, but in actuality = 26 kJ/mol of strain
- Practically no angle strain, but large torsional strain
- Twists to adopt a “puckered”, non-planar conformation to increase angle strain and decrease torsional strain
- Most H atoms are staggered with respect to their neighbors

  (4 carbons are in the same plane)



Conformations of polycyclic compounds

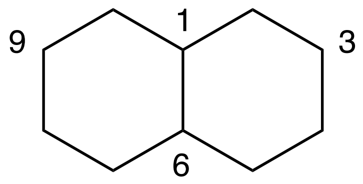
- Carbons 1 and 6 are called "bridgeheads"

- *Cis*- and *trans*- decalin are do ***not*** interconvert by ring flips or bond rotations

- Many other examples of polycyclic compounds in nature (i.e. steroids, terpenes)

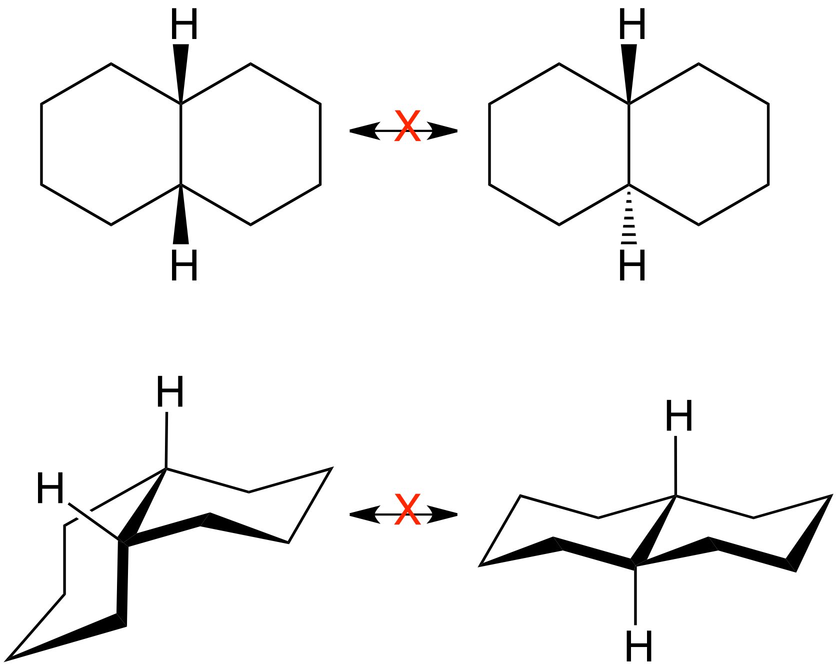
- Norborane is a conformationally "locked" cyclohexane "boat"

- Same rules of conformational analysis apply



Decalin

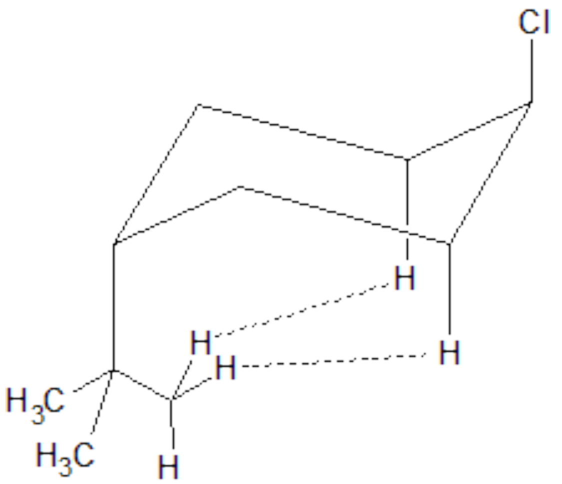
Cis-decalin *Trans*-decalin



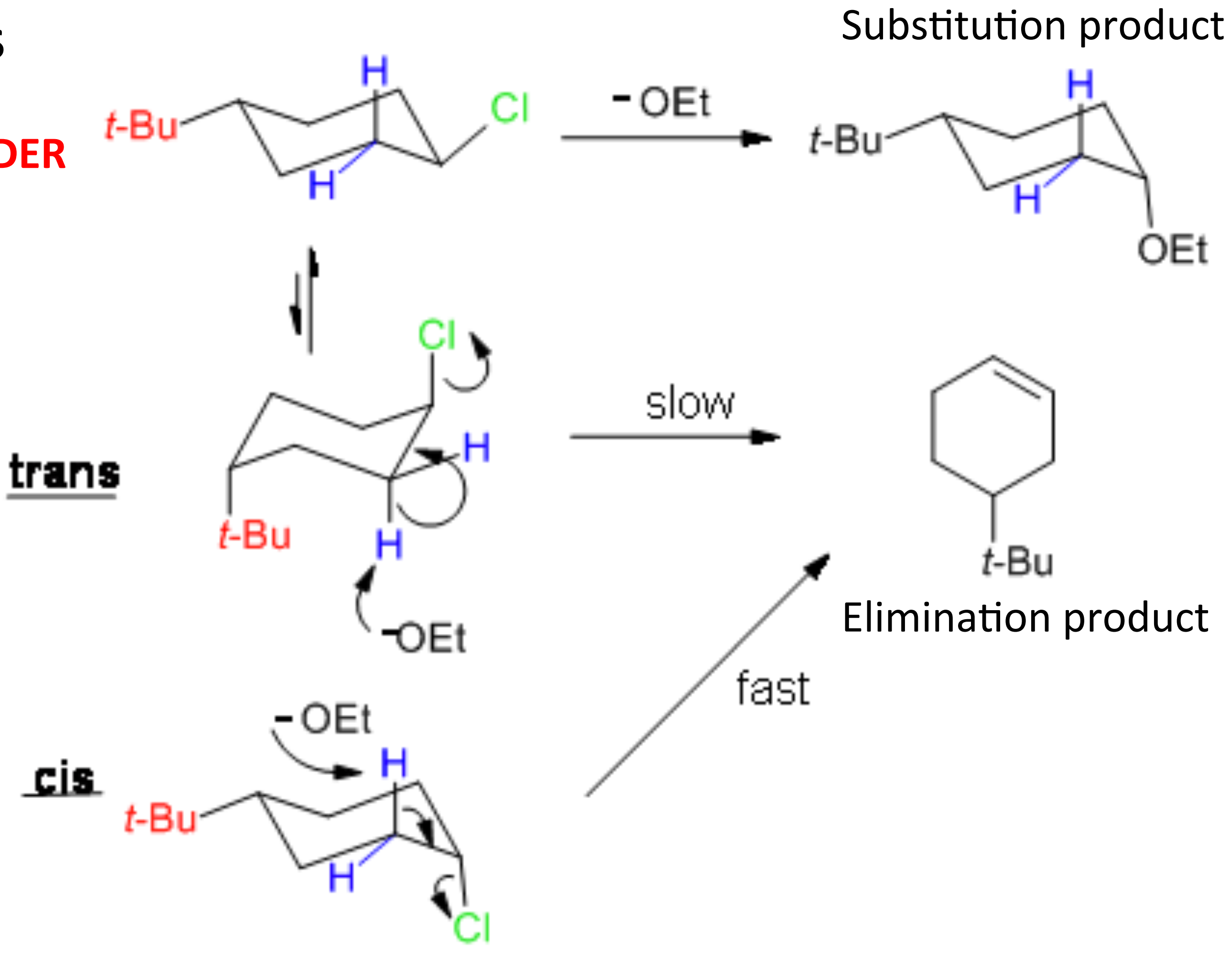
Conformation can determine ***rate*** and ***product outcome*** for organic reactions

- MODEL YOUR COMPOUNDS BEFORE YOUR SYNTHESIS

- WORK SMARTER, NOT HARDER



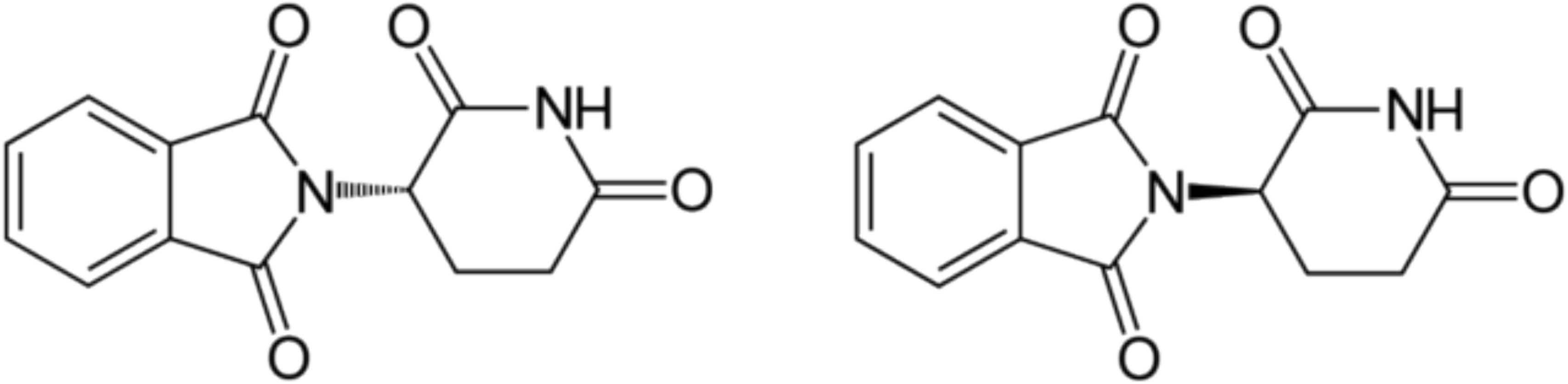
Conformationally unfavored *trans*-4-tert-butylcyclohexyl chloride



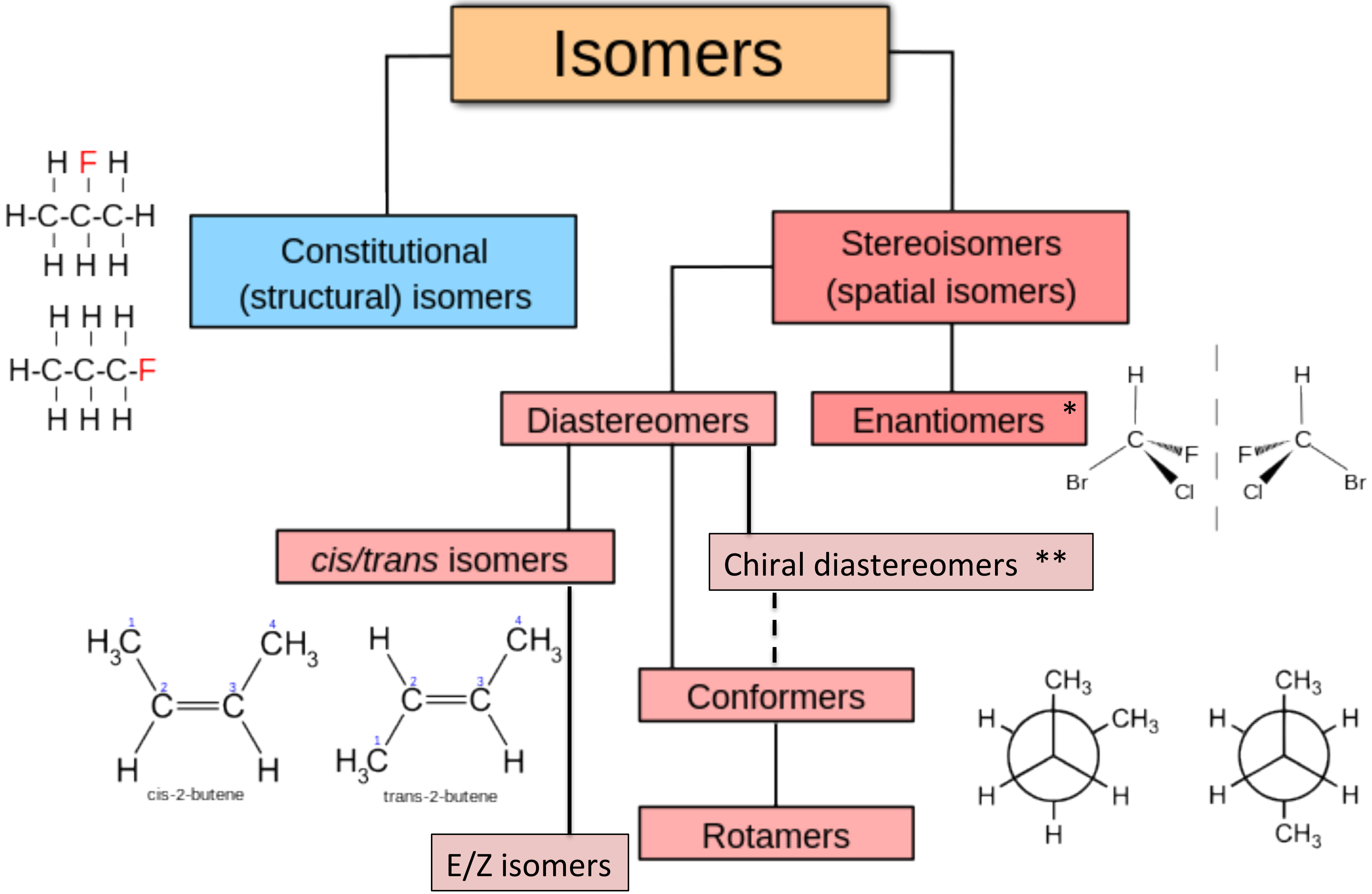
Stereochemistry and Isomers

- **Stereochemistry** = *The study of chemistry in three dimensions (3D), involving the relative spatial arrangement of atoms that form the structures of molecules.*

- **Isomer** = *compounds with the same number and kinds of atoms - but differ in the manner in which the atoms are connected, or arranged in space*



The (S) and (R) stereoisomers of Thalidomide – a teratogen



Isomers

Constitutional (structural) isomers

Stereoisomers (spatial isomers)

Diastereomers

Enantiomers *

cis/trans isomers

Chiral diastereomers **

Conformers

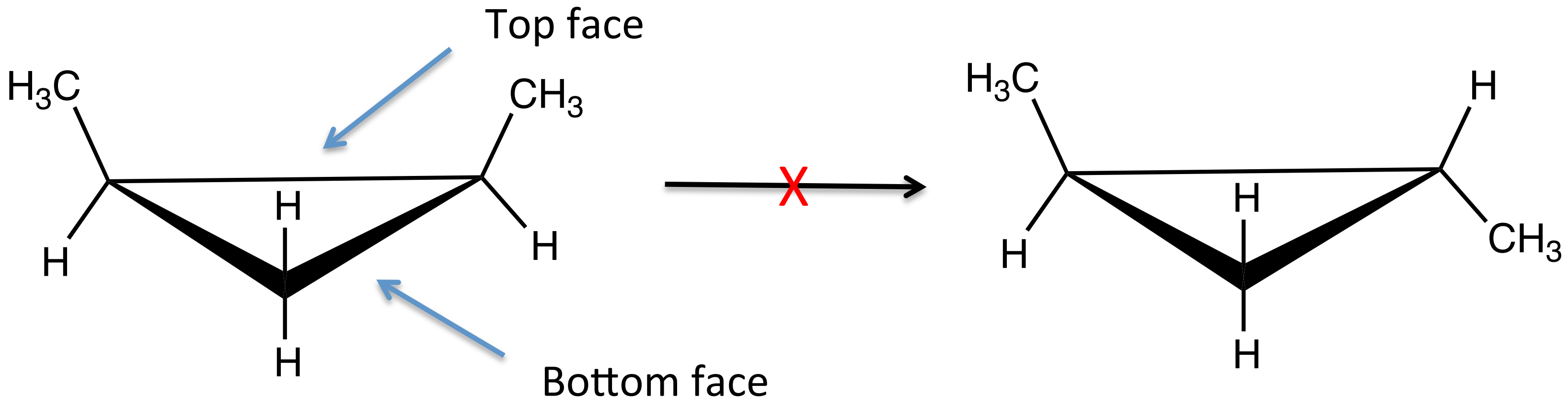
Rotamers

E/Z isomers

cis/trans refers to sides (or “faces”) of a molecule (top or bottom)
E/Z is best used for double bonds

Cis–Trans Isomers: cycloalkane example*

- When a molecule has two “faces”
- *Cis* orientation of substituents means “on the same side”
- *Trans* orientation of substituents means “on the opposite side”
- <u>Cannot</u> interconvert between *cis* and *trans* w/o breaking a C-C bond

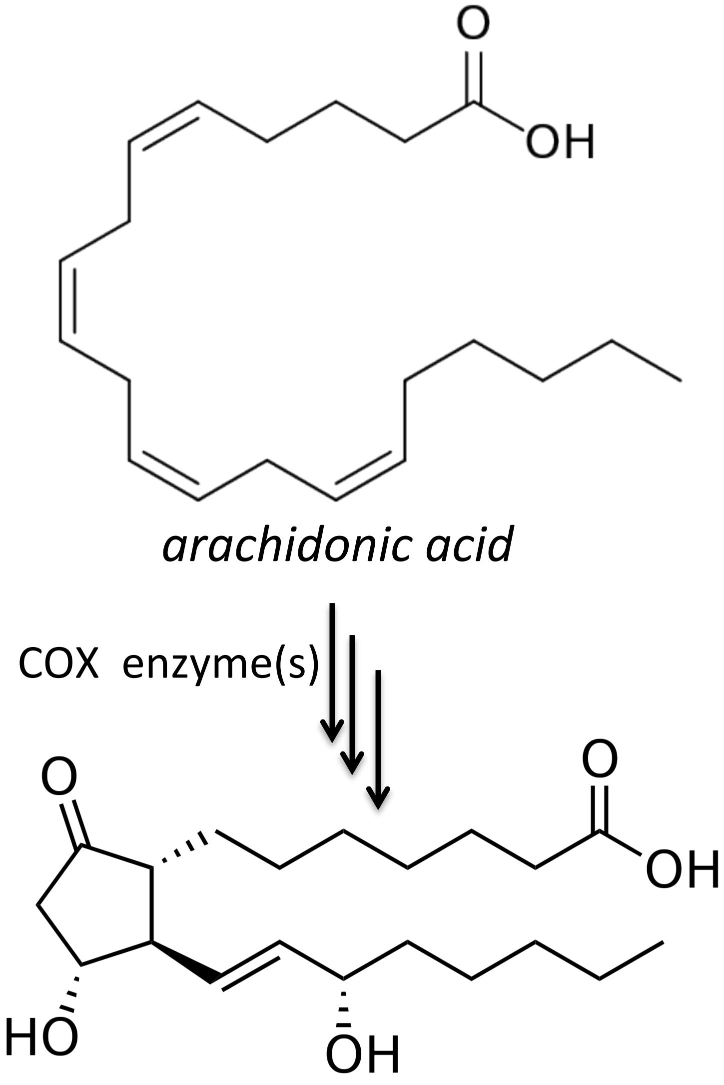


cis-1,2-dimethylcyclopropane

trans-1,2-dimethylcyclopropane

* *Cis-Trans* isomers are also possible at double bonds

Cis-trans cycloalkane isomers in biology



a representative prostaglandin

Prostaglandins:

- Found in almost every tissues in humans and animals
- Responsible for a diverse set of phenotypic affects
- Aspirin (COX inhibitor = NSAID)
- Hydroxyl group and and heptanoic acid chain are *cis*
- α-hydroxy octene chain is *trans*

Homework

- Chapter 3:

In text: 1, 2, 3, 4, 5, 6, 10, 11, 12, 16

End of Chapter: 22, 24, 29, 32, 35, 38, 52

- Chapter 4:

In text: 1, 2, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21

End of Chapter: 27, 28, 30, 34, 38, 40, 48, 54, 58, 61