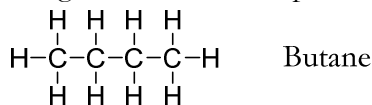


Loudon Ch. 2 Review: Alkanes

Jacque Richardson, CU Boulder – Last updated 4/20/2017

The simplest organic molecules are hydrocarbons. These contain just carbon and hydrogen. To be most stable, each C wants to have 4 total bonds and each H wants 1 bond. It's possible to link Cs together into long chains. For example, butane has four carbons.

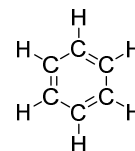


Hydrocarbons can still have multiple bonds between carbons. This gives us a basis to subdivide them into categories based on what types of bonds they contain: single, double, or triple. Another category is aromatic hydrocarbons, which react very differently and will be covered much later.

All single C-C bonds: alkane
At least 1 C-C double bond: alkene
At least 1 C-C triple bond: alkyne

} Aliphatic
hydrocarbons

Aromatic hydrocarbons: as far as we're concerned for now, anything with a six-membered ring of alternating single and double bonds



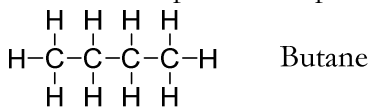
This chapter focuses only on alkanes. If all the carbons in an alkane are in a single, unbranched line, it's a **normal** or **n-alkane**. The names of these are listed below. These names are enough to uniquely identify each compound, but if you want to explicitly show that you're talking about the normal alkane, you can put "n-" at the start of the name. For example, five carbons in a row is pentane, but you can name it as n-pentane if you want to be absolutely clear you're discussing the linear form.

# of C	Name	Structure
1	Methane	CH ₄
2	Ethane	CH ₃ -CH ₃
3	Propane	CH ₃ -CH ₂ -CH ₃
4	Butane	CH ₃ -CH ₂ -CH ₂ -CH ₃
5	Pentane	CH ₃ -CH ₂ -CH ₂ -CH ₂ -CH ₃
6	Hexane	CH ₃ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₃
7	Heptane	CH ₃ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₃
8	Octane	CH ₃ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₃
9	Nonane	CH ₃ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₃
10	Decane	CH ₃ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₂ -CH ₃

This is one example of a **homologous series** – each subsequent item in the list has one more –CH₂– unit (also called a methylene group). Usually all members of a homologous series will have physical properties – melting point, boiling point, etc. – that vary in predictable ways.

The more carbons there are in a chain, the more work it takes to draw out the entire Lewis dot structure. For this reason, there are several different valid ways to draw the same compound, each one progressively more compact. We'll use butane as an example for all of them.

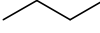
- Molecular formula: C₄H₁₀ for butane. This one is not actually a unique identifier, since with 4 or more carbons it's possible to put them together in different ways.

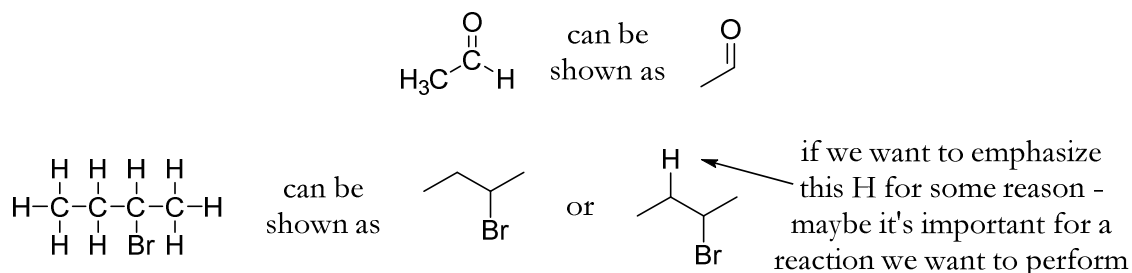


- Structural formula: $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ & | & | & | & | \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\ & | & | & | & | \\ & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ This is basically just the Lewis dot structure, with bonds indicated by lines rather than two shared dots.

Loudon Ch. 2 Review: Alkanes

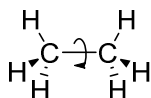
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- Condensed structural formula: $\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_3$ for butane. All H atoms are put either right before or right after the carbon atom to which they're attached.
- Highly condensed structural formula: $\text{CH}_3\text{-(CH}_2\text{)}_2\text{-CH}_3$ for butane. Any similar groups like the methylenes in the middle of the chain are grouped together with parentheses.
- Skeletal, line-bond or zigzag formula:  for butane. In this system, every bend or end of a line is a carbon unless explicitly stated otherwise. Hydrogen atoms are assumed to be present in the amount needed to fill octets (unless there's a charge on the atom that implies it does not have a filled octet). However, if an atom is shown explicitly, its H atoms must also be shown. Some other examples are shown below. Note that we have a choice in how much to show explicitly, depending on what parts of the molecule we're paying attention to. Any C or H can be drawn out. In the second example, the H that's shown happens to be important for a particular reaction.



Conformations of Alkanes

The conformation of a molecule is how the molecule arranges itself in space. Since bond length and bond angles are pretty much predetermined, we only have one type of variable to adjust: dihedral angles (a.k.a. torsion angles). We saw these in Ch. 1. As it turns out, there are better and worse dihedral angles. We can start looking at simple molecules and use this to make predictions for more complex ones. The simplest alkane where dihedral angles are possible is ethane. We will look at changing the dihedral angle by rotating around the C-C bond.



Using this system, we only have three ways to show the direction an H is pointing – either in-plane (regular bond), coming out of the plane (bold bond) or behind the plane (dashed bond). This is not enough detail to see the spatial relationships between Hs as the dihedral angle changes, so we need a more precise way to show them. We can use a **Newman projection** if we follow these steps:

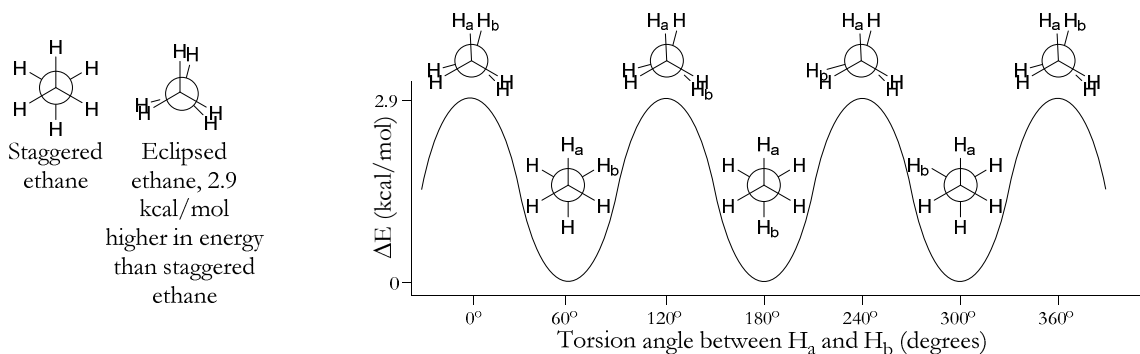
1. Choose a bond to sight along (for ethane, there's only one choice: the C-C bond).
2. Draw the front atom of this bond (the atom closer to you) as a dot, and the back atom as a circle.
3. Fill in the groups attached to each atom. If the groups are right on top of each other, you can space them out just a little to show them clearly, even though it's implied that the front groups are right in front of the back groups in this case.

Loudon Ch. 2 Review: Alkanes

Jacque Richardson, CU Boulder – Last updated 4/20/2017

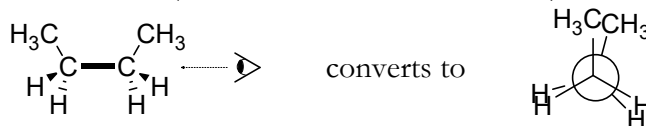


You can define the dihedral angle, θ (theta), as the angle between any two groups. In this case we can pick any H on the front C and any H on the back C to define our dihedral. We'll label these as H_a and H_b . Hold one carbon still (in the example below, this is the front C) and rotate the other carbon in 60-degree increments (in the example below, the back C is rotating clockwise). We can measure the energy experimentally as the back C rotates, and graph it as shown below. As it turns out, the conformations where a front H is covering up a back H (called **eclipsing** conformations) are 2.9 kcal/mol higher in energy than when the Hs are evenly spread out (called **staggered** conformations).



This energy difference is caused by **torsional strain** – the repulsion between electrons in the C-H bonds to the front and back carbons. Even though they're not overlapping in space, they still have a slight preference for being more spaced out from each other. This is not a strong preference though – this barrier is so small compared to the amount of energy available at room temperature that ethane can pass through its eclipsed form about 10^{11} times per second.

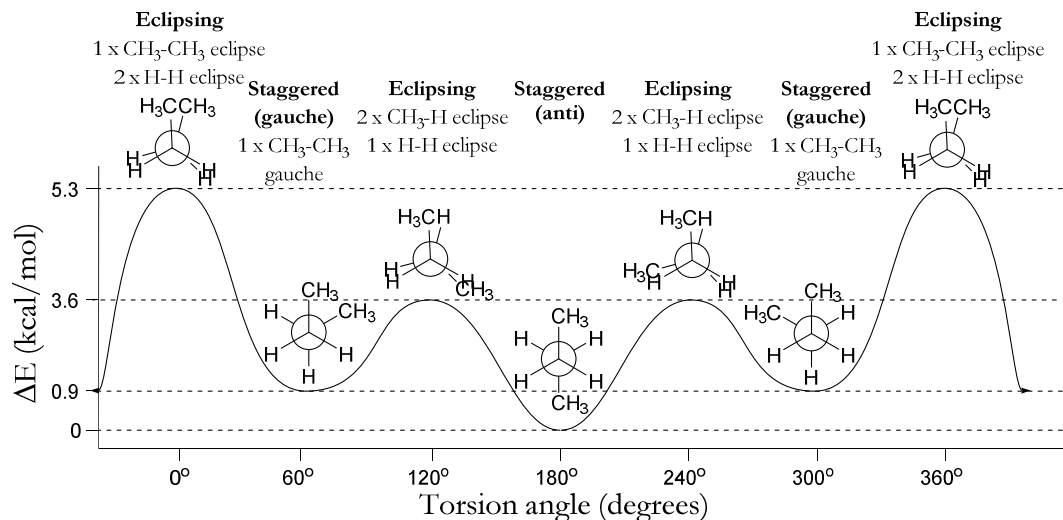
As a second example, we will look at the energy diagram for the dihedral angles of butane. In this case we have multiple C-C bonds we could sight along, but we will choose to sight along the middle bond of the molecule (referred to as the C2-C3 bond).



We're going to define our dihedral angle as the angle between the two methyl (CH_3) groups. Again, we can generate a Newman diagram for dihedral angles in increments of 60 degrees, and graph what the values are measured to be. Several things are different compared to ethane. For one thing, there are two different types of eclipsing conformations: one where the two methyl groups are eclipsing each other (costing 5.3 kcal/mol) and one where they're not (costing 3.6 kcal/mol). There are also two types of staggered interactions: one where the two methyl groups are 60° apart from each other (costing 0.9 kcal/mol) and one where they're 180° apart from each other (costing 0 kcal/mol). The conformation where the two methyl groups are 180° apart is called **anti**. The one where they're 60° apart from each other is called **gauche**, from the French word describing to pass nearby something.

Loudon Ch. 2 Review: Alkanes

Jacque Richardson, CU Boulder – Last updated 4/20/2017

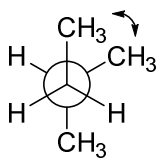


The energy cost of the gauche form is similar to the energy cost of eclipsed ethane: repulsion between electrons. However, something even more severe is happening in the $\text{CH}_3\text{-CH}_3$ eclipsed form of butane: not only are the methyl groups feeling electron repulsion, but they are impinging on each other's atomic radii by trying to physically cram into the same area of space. The repulsion they feel from this is called **van der Waals repulsion**, or **steric hindrance**. This is something that is quite important in predicting whether certain reactions will be able to happen or not; if the sterics are too crowded, the molecules cannot bring their reactive atoms together closely enough to react.

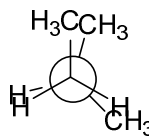
From the two graphs above, we can figure out the energy cost of each type of interaction. There is no energy cost for any type of gauche interaction involving H as a group – it's just too small to be affected by other groups gauche to it.

Interaction	Cost	Math
H-H eclipse	~ 1 kcal/mol	$(3 \text{ kcal/mol})/3$ - from ethane
$\text{CH}_3\text{-H}$ eclipse	1.3 kcal/mol	$(3.6-1) \text{ kcal/mol}/2$ - from butane
$\text{CH}_3\text{-CH}_3$ eclipse	3.3 kcal/mol	$(5.3-2) \text{ kcal/mol}$ - from butane
$\text{CH}_3\text{-CH}_3$ gauche	0.9 kcal/mol	0.9 kcal/mol - from butane

We can use this to estimate the energy of different conformations for unknown molecules. These predictions are not always exact but they're close enough to get an idea.



1 gauche interaction,
so total cost should
be 0.9 kcal/mol.



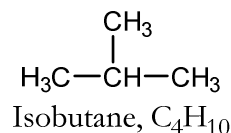
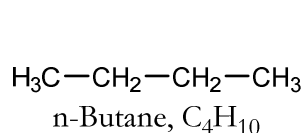
1 $\text{CH}_3\text{-CH}_3$ eclipse,
1 $\text{CH}_3\text{-H}$ eclipse,
1 H-H eclipse,
so total cost should be
 $1+1.3+3.3 = 5.6$ kcal/mol.

Nomenclature

This is the topic of how to name things – specifically, alkanes in this chapter. We've covered some names of normal alkanes above, but we need to also name branched alkanes. This is necessary because as we saw above, there can be multiple structures possible with the same formula. These are called **structural isomers**, and an example is shown below. The more carbons there are in a molecule, the more structural isomers are possible.

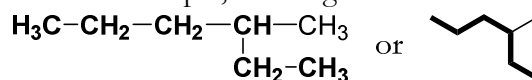
Loudon Ch. 2 Review: Alkanes

Jacque Richardson, CU Boulder – Last updated 4/20/2017

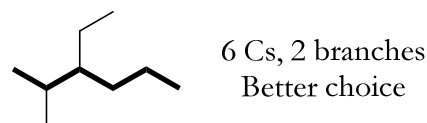
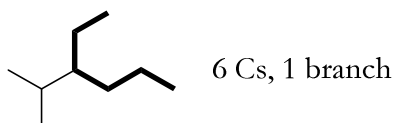


Although there are a lot of old, non-systematic names in use, it's better to use the names that follow rules defined under the **IUPAC system**. These are based on steps that you follow sequentially, although you can stop once you reach a point where there's only one choice of what to do.

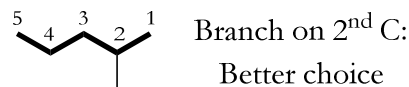
1. If a molecule is unbranched, follow the names given in the table for n-alkanes.
2. If a molecule is branched, first determine the longest/principal/parent chain. This is the one with the most carbon atoms, shown in bold here. They won't necessarily be all in a horizontal line. In this example, the longest chain is 6 carbon atoms.



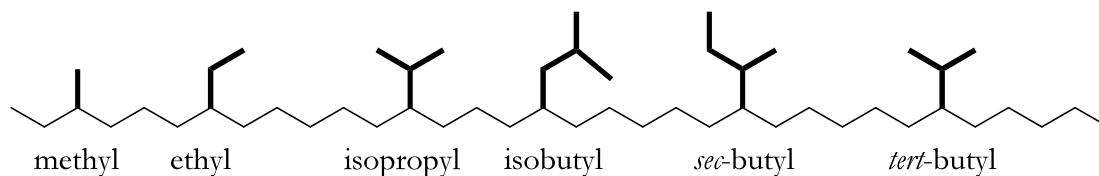
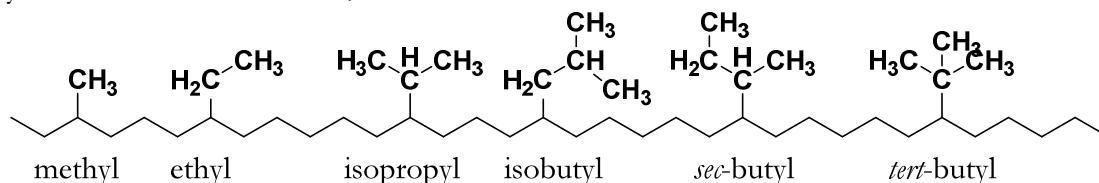
3. If multiple paths along the molecule have the same largest number of carbon atoms, choose the one with more branch groups attached to it. For this molecule, there are two choices, but the one on the right is better because it has two branch groups connected to it.



4. Number the carbons of the parent chain, starting at the end closest to a branch point.



5. Name each substituent branch and give the number of the carbon on the parent chain where it's attached. Each branch is named after the n-alkane with the same number of carbon atoms, but you drop "ane" from the name and add "yl". For example, a one-carbon branch group is a methyl group (as we saw for Newman projections). There are some other groups that are not named after n-alkanes that you should be able to name; these are shown below.



Most small alkyl groups have short abbreviations that show up frequently.

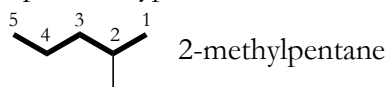
Methyl	Me	Propyl	Pr or nPr	Isopropyl	iPr	<i>sec</i> -Butyl	sBu
Ethyl	Et	Butyl	Bu or nBu	Isobutyl	iBu	<i>tert</i> -Butyl	tBu

Loudon Ch. 2 Review: Alkanes

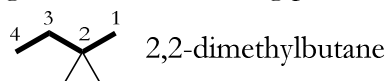
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For example, most people would write ethanol, $\text{CH}_3\text{CH}_2\text{OH}$, as EtOH. *tert*-Butyl iodide, or $(\text{CH}_3)_3\text{CI}$, could also be written as tBuI.

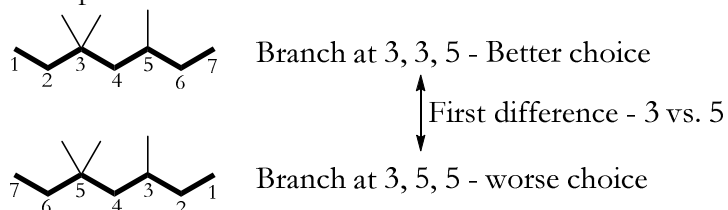
6. Name the compound as “attachment location”-“substituent”“parent”. In general, everything is separated with hyphens, except the last substituent and the parent – this is just put together with no space or hyphen.



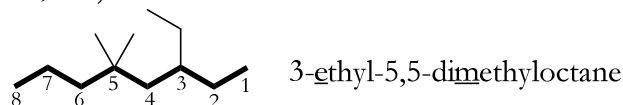
7. If the parent has multiple substituents, each gets its own location. Identical substituents get grouped together with a counting prefix like di, tri, tetra, penta, etc.



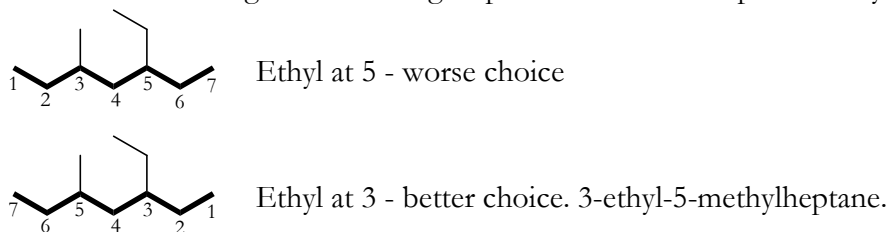
8. If the parent has multiple substituents and step 4 didn't resolve how to number the parent chain – in other words, if both ends started equally close to a branch point – then compare locations of each branch group and choose the one with the smallest number at the first point of difference.



9. If the parent has multiple substituents, cite groups in alphabetical order, regardless of where they appear on the chain. Include unhyphenated prefixes (*iso*, *neo*, and *cyclo*) for alphabetization, but exclude hyphenated prefixes (*sec*- and *tert*-) and counting prefixes (*di*, *tri*, *tetra*, etc.).

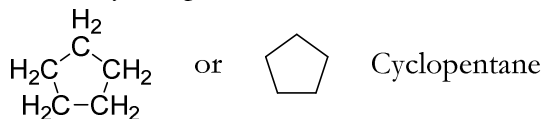


10. If the parent has multiple substituents and step 8 still didn't resolve how to number the parent chain – in other words, if the numbering system is identical for either direction – start numbering closer to the group that is cited first alphabetically.



Cycloalkanes

Carbon atoms can also be linked into a ring. These are named after the alkane with the same number of carbons, but with a “cyclo” prefix.



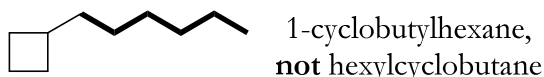
Loudon Ch. 2 Review: Alkanes

Jacque Richardson, CU Boulder – Last updated 4/20/2017

These follow roughly the same rules as for naming branched alkanes, except numbering can hypothetically start with any carbon on the ring. As before, though, you want to choose a point to start numbering that minimizes the location of the first substituent, or if that doesn't resolve it, then the numbering that minimizes the location at the first point of difference. Also, if there's only one substituent, it's automatically attached to carbon 1 so you can drop the location prefix.

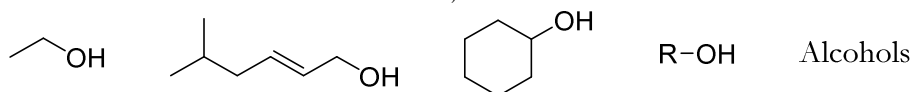


If a ring has fewer carbons than the chain it's attached to, then the chain becomes the parent instead, and the ring is named as a substituent.

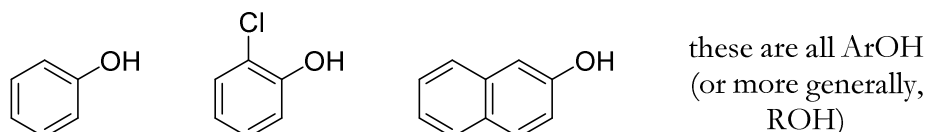


Functional Groups

These are small groups of atoms that react in a particular characteristic way, usually with no regard for what the rest of the molecule looks like. For example, all alcohols have an -OH group. The rest of the molecule is sometimes just abbreviated as R.



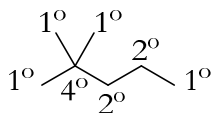
A subcategory of R is anything based on an aromatic ring. These are called **aryl groups**, or Ar for short.



The inside front cover of the textbook contains a list of functional groups (FGs) which you should learn. We'll cover a lot more about these later in organic chemistry.

Substitution Patterns

Carbon atoms can be described based on how many bonds they have to other carbon atoms. One bond is primary (1°), two bonds is secondary (2°), three bonds is tertiary (3°), and four bonds is quaternary (4°). In many reactions, these four types of carbon will all react slightly differently.



H atoms can also use these descriptors. Because they can each only make one bond, they just get the same descriptor as the carbon atom they're attached to. So the carbon atoms marked 2° in the example above would also have H atoms that are described as 2° .

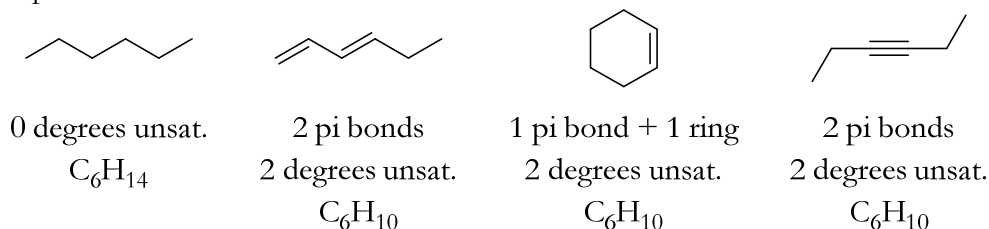
Degrees of Unsaturation

For linear or branched alkanes, the formula is always $\text{C}_n\text{H}_{2n+2}$. For example, methane is CH_4 , ethane is C_2H_6 , and propane is C_3H_8 . Each pair of missing H atoms from this formula is one **degree of unsaturation**. These can be caused by two things: pi bonds or rings. In any

Loudon Ch. 2 Review: Alkanes

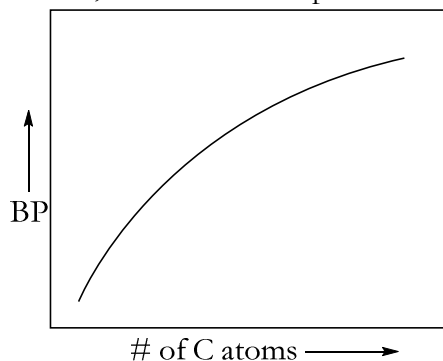
Jacque Richardson, CU Boulder – Last updated 4/20/2017

multiple bond between atoms, the first line of the bond is a sigma bond, and any additional lines are pi bonds.

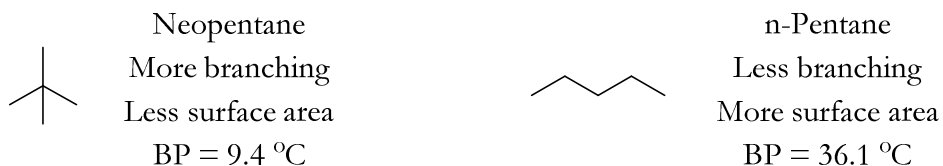


Physical Properties

These include things like melting point, boiling point, density, and solubility. **Boiling point** (BP) is the point where the vapor pressure of a compound equals the atmospheric pressure (usually set as 1 atm). For n-alkanes, this is a smooth plot.



BP measures the **intermolecular forces** (how strongly molecules stick together) in the liquid state. The weakest but most universal intermolecular force is **dispersion** (a.k.a. van der Waals) forces. These are caused by attraction between temporary dipoles, caused by the electron cloud around a molecule “sloshing” back and forth briefly. Other molecules feel these dipoles and make corresponding induced dipoles, which pull the molecules together slightly. The more surface area a molecule has, the stronger this effect is. Having more carbons increases dispersion forces, but branching lowers them because the molecule is rounder and less splayed-out.

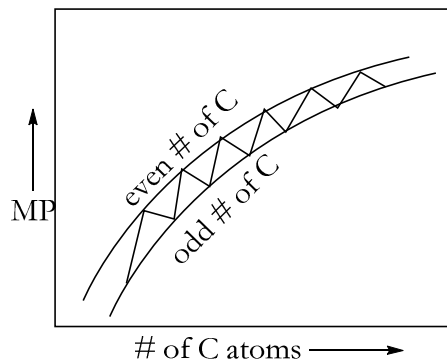


There are other, stronger intermolecular forces, but we'll cover these later.

Melting point (MP) is more dependent on intermolecular forces in the solid state. Higher MP means there are stronger intermolecular forces holding the molecules together into a crystal. Unlike BP, this does not increase linearly but has more of a sawtooth pattern. This is because it is alternating back and forth between two smooth curves – one for even numbers of carbon atoms, and one for odd.

Loudon Ch. 2 Review: Alkanes

Jacque Richardson, CU Boulder – Last updated 4/20/2017



This is because even-numbered molecules form crystals more easily than odd, because they can pack together more efficiently. This has to do with molecular symmetry. For branched molecules, branching usually lowers the MP because it disrupts packing.