Organic Chemistry

Chem 121: Topics

Carbon Bonding
Orbital Hybridization/ Molecular Shape / Structures
Hydrocarbon Backbones / Functionality / Nomenclature
Isomerism: Constitutional, Geometric, Enantiomeric, Diastereomeric
Optical Activity
Reactions: Oxidation / Reduction / Esterification / Condensation
Polymers / Biochemistry

ORGANIC CHEMISTRY

- The study of carbon-containing compounds.
- Organic compounds contain backbones comprised of chains and/or rings of carbon and hydrogen atoms.
- Commonly used formulas are empirical, molecular, structural (bond-line, condensed and 3-D), which are most commonly used over empirical, molecular formulas.

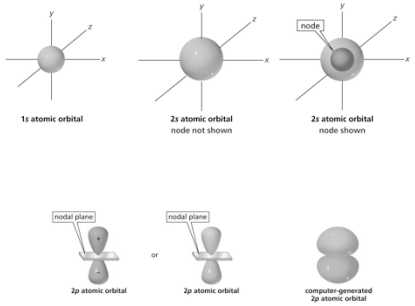
HYDROCARBONS

- Compounds composed of only carbon and hydrogen atoms (**C**, **H**).
- **Acyclic** (without rings); **Cyclic** (with rings); **Saturated**: only carbon-carbon single bonds; **Unsaturated**: contains one or more carbon-carbon double and/or triple bonds
- They represent a "backbone" when other "heteroatoms" (**O, N, S,** .....) are substituted for **H**. (The heteroatoms give function to the molecule.)
- Consider the bonding arrangements for (**C**, **H**, **O,** and **N**). **Particularly that each carbon has 4 bonds**.

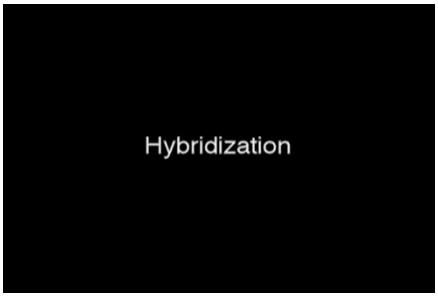
Bonding Arrangements

	C			H	O		N		
# of Valence's	4			1	6		5		
Total # of Bonds (neutral atom)	4			1	2		3		
Combinations of bonds (neutral atom)									
# of single bonds	4	2	1	1	2	0	3	1	0
# of double bonds	0	1	0	0	0	1	0	1	0
# of triple bonds	0	0	1	0	0	0	0	0	1
Total Bonds	4	4	4	1	2	2	3	3	3
# of Free Pairs of electrons	0	0	0	0	2	2	1	1	1

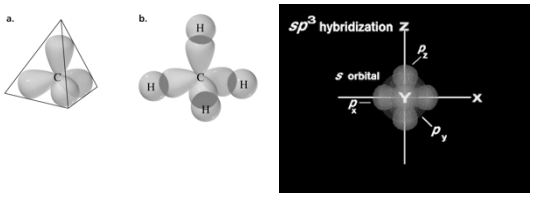
Orbitals / Bonding / Shape
Atomic s and p orbitals



Orbitals / Bonding / Shape
Mixing Atomic Orbitals
Hybridization of s and p orbitals

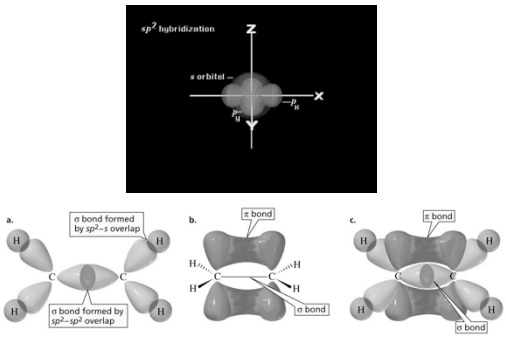


The atomic orbitals used in bond formation determine the bond angles

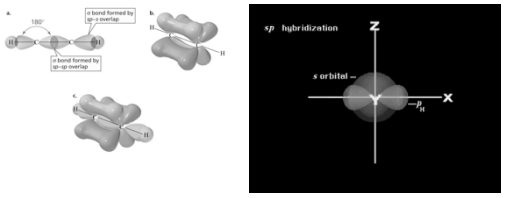


- *Tetrahedral bond angle: 109.5°*
- *Electron pairs spread themselves into space as far from each other as possible*

sp² hybridization



A Triple Bond
sp-hybridization



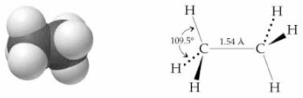
• A triple bond consists of one σ bond and two π bonds with a bond order of 3.
•Triple bonds are shorter and stronger than double bonds
• There is a bond angle of the sp carbon: 180°

HYDROCARBONS

- Alkanes contain only single (σ) bonds and have the generic molecular formula: $[C_nH_{2n+2}]$
- Alkenes also contain double ($\sigma + \pi$) bonds and have the generic molecular formula: $[C_nH_{2n}]$
- Alkynes contain triple ($\sigma + 2\pi$) bonds and have the generic molecular formula: $[C_nH_{2n-2}]$
- Aromatics are planar, ring structures with alternating single and double bonds: eg. C_6H_6

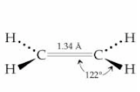
Types of Hydrocarbons

(a) ALKANE Ethane CH_3CH_3



Each C atom is tetrahedral with sp^3 hybridized orbitals.

(b) ALKENE Ethylene $CH_2=CH_2$



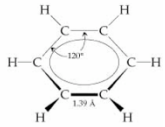
Each C atom is trigonal planar with sp^2 hybridized orbitals. There is no rotation about the C=C bond in alkenes.

Types of Hydrocarbons

(c) ALKYNE Acetylene $CH\equiv CH$

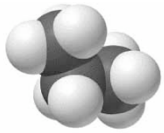
Each C atom is linear with sp hybridized orbitals.

(d) AROMATIC Benzene C_6H_6

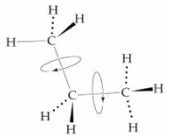


Each C--C bond is the same length; shorter than a C-C bond: longer than a C=C bond. The concept of resonance is used to explain this phenomena.

Propane



It is easy to rotate about the C-C bond in alkanes.



QUESTION

An acyclic (noncyclic) hydrocarbon alkane has 12 carbon atoms. How many hydrogen atoms would one molecule of the compound possess?

A. 12
B. 24
C. 26
D. It would depend on more than just the number of carbon atoms; it cannot be predicted without more information.

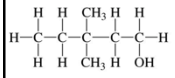
Molecular Representations

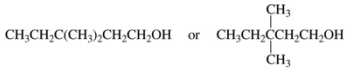
Representing Substances

*Empirical Formula, Molecular Formula, Structure: (Lewis, Kekule, **Condensed, Line**), **Visual Model**: wireframe, stick, ball & stick, space filling, electrostatic, energy surface*

Formulas & Kekulé / Condensed / Bond-Line Structures / Drawings

Molecular formula: ?? *Empirical Formula: ??*





Bond-Line Structure ??:

Naming Alkanes

***C_1 - C_{10}**: the number of C atoms present in the chain.*

FIRST SEVERAL MEMBERS OF THE STRAIGHT-CHAIN ALKANE SERIES

Molecular Formula	Condensed Structural Formula	Name	Boiling Point (°C)
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	20.5
C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$	Pentane	36
C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$	Hexane	68
C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	Heptane	98
C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Octane	125
C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Nonane	151
$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Decane	174

Each member C_3 - C_{10} differs by one CH_2 unit. This is called a homologous series.
Methane to butane are gases at normal pressures.
Pentane to decane are liquids at normal pressures.

Nomenclature: Alkanes

Names to Structures

1. For alkanes: $C_{1,2,3,4}$- methane, ethane, propane, butane; beyond C_4, butane, add -ane to the Greek root for the number of carbons.

   C-C-C-C-C-C = hexane

2. Alkyl substituents: drop the -ane and add -yl.

   $-CH_3$: methyl

   $-C_2H_5$: ethyl

Names of Some Alkyl Groups

methyl	CH_3-	*sec*-butyl	$CH_3CH_2\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-$
ethyl	CH_3CH_2-		
propyl	$CH_3CH_2CH_2-$	*tert*-butyl	$CH_3\underset{\displaystyle CH_3}{\underset{\vert}{\overset{\displaystyle CH_3}{\overset{\vert}{C}}}}-$
isopropyl	$CH_3\underset{\displaystyle CH_3}{\underset{\vert}{CH}}-$		
butyl	$CH_3CH_2CH_2CH_2-$	pentyl	$CH_3CH_2CH_2CH_2CH_2-$
isobutyl	$CH_3\underset{\displaystyle CH_3}{\underset{\vert}{CH}}CH_2-$	isopentyl	$CH_3\underset{\displaystyle CH_3}{\underset{\vert}{CH}}CH_2CH_2-$

Examples of Alkyl Substituents

CH_3OH methyl alcohol	$CH_3CH_2NH_2$ ethylamine	$CH_3CH_2CH_2Br$ propyl bromide	$CH_3CH_2CH_2CH_2Cl$ butyl chloride
CH_3I methyl iodide	CH_3CH_2OH ethyl alcohol	$CH_3CH_2CH_2NH_2$ propylamine	$CH_3CH_2CH_2CH_2OH$ butyl alcohol

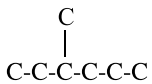
QUESTION

2,3-dimethylbutane has how many carbon atoms in its longest continuous carbon chain?

A. 2
B. 3
C. 4
D. 6

Naming Alkanes

3. Positions of substituent groups are specified by numbering the longest chain sequentially.



3-methylhexane

4. Location and name are followed by root alkane name. Substituents in alphabetical order and use di-, tri-, etc.

QUESTION

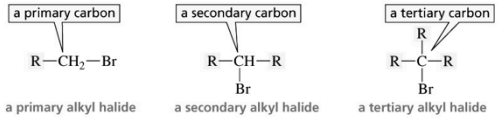
How many carbon atoms are present per molecule in the compound 3-methyl-4-ethyloctane? How many of those are present on the side chains (branches) only?

A. 11 total; 3 on branches
B. 15 total; 7 on branches
C. 12 total; 3 on branches
D. 15 total; 2 on branches

Structures ↔ Names

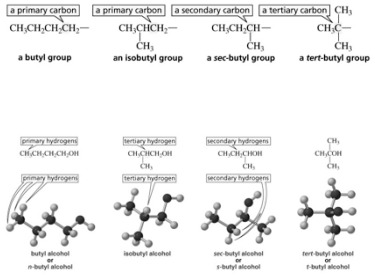
Draw a bond-line structure for:
4-ethyl-3,5-dimethylnonane

Different Kinds of Alkyl Carbon Atoms



1. *Notice that methyl itself is not considered.*
2. *Notice the number of H atoms: 1º= 2H; 2º= 1H; 3º= 0*
3. *This distinction is not limited to halides, but applies to all sp^3 hybridized carbon atoms with a substituent, eg. –OH (alcohols), etc.*
4. *For non-substituted C atoms an H atom replaces the substituent. eg. R-CH_2-H = R-CH_3 = primary, etc.*

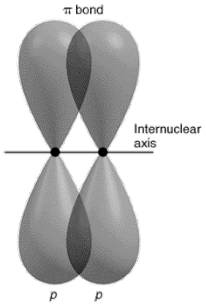
Different Kinds of sp^3 Carbon and Associated Hydrogen Atoms



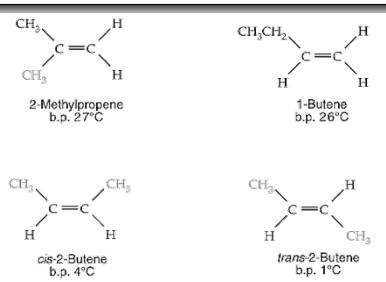
Unsaturated Hydrocarbons
Alkenes

- Alkenes contain C, H atoms and single and double bonds.
- The simplest alkenes are $H_2C=CH_2$ (ethene) and $CH_3CH=CH_2$ (propene):
  - Their trivial names are ethylene and propylene.
- Alkenes are named in the same way as alkanes with the suffix -ene replacing the -ane in alkanes.
- The location of the double bond is indicated by a number.
- Geometrical (cis-trans) isomers are possible since there is no rotation about a C=C π bond.

Unsaturated Hydrocarbons
Alkenes



Unsaturated Hydrocarbons
Alkenes



Structures ↔ Names

Draw a bond-line structure for:
cis-4-methyl-2-hexene

QUESTION

How many hydrogen atoms would be part of one molecule of cyclopentene?

A. 4
B. 5
C. 8
D. 10

Unsaturated Hydrocarbons Alkynes

- Alkynes are hydrocarbons with one or more C≡C bond. The triple bond in alkynes have one σ and two π bonds between two C atoms.
- Ethyne (acetylene) is a reactive alkyne: HC≡CH.
- When acetylene is burned in the presence of oxygen (oxyacetylene torch) the temperature is about 3200 K.
- Alkynes are named in the same way as alkenes with the suffix -yne replacing the -ene for alkenes.

Structures ↔ Names

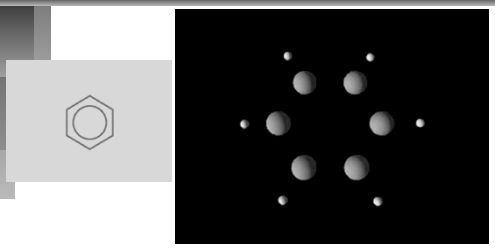
Draw a bond-line structure for:
4-methyl-1-pentyne

QUESTION

One of the ingredients on a margarine container is listed as "polyunsaturated corn oil." The most likely best meaning is that:

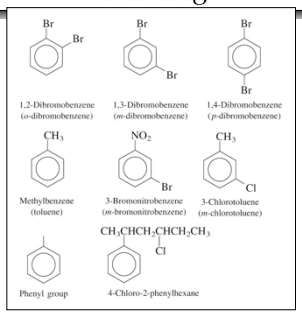
A) all the carbon bonds in the oil are single bonds.
B) corn oil is a polymer without any single bonds.
C) all of the carbon–carbon bonds are triple bonds.
D) all of the carbon–carbon bonds are double bonds.
E) there are many carbon–carbon bonds, which are either double or triple bonds.

Unsaturated Hydrocarbons Aromatics

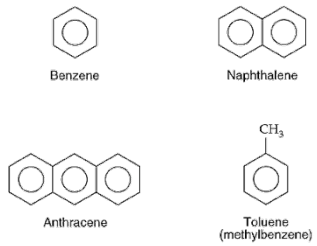


- Aromatic structures are formally related to benzene.
- Resonance forms provide for delocalized π electrons leading to equal bond lengths. The net result is represented as a circle in the ring.

Substituted Benzenes: Naming

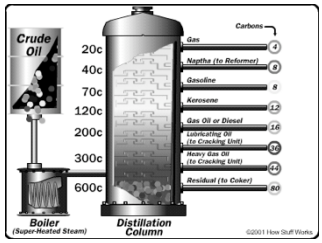


Unsaturated Hydrocarbons Aromatics



Hydrocarbons / Oil Refining

http://science.howstuffworks.com/environmental/energy/oil-refining4.htm



Functional Groups

"Functionality" relates to a chemically distinct, generally reactive portion of a molecule.

- Alkanes do not have functionality.
- The simplest functional groups contain π electrons.
- Common functional groups contain heteroatoms, elements other than C or H, in particular bonding arrangements. ***Recognition of these patterns are essential to understanding organic chemistry.***
- **NOTE:** *A generic representation, R-, can be used to represent the entire C-H portion (backbone) of the molecule.*

Common Functional Groups

Key Oxygen & Nitrogen Functions		
Alcohol		CH_3CH_2OH
Ether		CH_3OCH_3
Aldehyde		CH_3CHO
Ketone		CH_3COCH_3
Carboxylic Acid		CH_3COOH
Ester		$CH_3CO_2CH_3$
Amide		$CH_3CONHCH_3$
Amine		CH_3NHCH_3

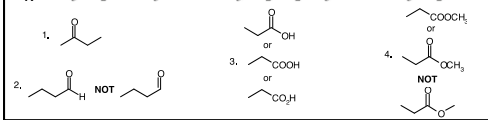
Bond-line structures (omitting H atoms).

1. $CH_3CH_2\overset{O}{\overset{\|}{C}}CH_3$ or $CH_3CH_2COCH_3$ or $CH_3CH_2C(=O)CH_3$ ***ketone***

2. $CH_3CH_2CH_2\overset{O}{\overset{\|}{C}}H$ or $CH_3CH_2CH_2CHO$ or $CH_3CH_2CH_2CH{=}O$ ***aldehyde***

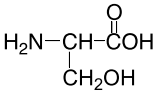
3. $CH_3CH_2\overset{O}{\overset{\|}{C}}OH$ or $CH_3CH_2CO_2H$ or CH_3CH_2COOH ***carboxylic acid***

4. $CH_3CH_2\overset{O}{\overset{\|}{C}}OCH_3$ or $CH_3CH_2CO_2CH_3$ or $CH_3CH_2COOCH_3$ ***ester (carboxylic acid ester)***



QUESTION

Identify the functional groups in the following molecule.



A) Alcohol, amide, carboxylic acid

B) Aldehyde, amine, ester

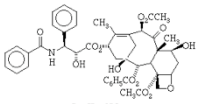
C) Alcohol, amine, carboxylic acid

D) Aldehyde, amide, ketone

Spectroscopy in Organic Chemistry

- *IR* is used to determine the function(s) in the molecule.
- *NMR* is used to determine the carbon backbone and hydrogen arrangements.
- Mass Spectrometry (*MS*) is used to determine the molecule weight (molar mass), to identify unique structural features from high energy structural fragments, and to determine the molecular formula.

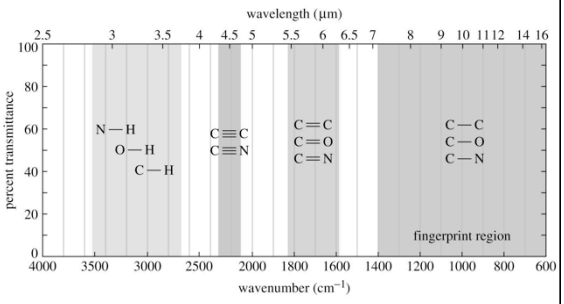
Taxol / Identification



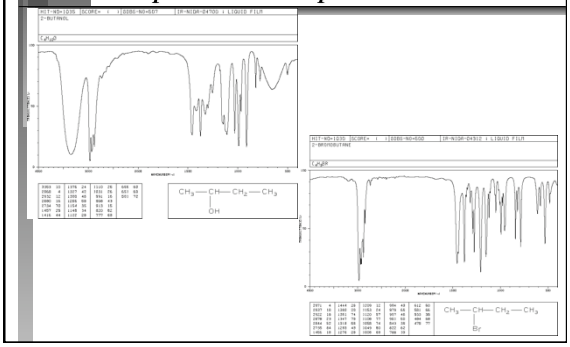
$C_{47}H_{51}NO_{14}$

Physical Properties m.p. / b.p. index of refraction	Infrared Spectroscopy (Functionalities)
Chemical reactions:	Ultraviolet Spectroscopy (Unsaturation: double bonds)
Combustion: % C,H,N,O plus others, [O], etc.	NMR Spectroscopy (Nuclear Magnetic Resonance) Atom attachments: ^{1}H, ^{13}C, ^{15}N & Others
Reduction [H]: Degrees of unsaturation	Mass Spectroscopy High Energy Fragments; GC/MS: Low Conc. (ppb)
Synthetic Derivatives (Solids: m.p.)	*OTHER:* ESR / CD / ORD

IR- Absorbance



IR- Empirical Comparisons



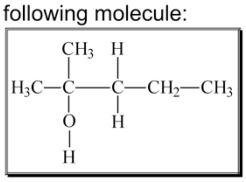
IR- Empirical Comparisons

Functional Groups:
Alcohols *(R-OH)*

- Alcohols contain -OH groups.
- The names are derived from the hydrocarbon name with --ol in place of the -ane suffix. Example: ethane becomes ethanol.
- Since the -O-H bond is polar, similar to H-O-H, alcohols are quite soluble in water.
- CH_3OH, methanol, is used as a gasoline additive and a fuel. CH_3CH_2OH, ethanol is a legal recreational drug that can be dangerous.

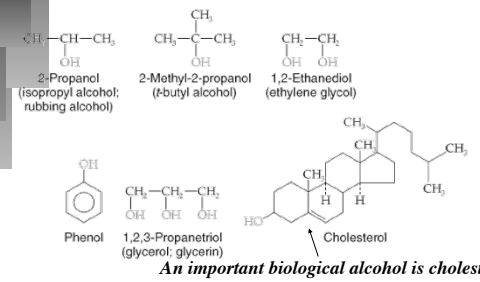
QUESTION

Classify the following molecule:



A) primary alcohol
B) secondary alcohol
C) tertiary alcohol
D) ether
E) phenol

Functional Groups: Alcohols (R-OH)



An important biological alcohol is cholesterol. Cells cannot survive without it!

Functional Groups: Ethers (R-O-R)

- Like alcohols ethers have an oxygen atom with two single bonds.
- But instead of a hydrogen atom being bonded to the oxygen as in alcohols, ethers have oxygen bonded to two carbons (R-).
- Ethers are commonly used as solvents.
- Certain ethers are biologically active. Some are used as anesthetics.

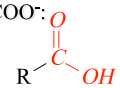
Compounds with a Carbonyl Group: Aldehydes & Ketones

- The carbonyl functional group is C=O. Oxygen has a double bond.
- Aldehydes must have at least one H atom attached to the carbonyl group:

- Ketones must have two C atoms attached to the carbonyl group:

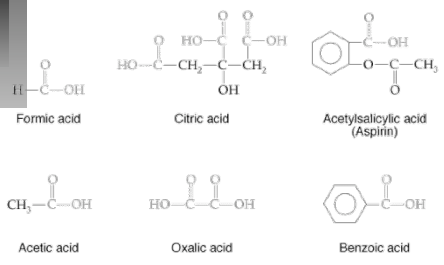
Compounds with a Carbonyl Group: Carboxylic Acids

- Carboxylic acids contain a carbonyl group with an -OH attached.
- The "carboxylate" functional group is $-COO^-$:



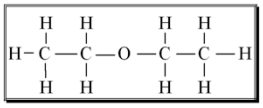
- Carboxylic acids are weak acids.
- Carboxylic acids are found in spinach, vinegar, cleaners, vitamin C, aspirin, and citrus fruits.
- Carboxylic acids are also used to produce polymers used in fibers, paints, and films.

Compounds with a Carbonyl Group: Carboxylic Acids

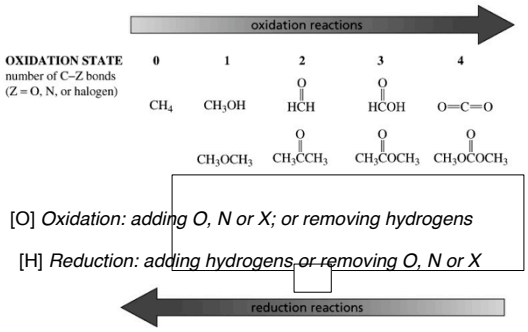


QUESTION

The following molecule has which function?



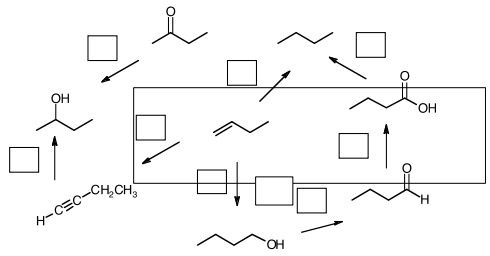
A) alcohol
B) aldehyde
C) ketone
D) ether
E) none of these



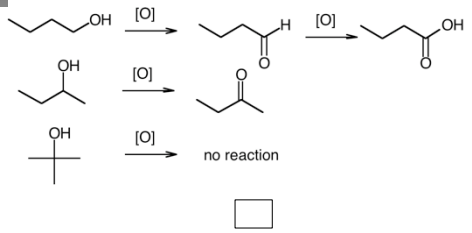
[O] *Oxidation: adding O, N or X; or removing hydrogens*

[H] *Reduction: adding hydrogens or removing O, N or X*

Indicate if the reaction in the direction of the arrow is respectively oxidation [O] *or reduction* [H].



Alcohol Oxidation: (Removing 2 hydrogen atoms)



1º alcohols produce aldehydes, which can oxidize further
2º alcohols produce ketones
3º alcohols ***do not react***

QUESTION

Name an oxidation product of 2-butanol.

A. Butanoic acid
B. 2-butanal
C. Butanone
D. Butanal

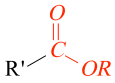
QUESTION

Which of the following possible starting materials would be best used to prepare benzoic acid in one step using an oxidation reaction?

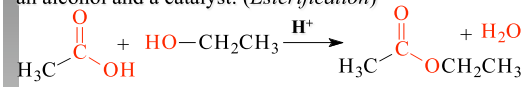
A. Benzaldehyde
B. 2-phenylethylalcohol
C. Benzene
D. Phenol

Compounds with a Carbonyl Group: Carboxylic Acid - Esters

- Some common esters are wintergreen oil, vegetable oil and aspirin.
- Esters contain -COOR groups:



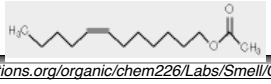
- Esters can be prepared by reacting a carboxylic acid with an alcohol and a catalyst: (*Esterification*)



Compounds with a Carbonyl Group: Carboxylic Acid - Esters

- Most esters tend to have sweet, fruit like odors and are used as food flavorings and scents.
  - $CH_3COOCH_2CH_3$
- Esters are named first using the alcohol part and then the acid part; in the above example: **ethyl** from ethanol and **acetate** from **acetic acid**.
- In the presence of a strong base, esters hydrolyze, the ester molecule splits into an acid and an alcohol. (saponification: the process used to make soap).

Chemical Communication



http://chemconnections.org/organic/chem226/Labs/Smell/ChemComm.html

Pheromone Synthesis
[20:40-23:51]

http://www.learner.org/resources/series61.html

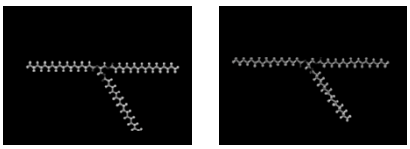
QUESTION

Esters are often associated with the aromas and tastes of fruits. The ester methyl butyrate is associated with apples. What compounds would be observed if this ester were to break down into its original components?

A. Methanal and butanone
B. Methanol and butanone
C. Methanol and butanoic acid
D. Methanoic acid and butanol

Fats:
Esters of glycerol, a molecule with three -OH groups

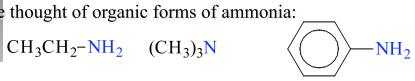
Saturated vs. Unsaturated



***Saponification**, hydrolysis of an ester in the presence of a base, is the reverse of esterification. Fats saponify to give fatty acids plus glycerols. (eg.triglycerides)*

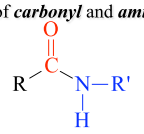
Compounds with a Nitrogen atom: Amines & Amides

- ***Amines*** are organic bases. They are weak bases.
- Just as alcohols can be thought of organic forms of water, amines can be thought of organic forms of ammonia:



Ethylamine Trimethylamine Aniline

- ***Amides*** are composites of ***carbonyl*** and ***amine*** functionalities:

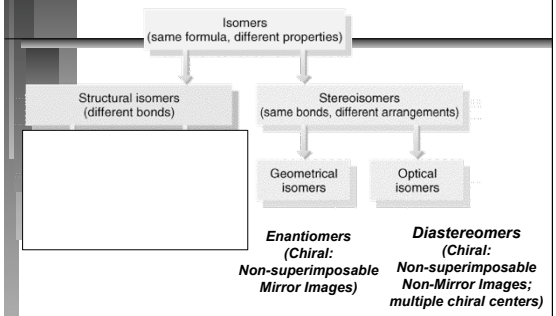


QUESTION

The compound diethyl amine that can be used as a curing agent in some epoxy materials would have how many hydrogen atoms per molecule?

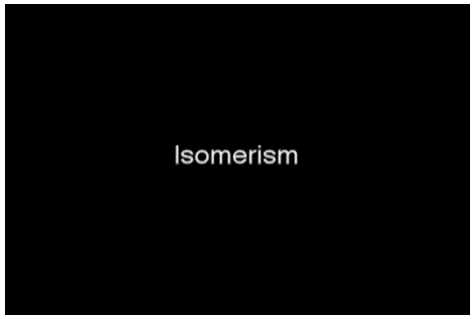
A. 7
B. 10
C. 11
D. 12

Isomerism



Isomerism

- *Molecules which have the same molecular formula, but differ in the arrangement of their atoms, are called isomers.*
- *Constitutional (or structural) isomers differ in their bonding sequence.*
- *Stereoisomers differ only in the arrangement of the atoms in space.*



QUESTION

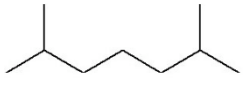
How many structural / constitutional alcohol isomers have the molecular formula $C_4H_{10}O$?

A) two
B) three
C) four
D) five

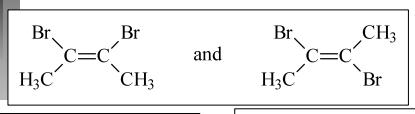
QUESTION

The carbon skeleton shown at the bottom right accounts for 9 carbon atoms. How many other isomers of $C_{10}H_{22}$ ***that have 7 carbons in their longest continuous chain*** *can be generated by adding a single carbon to various positions on this skeleton?*

A) 2
B) 3
C) 4
D) 5



Geometric Isomerism

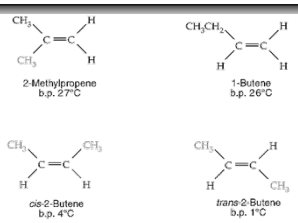


cis – or (Z-) same side

trans – or (E-) across

cis-trans isomers are geometric isomers.
There must be two different groups on the sp^2 carbons.

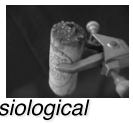
Geometric Isomerism



No cis-trans isomers in top two isomers, only the bottom two.

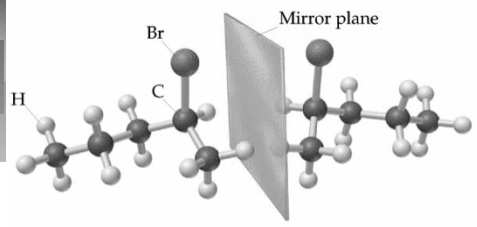
Stereoisomerism

- *Enantiomers are chiral: i.e. They are non-superimposable mirror images.*
- *Enantiomers are "optical isomers." eg. (+) and (-) carvone*
- *Most physical and chemical properties of enantiomers are identical.*
- *Therefore, enantiomers are very difficult to separate eg. Tartaric acid… ask Louis Pasteur.*

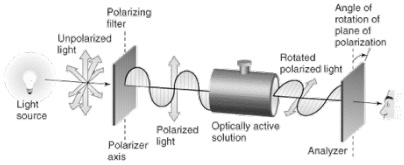


- *Enantiomers can have very different physiological effects: eg. (+) and (-) carvone*

Enantiomers of 2-bromobutane



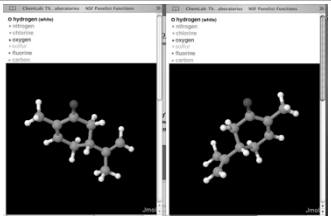
Optical Activity



(+) dextrorotatory
(-) levorotatory

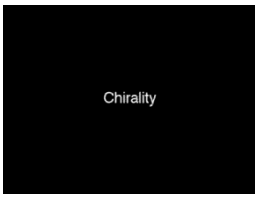
d,l-Carvone: Mint or Caraway

http://chemconnections.org/organic/chem226/jmol-html/d-carvone.html
http://chemconnections.llnl.gov/Organic/Chem226/jmol-html/l-carvone.html



The mirror image of an enantiomer will rotate the plane of polarized light by the same amount in the opposite direction. Eg (+) d-carvone $+62^{o\ (caraway)}$ and (-) l-carvone $-62^{o\ (spearmint)}$…. What about a 50:50 (racemic) mixture?

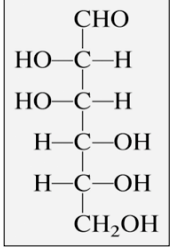
Chirality & Carbon Atoms



Each sp^3 carbon atom with four different substituents are chiral. Tartaric acid has 2 chiral carbon atoms.

QUESTION

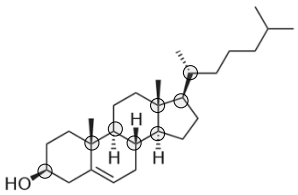
D-Mannose



The monosaccharide mannose has how many chiral carbon centers?

A. None
B. Two
C. Four
D. Six

QUESTION

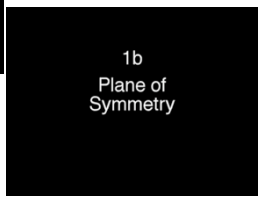


Cholesterol can have how many possible stereoisomers?

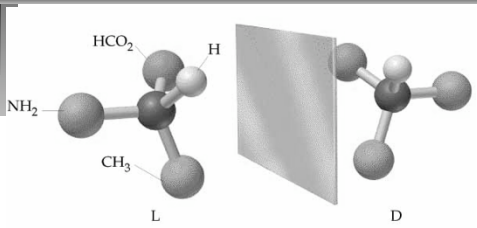
Chirality, Enantiomers & Asymmetry

***Enantiomers** are non-superimposable mirror images. They are asymmetric. They **do not** have an internal plane of symmetry.*

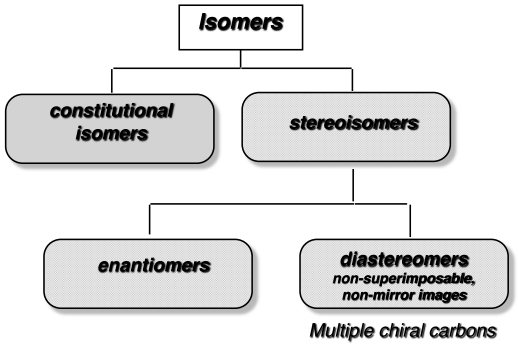
An internal plane of symmetry:

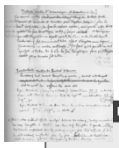


Enantiomers of Alanine



Most amino acids are enantiomeric. However glycine, $\mathbf{H_2NCH_2CO_2H}$, is not. Why?





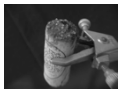
Louis Pasteur's lab notebook page (1848)

Physical Properties of the Stereoisomers of Tartaric Acid

		Melting point, °C	$[\alpha]_D^{25}$ °C	Solubility, g/100 g H_2O at 15 °C
A.	(2*R*,3*R*)-(+)-Tartaric acid	170	+11.98°	139
B.	(2*S*,3*S*)-(−)-Tartaric acid	170	−11.98°	139
C.	(2*R*,3*S*)-Tartaric acid	140	0°	125
D.	(±)-Tartaric acid	206	0°	139

A. & B. = enantiomers

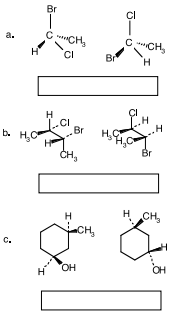
A. & C. and B. & C. = diastereomers



A. = naturally occuring form found in wine

D. = racemic mixture (50% A. & 50% B.)

Classify the following pairs of compounds as being either enantiomers, or identical compounds, or diastereomers.



Polymers

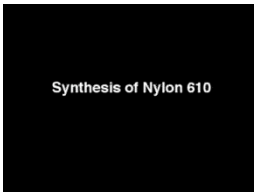
Polymers

Macromolecules which are made from small molecules, monomers, or co-monomers which structurally repeat themselves.

Monomer	**Polymer**
Ethylene	Polyethylene
Vinyl chloride	Polyvinyl chloride PVC
Tetrafluoroethylene	Teflon
Proteins	Amino Acids

Nylon

A macromolecule which is a poly-amide.



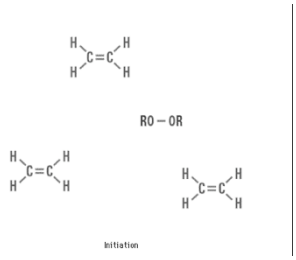
*-HN(CH_2)$_6$-**NHCO**(CH_2)$_x$CO-*

QUESTION

Using a condensation mechanism predict the number of hydrogen atoms found in one unit of the theoretical copolymer dimer formed between hexamethylenediamine and oxalic acid.

1. 14
2. 16
3. 18
4. 20

Polyethylene: Polymerization Mechanism



QUESTION

The synthetic polymer polyethylene is made from the monomer ethene or also referred to as ethylene. The polymer has no carbon branching. Polypropylene is made from the monomer propene. As propene monomers are added together, a chain with methyl branches can form. In such a chain how many carbon atoms would be between each branch. Note: these carbon atom(s) themselves would have no branches.

A. 1
B. 2
C. 3
D. none

Waste / Recycling?

~250 billion pounds produced annually, worldwide.

Recycling categories for common plastics

Plastic recycling number	Acronym and name of polymer	Original uses	Recycle uses
1	PET Poly(ethylene terephthalate)	Beverage bottles, food and cleanser bottles	Carpet fibers, fiberfill insulation, nonfood containers
2	HDPE High-density polyethylene	Milk, juice, water bottles, grocery bags (crinkly)	Oil and soap bottles, trash cans, grocery bags, pipes
3	PVC (or V) Polyvinyl chloride	Food and water bottles, food wraps, blister packs, construction materials	Drainage pipes, flooring tile, traffic cones
4	LDPE Low-density polyethylene	Flexible bags for trash, bread, milk, groceries; flexible wraps and containers	Bags for trash, groceries; irrigation pipes; oil bottles
5	PP Polypropylene	Handles, bottle caps, lids, wraps, bottles	Auto parts, fibers, pails, refuse containers
6	PS Polystyrene	Foam cups, packaging; cutlery; furniture; appliances	Insulation, toys, trays, packaging "peanuts"
7	Other	Various	Plastic "timber," posts, fencing, pallets

Reprinted from C. Baird, *Environmental Chemistry*, 2nd edition, W. H. Freeman, 1999, p. 527.