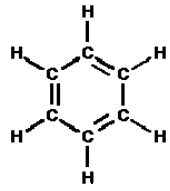
3.12 AROMATIC MOLECULES: MOLECULES WITH *DELOCALIZED* ELECTRONS

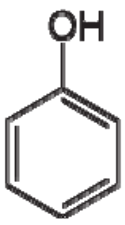
These molecules really are no more or less literally "aromatic" than other organic molecules. A really correct chemical definition of aromatic is beyond the scope of this course. The examples of aromatic molecules discussed in this course are cyclic alkenes containing 3 alternating conjugated double bonds which give them some unique electronic properties different from other alkenes.

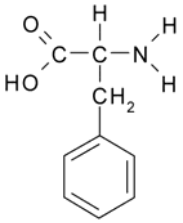
The primary aromatic molecule is benzene whose structure is shown below.

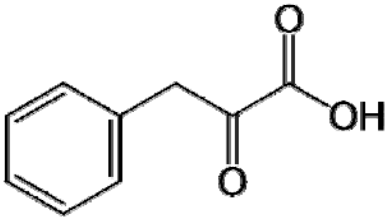


According to the naming rules we have given earlier, this would be named 1,3,5-cyclohexatriene. But it was named benzene by a German chemist at the time of its discover in 1833 and that name has been accepted as the systematic name.
When the benzene molecule was first isolated and studied, the Germans called it **benzene** while the French and British chemists called it **phene.** Although the German name won out, a benzene ring with an alcohol group is called phenol, and when we refer to a benzene ring as a side group of larger molecule it is referred to as a **phenyl** group.

Phenol phenylalanine phenylpyruvic acid



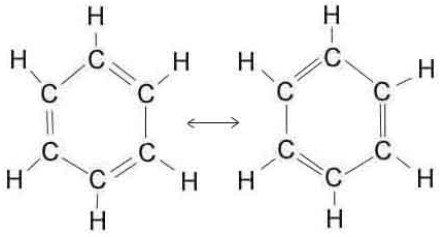




Notice the alternating conjugated double bonds in the ring structure. Because of the double bonds the C=C bonds have a trigonal planar geometry with a C-C-C bond angle of 120^{o}. This is the angle found in a flat hexagon, and hence benzene forms a flat molecule, unlike cyclohexane which forms a chair or boat conformation. Also note that the presence of the double bonds results in just one H

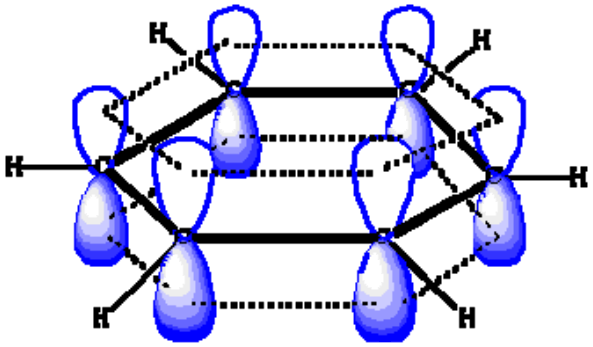
atom bonded to each C in the ring, and this H is in the plane of the ring. As a result there is no possibility of cis-trans isomers in benzene rings. (You can have cis-trans isomers in rings **or** on double bonds, but not on double bonds in rings!)

As organic chemists studied benzene and related compounds in more detail they discovered that the C-C bonds in the ring do not act like alternating double and single bonds. Double bonds are stronger than single bonds and tend to pull the two atoms closer together than single bonds. When chemists look at the actual structure of benzene, they find that all the bonds in the ring were the same length, intermediate between that of a single bond and a double bond. Linus Pauling, Nobel laureate in chemistry in 1954, suggested that the real benzene is intermediate between the two **resonance** structures:

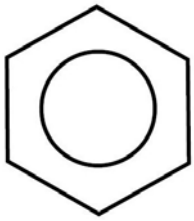


Linus Pauling

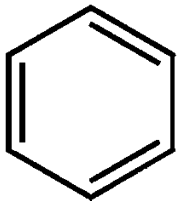
Another way of explaining this data is that the pi electrons are NOT localized between just two carbon atoms; instead they act like they're **delocalized** over the whole ring system. This comes about because of the way the pi orbitals overlap in the ring. All the pi orbitals overlap throughout the whole ring and as a result the pi electrons are free to spread themselves out in 2 donuts above and below the plane of the carbon atoms. The pi electron density between any 2 C atoms is the same, but at a lesser density than if it was a full C=C.



To indicate that the electrons in the alternating conjugated double bonds are really delocalized over the whole ring, the structure is frequently written as:

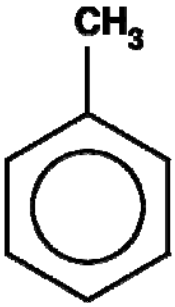


as well as

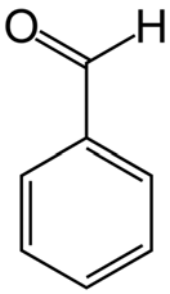


Some common benzene derivatives with names you should learn:

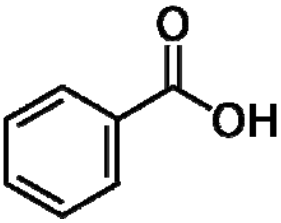
toluene



benzaldehyde



benzoic acid



phenol

Benzene was used as a common solvent in paint stripper until 1978. It was removed because epidemiologists had collected epidemiological data showing a positive statistical correlation between people working regularly with paint stripper and reduced levels of red blood cells (anemia) and elevated incidence of adult leukemia. As a result, benzene is no longer used as a solvent in paint stripper. Benzene is a naturally occurring component of gasoline where it increases the octane number of unleaded gasoline, and oil refineries often try to increase the benzene content to raise the octane value of their gasoline, but EPA requirements limit its content to 1% by weight of the gasoline. Human exposure to benzene due to gasoline spills at gas stations is regarded as a primary source of exposure to the

general population and one (of many!) reasons why "topping off the gas tank" is officially discouraged.

Most of the gasoline sold in the Pacific Northwest is made from Alaskan crude oil which has a higher amount of benzene than oil from most other sources. As a result benzene from gas spills and incomplete combustion is found at higher than recommended levels in large metropolitan areas like Portland and Seattle especially near the major interstate freeways. The recommended EPA "benchmark" limit for ambient air is 0.13 mcg(micrograms) benzene per m^3 of air. Exposure at this level over a 70 year lifetime is estimated to increase the risk of death by 1 part in a million (.0001%)(Oregonian newspaper).

Benzene can be formed in trace amounts in other consumer products and although the amounts are extremely small, its presence has created concern in some quarters, as shown in the web site quoted below.

"Watch out, that next can of carbonated fizzy water you guzzle could turn your esophagus into a tumorous pipe oozing with cancer and bile. The carcinogen in question is Benzene and according to *Beverage Daily*, benzene levels in most soft drinks are up to five times the World Heath Organization's limit for drinking water.

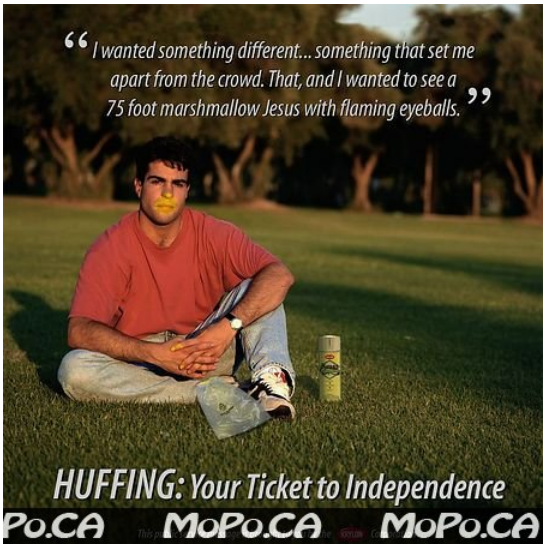
Of course, the Coca Cola company isn't quite so stupid to purposely add benzene to their sodas. It's formed by a chemical reaction between ascorbic acid and potassium benzoate. Vitamin C and Preservatives, in other words. If you leave a can of pop out in the light, chances are it's already starting to become laced with traces of benzene.

Benzene exposure is commonly associated with leukemia and a swath of blood disease. The sodas that are most risky to drink include such favorites as Fanta Orange, Hawaiian Punch, Mug

Root Beer and Tropicana Lemonade. Luckily, IBC Root Beer and Cherry Coke aren't on the list — we're not sure we could live without those."

www.consumerist.com/.../2006/03/mugrootbeer.gif

Toluene has replaced benzene as a common solvent in paint stripper and is also used in glue and in some types of "white-out". Although toluene does not appear to be carcinogenic, breathing large quantities of toluene can cause heart dysrhythmias (including **asystole!**) and brain damage. Glue sniffers and *huffers* are at risk for both of these health problems. (What is asystole? Check it out in a medical dictionary or on Google!)

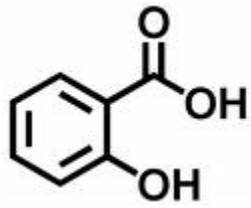


Benzaldehyde has an odor similar to that of almonds (benzaldehyde contributes to the smell of almond smell/flavor). Benzaldehyde is used in artificial flavored almond pastries, Maraschino cherries and other pastries.

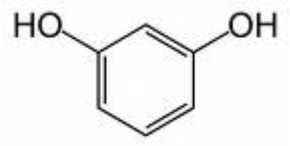
Benzoic acid is very commonly used as a food preservative. It is particularly effective at inhibiting mold growth. As a result it is a routine food preservative in bread, pastries, and deli products like dips.

Phenol is an antiseptic. It was the original surgical antiseptic used by Lister and is still used in Chloroseptic and other disinfectants. It used to be called carbolic acid because of its acidic properties. Its chemical burning properties are used in facial peels to exfoliate (remove) the top layers of skin by people wishing to remove wrinkles and aging skin. Facial peels must be done with careful attention to the

concentration of the phenol and the length of time it is allowed to remain on the skin. Too high a phenol concentration or too long a period of exposure can cause deep chemical burns. After a facial peel, patients should not expose their skin to direct sunlight or at least use a sun screen for at least a month, but this recommendation is often ignored. Facial peels are a big business in Hollywood. Facial peels may use several other phenolic compounds: salicylic acid (related to aspirin) and resorcinol. What do all three structures have in common?

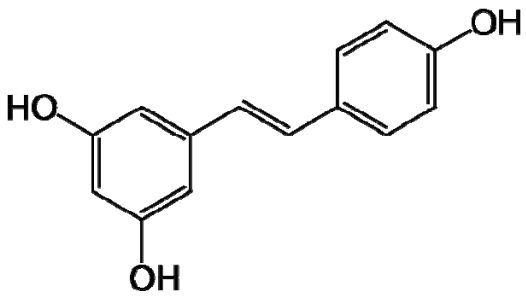


Salicylic acid



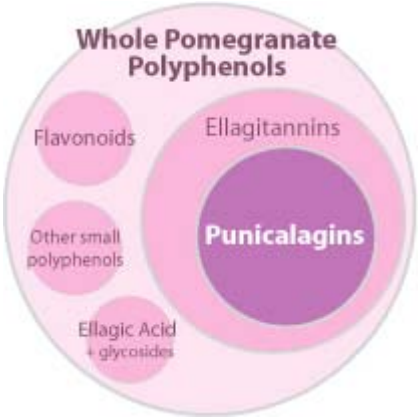
Resorcinol

Polyphenolics are a diverse group of compounds containing 2 or more phenol rings. They are found in most plants, particularly fruits. Grapes and wine are a source of **polyphenolic** compounds that have received particular media attention recently. Epidemiological data suggests that consuming foods with polyphenolic compounds (grape juice, blueberries, pomegranites, wine) is associated with lower risk of cardiovascular disease and cancer. It is claimed that these correlations may be due to their antioxidant and free radical stabilizing properties of phenol compounds although direct data is limited. Speculative claims, especially by diet supplement companies, on the other hand are extensive.

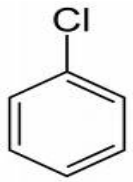


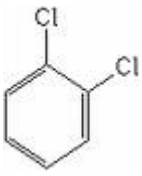
Resveratrol: ingredient in red grapes

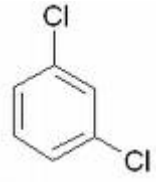
www.helsinki.fi/.../research/polyphenolics.htm



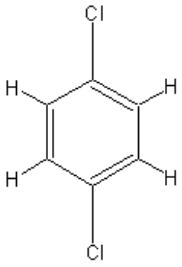
Naming substituted benzene rings

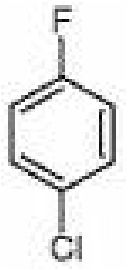


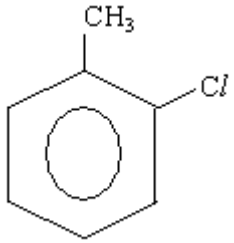




chlorobenzene 1,2-dichlorobenzene 1,3-dichlorobenzene
ortho dichlorobenzene meta dichlorobenzene







wikipedia

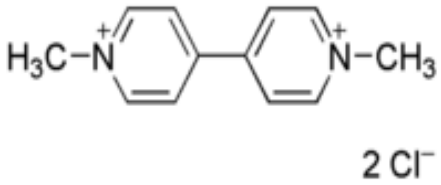
1,4-dichlorobenzene 1-chloro-4-fluorobenzene 2-chlorotoluene

para dichlorobenzene parachlorofluorobenzene orthochlorotoluene

mothballs

There are no cis or trans isomers in benzene ring because there is only one additional bond to C outside the benzene ring. Because the benzene C has a (delocalized) double bond it has trigonal **planar** geometry and the bond is in the plane of the benzene ring. As a result there are **no** cis/trans possibilities on the flat planar benzene ring.

The prefixes ortho-, meta-, and para- are special names used **only** on benzene derivatives and are alternate names for 1,2; 1,3 and 1,4 respectively. Examples of these prefixes are found in the herbicide paraquat.



Based on the structure, comment on the basis for both the “para” and the “quat” in the herbicide’s name.

Paraquat is an herbicide which works by inhibiting photosynthesis. It has been used by the US government to spray marijuana fields (especially in Latin America) to kill marijuana plantations. Small amounts of paraquat may be found in marijuana that was not killed by the spray and there has been concern about lung injury when volatilized paraquat is inhaled into the lungs. More recently strains of marijuana whose roots are resistant to paraquat have been reported.

Draw the structure and give an alternative name using numbers for

a) ortho dimethyl benzene b) meta-dibromobenzene c) para-difluorobenzene

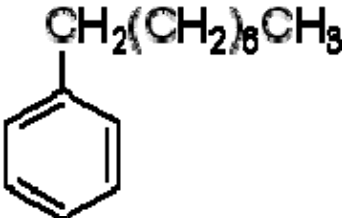
d)ortho-methyl benzoic acid e)para-chlorophenol

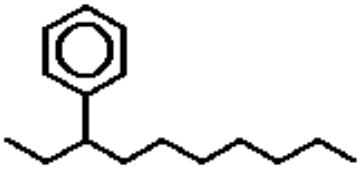
Draw the structure for 2,3,4,5,6-pentachlorophenol

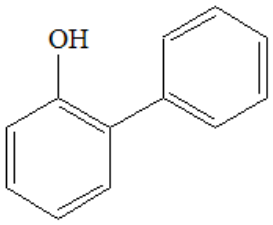
Pentachlorophenol was a commonly used wood preservative until the 1987 when its use was terminated for the general public because of public health concerns that it could cause damage to the central nervous system, reproductive system, and liver.

According to its revised risk assessment, EPA does not believe children play near utility poles. If you have pictures of children playing on or around utility poles, send them to EPA.

When a benzene ring is regarded as a group branching off of another chain, it is referred to as a phenyl group. This comes from the old British name for benzene: phene. Examples





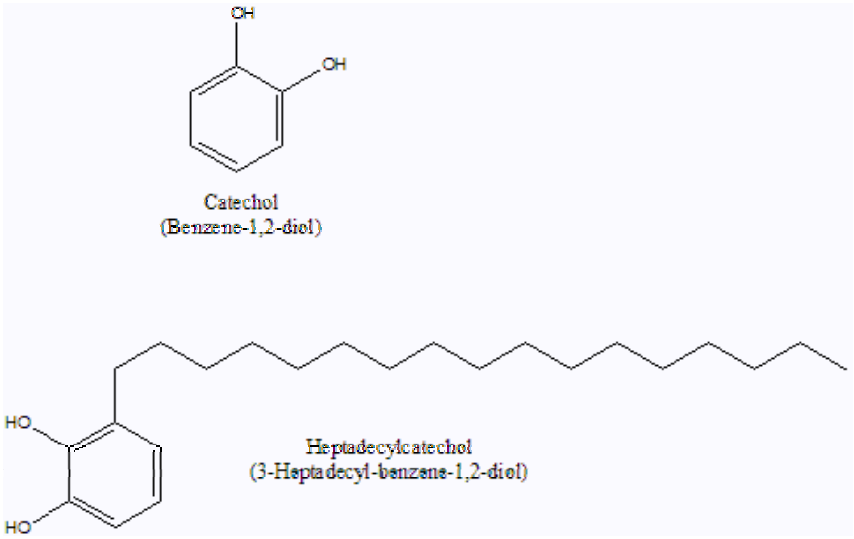


1-phenyl octane 3-phenyl decane ortho-phenyl phenol
2-phenylphenol

Orthophenylphenol is found in a variety of household disinfectants and is also applied to citrus peel as a fungicide.
There are many other closely related aromatic compounds.

Catechol (or pyrocatechol) is the common name for the benzene molecule with two alcohol functional groups in the ortho(1,2) configuration. Draw its structure.

Urushiol is the active ingredient in poison ivy and poison oak that causes a rash and blistering (contact dermatitis) when it comes in contact with human skin. In poison oak it is a mixture of saturated 3-heptadecylcatechol and related compounds containing 1,2 or 3 double bonds in the 17 C chain. In poison ivy the alkyl chain off of the catechol molecule is 15 C long (3-pentadecylcatechol) and the chain can also be either saturated or unsaturated. The **unsaturated** molecules are the most irritating. The urushiol is quite hydrophobic (explain!) and dissolves into the epidermis and reacts with membrane proteins in epidermal cells. This changes the surface of those membrane proteins so that the body's T cells are tricked into thinking it is foreign and attack it. Washing with water will not remove the urushiol (why?), but most sources suggest that washing **quickly** after contact with a relatively non-polar solvent such as rubbing alcohol or with soap may dissolve the urushiol out of the top layer of skin before it reacts with membrane proteins.



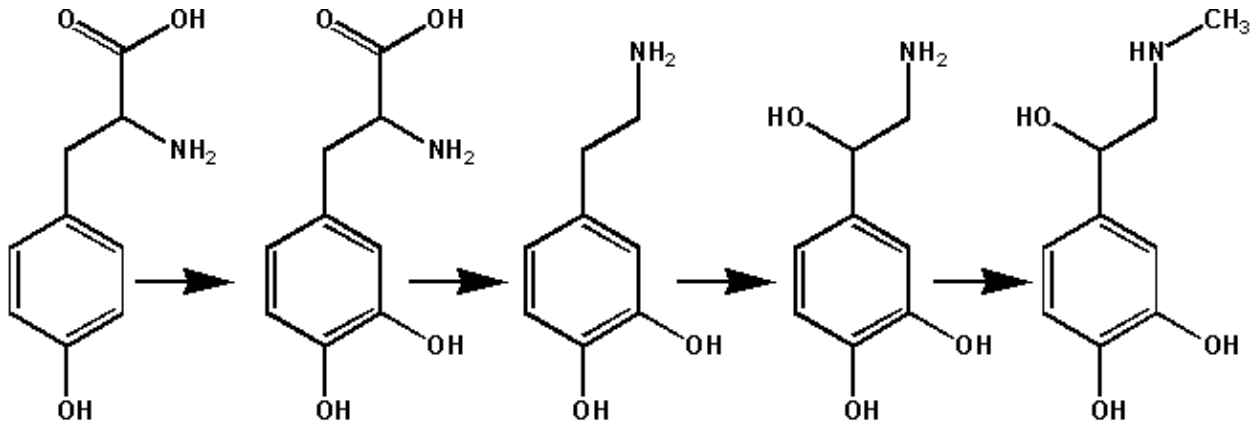
Leaves of 3, let them be.

bayareahealth.org/PoisonIvy.html

serendip.brynmawr.edu/exchange/node/834

Catecholamines and Neurotransmitters

The amino acid tyrosine is metabolized first into DOPA (dihydroxyphenalanine) and then into the series of common **neurotransmitters dopamine, norepinephrine (noradrenaline) and epinephrine (adrenaline).** Because all three of these neurotransmitters have both a catechol ring system and an amine group they are collectively referred to as **catecholamines.**



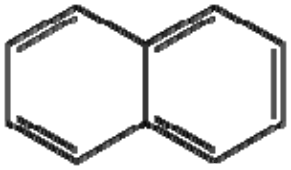
Epinephrine(adrenaline) is the neurotransmitter primarily responsible for the "adrenaline rush".

Dopamine has a large variety of roles in different parts of the brain stimulating everything from voluntary,motion, sleep, learning, memory, and mood. A lack of dopamine in the striatum produces Parkinson's; an excess of dopamine in the limbic center of brain can produce euphoria.

3.13 MOLECULES WITH MULTIPLE AROMATIC RINGS

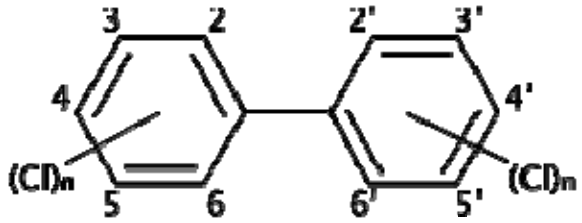
Naphthalene was formerly used in some brands of mothballs because the crystals slowly evaporated (sublimed) and the pungent smell of naphthalene vapor repelsled moths from woolens. Concern about flammability have resulted in 1,4 dichlorobenzene being used instead. The chlorination reduces the flammability of the compound.

Naphthalene:



or

Polychlorinated Biphenyls(PCBs)



Polychlorinated biphenyls are a group of aromatic compounds with two ore more Cl atoms substituted on 2 benzene rings, as shown in the structure above. The number of Cl atoms and the position of those Cl atoms on the two benzene rings can vary considerably and that is indicated in the above structure by having the Cl bonding into the center of the ring and with the $(Cl)_n$ indicating a variable number of Cl's.

Polychlorinated biphenyl compounds (PCBs) are very stable (unreactive) non-flammable compounds that were used to absorb heat in electrical transformers and lubricants from 1929 until about 1977.