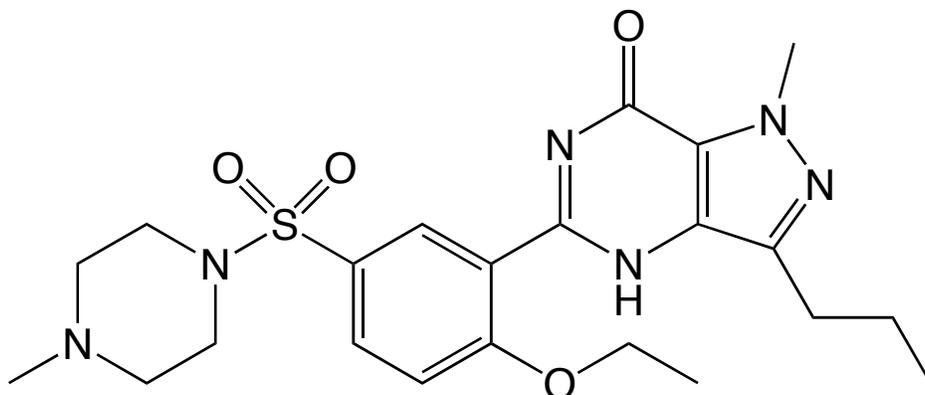
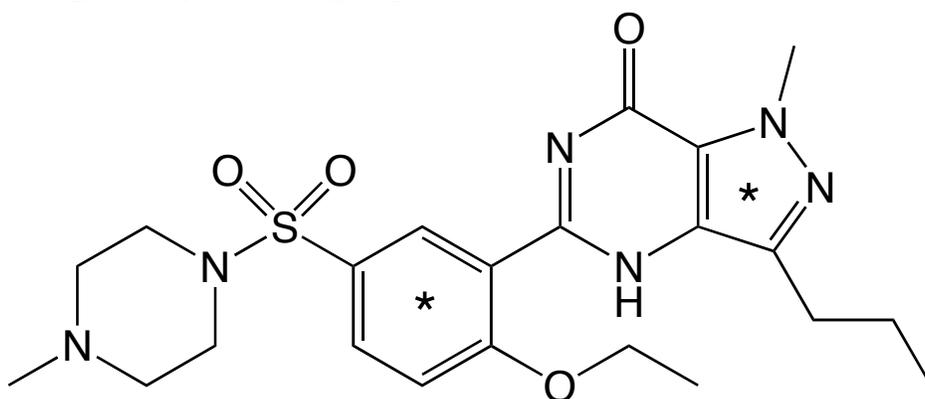


Some things you should know: functional groups and structure



The molecule shown is **Viagra**. It generates more than \$ 2.3 billion U.S. per year. Amongst other things, it aids jet lag recovery in hamsters.

Can you recognize its functional groups?



Are the rings with asterisk aromatic?

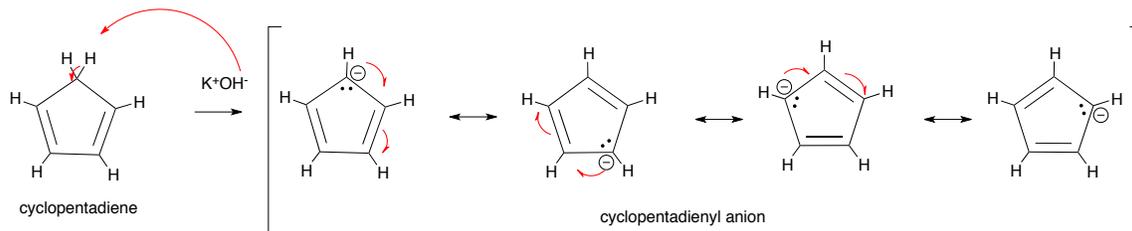
Answer: Yes. It is. Think back to last lecture on heterocycles and criteria for aromaticity. The 5-membered ring is cyclic, it has two double bonds (4 pi electrons) that are conjugated, and it is planar. The methyl-substituted nitrogen donates its lone pair into the 5-member ring to fit the $4n+2$ rule. The other nitrogen has lone pair in sp^2 orbital perpendicular to the pi (π) system.

What is the molecular formula? ($C_{22}H_{30}N_6O_4S$)

Are there any stereogenic centres? (No)

If given a molecule, know how to analyze its parts and functional groups on the exam.

Consider another system:



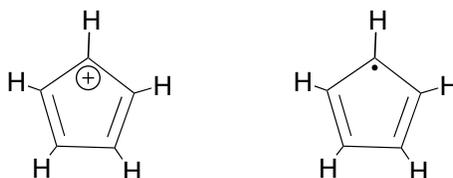
Is cyclopentadienyl anion aromatic?

Answer: Yes. It is cyclic, planar, and conjugated. It has 6 π electrons (therefore it fits the $4n + 2$ rule where $n = 1$).

The pK_a of the hydrogen shown on the parent cyclopentadiene on the above figure is around 16. A normal alkane hydrogen pK_a is around 45.



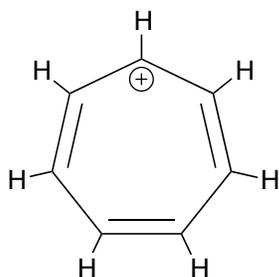
The acidity of the cyclopentadiene hydrogen has been enhanced by 30 orders of magnitude (30 pK_a units) due to the extra stability of the cyclopentadienyl anion (recall that the acidity of a molecule depend on the stability of its conjugate base).



Are the cyclopentadienyl cation and radical aromatic?

Answer: No. They are cyclic, planar, conjugated, but do not follow the $4n+2$ rule.

Another example:

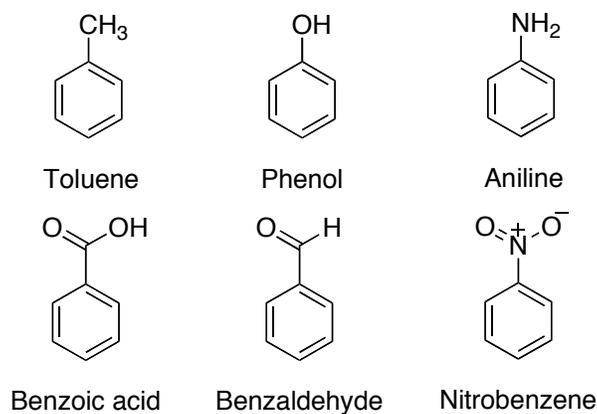


Is this cycloheptatrienyl cation aromatic?

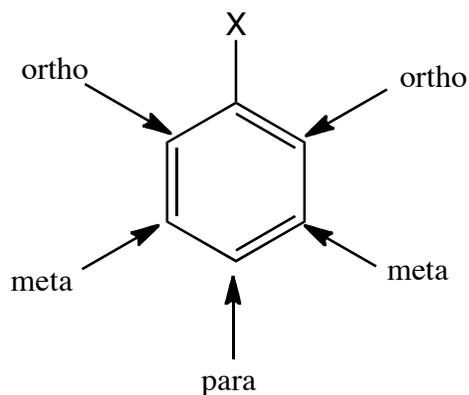
Answer: Yes, it is. The cation is cyclic, planar, fully conjugated, and has 6 π electrons. The electrons are delocalized in the ring, and each carbon shares $1/7$ positive charge.

Nomenclature of substituted benzene rings

You should know the names of the following structures:

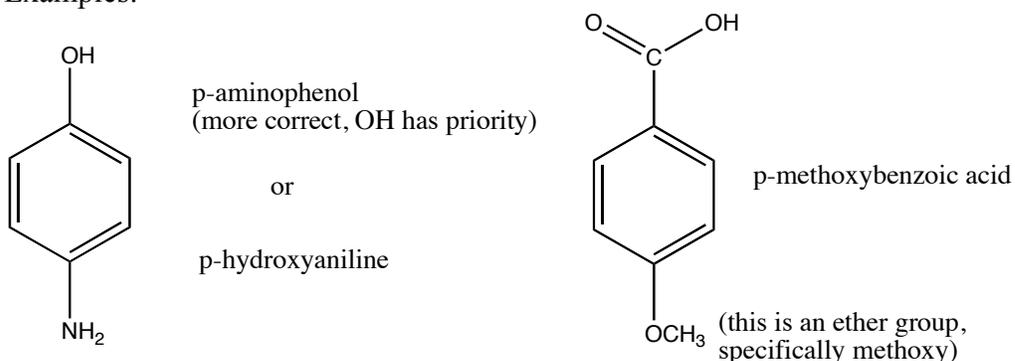


When you have two substituents on a benzene ring, *ortho*, *meta*, and *para* are used to tell where the second substitution is relative to the first one.



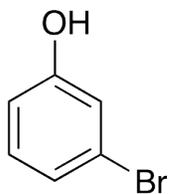
Ortho refers to 1,2-substitution and is abbreviated o-
Meta refers to 1,3-substitution and is abbreviated m-
Para refers to 1,4-substitution and is abbreviated p-

Examples:



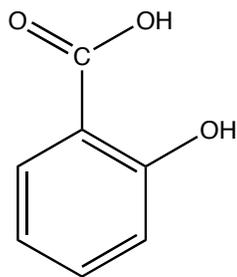
Nomenclature: p-aminophenol or 4-aminophenol:

The amine and hydroxyl group are in the 1 and 4 positions, so they are *para* to each other. The parent structure in this molecule can be either aniline or phenol. For this course, it doesn't matter which parent structure you pick in the nomenclature with these substituents. Usually when naming the substituents, the atomic number takes priority, but there are many exceptions for historical reasons.

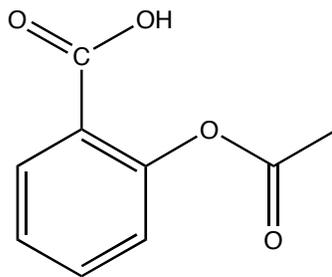


Nomenclature: *m*-bromophenol or 3-bromophenol

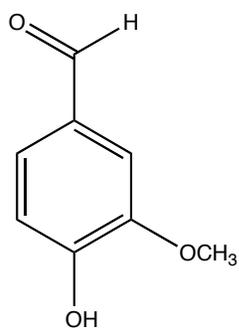
In this compound, the -OH (hydroxy) and -Br are in the 1 and 3 positions, so they are *meta* (or abbreviated *m*) to each other. The parent structure is phenol (phenol is a benzene with a hydroxyl group directly attached, not to be confused with phenyl which means just a benzene ring as a substituent), so we call this meta-bromophenol.



2-hydroxybenzoic acid
aka salicylic acid

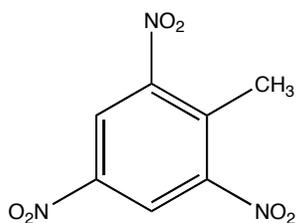


aspirin
acetylsalicylic acid



Nomenclature: 4-hydroxy-3-methoxybenzaldehyde (or vanillin from vanilla extract). The carbon substituent (an aldehyde group) gets priority.

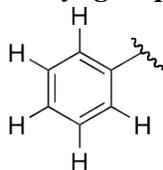
Note: we number the ring in a way such that the substituents have the lowest numbers (so it's not 4-hydroxy-5-methoxy-, but 4-hydroxy-3-methoxy-). The substituents are listed in alphabetical order before the parent compound, but this course will not be incredibly picky with the order.



Nomenclature: 2,4,6-trinitrotoluene (TNT)
An explosive

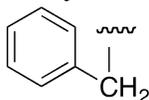
Nomenclature of some Aromatic Groups

Phenyl group = ϕ = Ph = C₆H₅ =



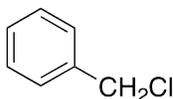
Aryl = Ar = aromatic group. It is a broad term, and includes any aromatic rings.

Benzyl = Bn =



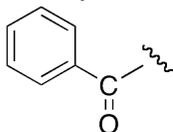
It has a -CH₂- (methylene) group attached to the benzene ring.

This group can be used to name particular compounds, such as the one shown below.

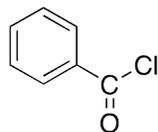


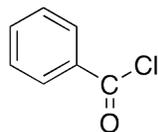
This compound has chlorine attached to a benzyl group, therefore it is called benzyl chloride.

Benzoyl = Bz =



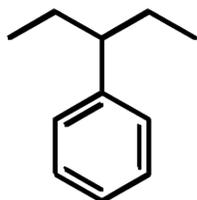
This is different from benzyl group (there is an extra “o” in the name). It has a carbonyl attached to the benzene ring instead of a methylene group.



For example,  is named benzoyl chloride.

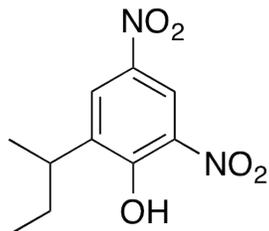
Therefore, it is sometimes useful to name a compound with the aromatic part as a substituent rather than it forming a part of the parent name.

Example:



Nomenclature: 3-phenylpentane (pentan-3-ylbenzene is also an acceptable name, but it is more complicated and isn't the best name). (Note that this molecule is achiral: it has a plane of symmetry)

Example:



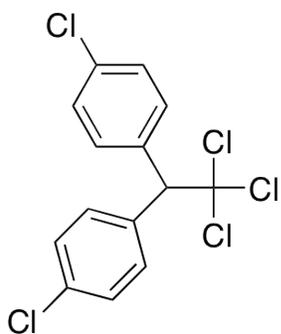
Naming this compound is a little complicated, and for the purposes of this course, there are a few names that would be accepted:

2-(2-butyl)-4,6-dinitrophenol
6-(but-2-yl)-2,4-dinitrophenol
6-(1-methylpropyl)-2,4-dinitrophenol

This is Amaize. It is used to enhance the yield of corn production.

The systematic name for this compound is 2-*sec*-butyl-4,6-dinitrophenol.

Example:

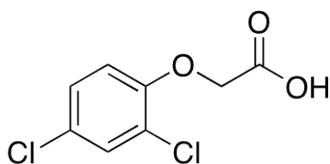


1,1,1-trichloro-2,2-bis-(4-chlorophenyl)ethane

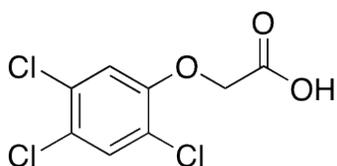
Note: although the two 4-chlorophenyl can also be named using di-, bis is used instead. bis is commonly used for large groups. The 4-chlorophenyl could also be called p-chlorophenyl

DDT is an insecticide and helped to wipe out malaria in many parts of the world. Consequently, the person who discovered its properties (Paul Müller) won the Nobel Prize in Medicine in 1948.

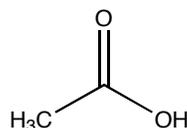
Example:



2,4-dichlorophenoxyacetic acid (2,4-D)

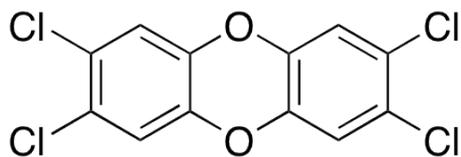


2,4,5-trichlorophenoxyacetic acid (2,4,5-T)

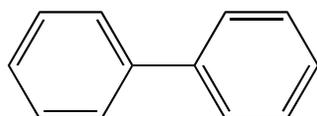


Note: Acetic acid is the parent structure

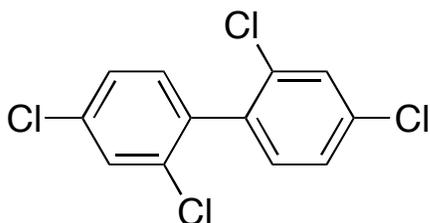
Agent Orange (2,4-D + 2,4,5-T), a broad leaf herbicide, was used in the Vietnam War to defoliate large areas. It was used in Edmonton on lawns as Weed and Feed to get rid of weeds.



This potent toxin and carcinogen that can contaminate Agent Orange and can occur in pulp mill waste. While this is only an example of one dioxin, typically the term dioxin refers to this particular molecule.



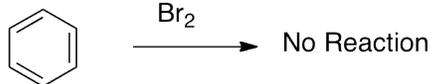
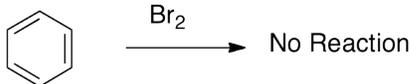
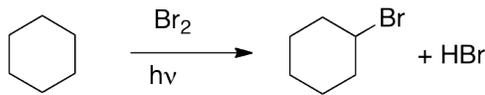
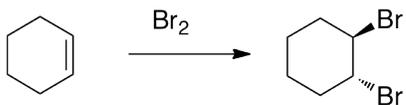
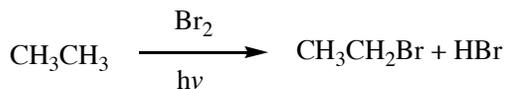
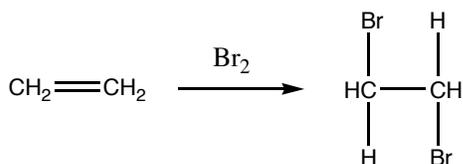
biphenyl



A polychlorinated biphenyl (PCB)
If the Cl's were Br's this would be a polybrominated biphenyl (PBB)

Electrophilic Aromatic Substitution

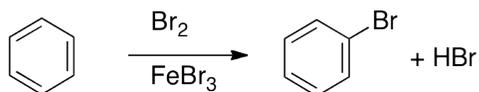
Benzene appears to be a remarkably stable and unreactive compared to alkenes, such as cyclohexene or ethylene, or even alkanes, such as cyclohexane or ethane.



When ethylene or cyclohexene is allowed to react with bromine (an addition reaction), a dibrominated product is formed. However, when benzene is allowed to react with bromine in the absence of catalyst, nothing occurs. It is much less reactive.

In the case of alkanes such as ethane or cyclohexane, light ($h\nu$) or heat are required for the bromination to occur (this is a substitution). For benzene, there is still no reaction under these conditions.

However, this is not to say that benzene is completely unreactive. Under certain conditions, benzene can be forced to react.

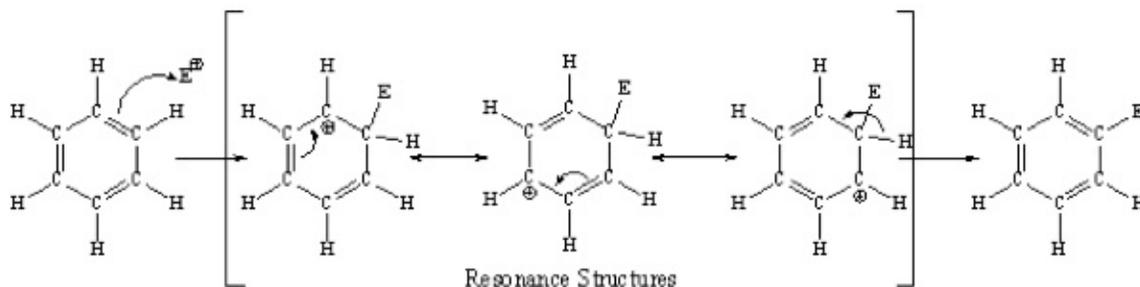


This is an Aromatic Electrophilic Substitution.

In electrophilic aromatic substitution, an electrophile (E^+) is substituted for a hydrogen on the aromatic (e.g. benzene) ring.

Aromatic compounds are very stable and un-reactive. In this type of reaction, the electrophile must be especially reactive (electron deficient).

The General Mechanism:



The pi system of the benzene ring acts as the nucleophile.

The cation formed in the reaction is resonance stabilized (conjugated with the two double bonds). However, it is not aromatic. Note that the positive charge is ortho and para to the electrophile.

Once the aromatic stabilization is lost, it is easily regained (remember that by staying aromatic, the compound becomes more stable). Hence the last step (loss of proton) is fast to regenerate the aromatic system.