Chemistry 2220
Organic Chemistry II
Fall Semester 2023
Dr. Rainer Glaser

TEST #2

"**Ch. 15**: Reactions of Aromatic Compounds. Halogenation, Nitration, Sulfonation, FC-Alkylation, FC-Acylation. Mechanism of electrophilic aromatic substitution. Directing effects, activation & deactivation. Ph-R oxidations. Nucleophilic aromatic substitution: Meisenheimer and benzyne mechanisms. **Ch. 16**: Aldehydes and Ketones. Nomenclature. Properties. Preparations of A/K: Ox. of alcohols and alkenes, reductions of CA derivatives (hydride, carbanion). Additions to C=O bonds: Hydrates, hemiacetals, acetals, cyanohydrins. Add./Elims.: Imines, enamines. Wittig reaction & variants. Baeyer-Villiger reaction. **Ch. 17**: Carboxylic Acids and Their Derivatives. Nomenclature: Acids & diacids, acyl halides, anhydrides, esters & lactones, amides and lactams, nitriles. CA Acidity. Relative stabilities and amide resonance. Preparations: Many, including acid halide synthesis, CO_2 add. to organometallics. Reactions: Many nucleophilic acyl subst. rxns., Fischer esterification, ester saponification. Alcohol inversion with sulfonates.

Friday, Oct. 27, 2023, 8 - 8:50 am

Name: Answer Key

Question 1. Electrophilic aromatic substitution.	35	
Question 2. Nucleophilic aromatic substitution.	15	
Question 3. Aldehydes and Ketones. Nomenclature, Properties, Preparations, and Reactions.	25	
Question 4. Carboxylic Acids and Derivatives: Nomenclature, Properties, Preparations, and Reactions.	25	
Total	100	

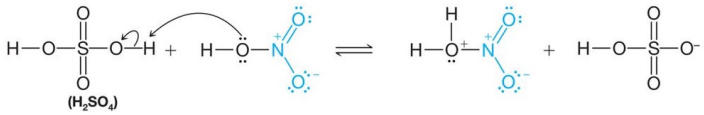
ALLOWED: Periodic System of the Elements (printed, w/o handwriting on it). Molecular models (you can bring pre-made models). Simple, non-programmable calculator (not really needed).

NOT ALLOWED: Books. Notes. Electronic devices of any kind (other than a simple calculator).

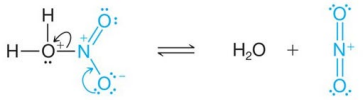
Question 1. Electrophilic Aromatic Substitution. (35 points)

(a) Nitration of benzene using HNO_3 and H_2SO_4. Using complete structural formulas (all atoms, all bonds, all lone pairs, formal charges), show the reactions leading to the formation of the **nitronium ion, $[NO_2]^+$**. Draw the three important resonance forms of the sigma complex (the arenium ion) formed by the addition of $[NO_2]^+$ to benzene. Show proper resonance arrows. (12 p.)

$[NO_2]^+$ generation (6 p.):



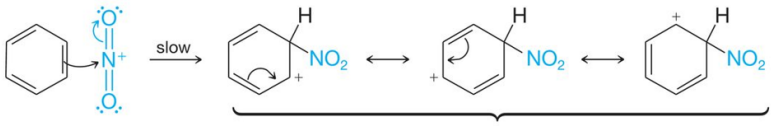
In this step nitric acid accepts a proton from the stronger acid, sulfuric acid.



Nitronium ion

Now that it is protonated, nitric acid can dissociate to form a nitronium ion.

Resonance forms of sigma complex (6 p.):

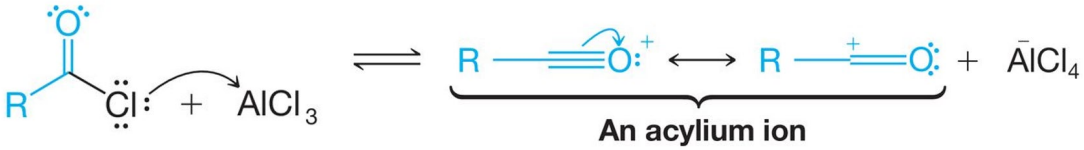


Arenium ion

The nitronium ion is the electrophile in nitration; it reacts with benzene to form a resonance-stabilized arenium ion.

(b) Acetylation of nitrobenzene using acetyl chloride and $AlCl_3$. Using complete structural formulas (all atoms, all bonds, all lone pairs, formal charges), show the reaction(s) leading to the formation of the **acetylium ion, $[H_3C\text{-}CO]^+$**. You may show the methyl group as "CH_3". Draw the most important resonance forms of the sigma complex formed by the addition of the acetylium ion to the *meta*-position of nitrobenzene. Show proper resonance arrows. (14 p.)

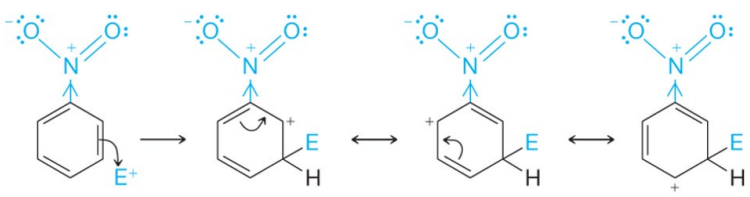
$[H_3C\text{-}CO]^+$ generation (6 p.): show for R = Me, one resonance structure suffices



An acylium ion
(a resonance hybrid)

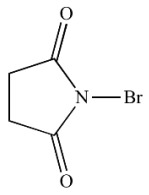
Resonance forms of sigma complex leading to *meta* product (8 p.): show for E being C(Me)=O

Meta Attack



Draw corner brackets around RFs

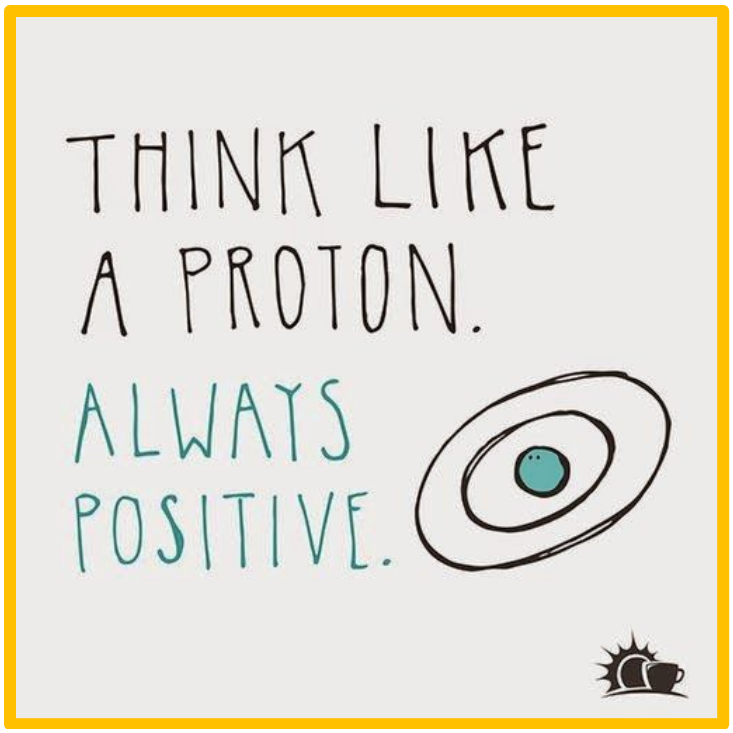
(c) Bromination of ethylbenzene with NBS (*N*-bromosuccinimide) and light. Draw the reaction diagram for the formation of the major product of monobromination. (4 p.)

$Ph–CH_2–CH_3 + NBS + light \rightarrow Ph–CHBr–CH_3$ NBS = 

Succinimide product not shown.
Side chain and in benzyl position only.

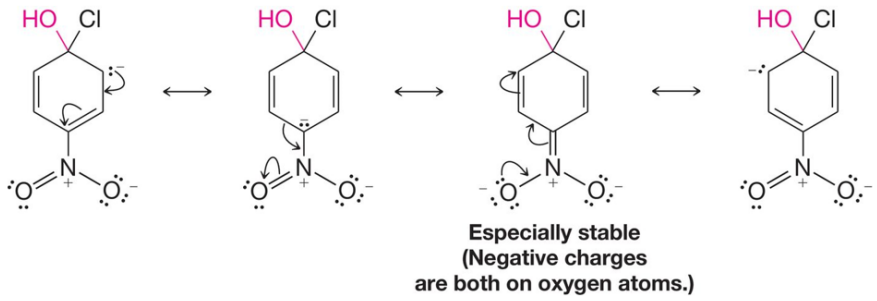
(d) Bromination of ethylbenzene with Br_2 and $FeBr_3$. Draw the reaction diagram for the formation of the product(s) of monobromination. Pay attention to regiochemistry. (5 p.)

Draw ethylbenzene, $Ph\text{-}CH_2\text{-}CH_3$
Draw *ortho*-brominated ethylbenzene.
Draw *para*-brominated ethylbenzene.
Ethyl group is activating and o/p directing.

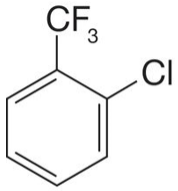
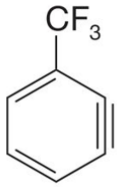
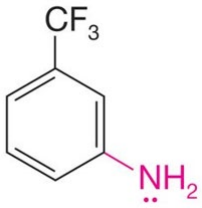
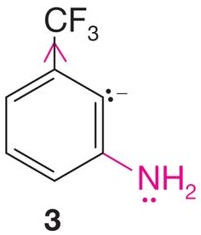


Question 2. Nucleophilic Aromatic Substitution. (15 points)

(a) KOH allows for the conversion of *para*-nitrochlorobenzene to *para*-nitrophenol. This reaction is a nucleophilic aromatic substitution with _**hydroxide**_ ion being the nucleophile and with _**chloride**_ ion being the leaving group. This reaction involves a 2-step mechanism, and proceeds via a "Meisenheimer intermediate". As best as possible, draw at least three resonance forms of the Meisenheimer intermediate in the box below. Include all atoms, all bonds, all lone pairs, and show any charges. Show resonance arrows, show corner bracket around resonance forms. (7 p.)

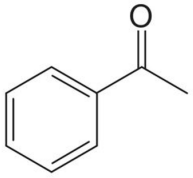
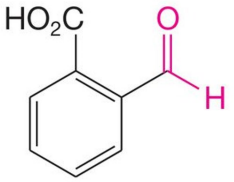


(b) $NaNH_2$ allows for the conversion of *ortho*-(trifluoromethyl)chlorobenzene to *meta*-(trifluoromethyl)aniline. This reaction is a nucleophilic aromatic substitution, and it proceeds via a benzyne intermediate and a carbanion intermediate. Draw the requested structures and include all atoms, all bonds, all lone pairs, and show any charges. (8 points)

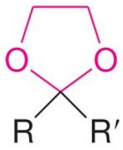
Substrate: *ortho*-(trifluoromethyl)chlorobenzene  **1**	**First Intermediate:** Benzyne  **2**
Product: *meta*-(trifluoromethyl)aniline 	**Second Intermediate:** Carbanion formed by nucl. add. to benzyne  **3**

Question 3. Aldehydes & Ketones. (25 points)

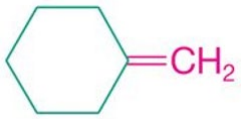
(a) Nomenclature. Provide name or complete structure. (6 p.)

H_3C-CO-$(CH_2)_2$-CH_3	Acetophenone	2-Methanoylbenzoic acid
2-pentanone		

(b) Additions to C=O bonds. For each of the reactions in the four boxes, draw the complete structure of the product (all bonds and all lone pairs) and name the class of compounds to which the product belongs. (12 p.)

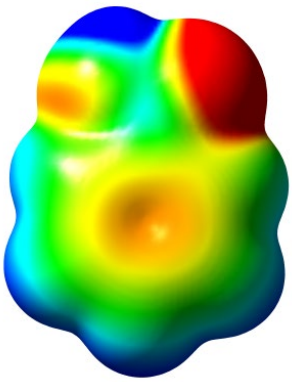
Benzophenone w/ H_2N-CH_3	Acetone w/ HO-$(CH_2)_2$-OH & mineral acid
$(C_6H_5)_2C{=}N{-}CH_3$ An imine	 **Cyclic acetal**, R = R' = Me
Benzophenone w/ H_2N-NH_2 w/ KOH w/ heat	Acetaldehyde w/ $HN(CH_3)_2$
$Ph{-}CH_2{-}Ph$ A methylene compound	$H_2C{=}CH{-}N(CH_3)_2$ An enamine

(c) Wittig Reaction. Consider the Wittig reaction that converts substrate cyclohexanone to product methylenecyclohexane. Draw the structures of cyclohexanone and of methylenecyclohexane, of the required triphenylphosphine ylide (all lone pairs, charges, etc.; one resonance form suffices), and of the alkyl halide needed to form the ylide. (7 p.)

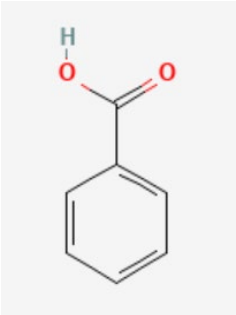
Substrate cyclohexanone (1 p.):	Product methylenecyclohexane (2 p.):
	
Reagent triphenylphosphine ylide (3 p.):	Alkyl halide needed to make the ylide (1 p.):
	$H_3C{-}Cl$ Chloromethane

Question 4. Carboxylic Acids and Derivatives. (25 points)

(a) The electrostatic potential (ESP) surface plot is shown of **benzoic acid, H_5C_6–COOH**. Draw the complete structure of benzoic acid. Your structure drawing should be aligned as much as possible with the orientation of the molecules in the ESP plot. In your structure drawing, draw a SQUARE around the hydrogen bond donor and draw a CIRCLE around the best hydrogen bond acceptor. Provide a drawing of the H-bonded dimer formed by two benzoic acid molecules in any orientation you like. (6 points)

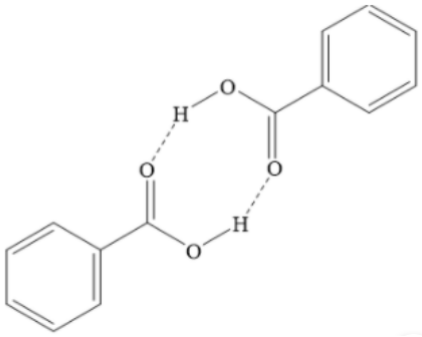


Benzoic Acid



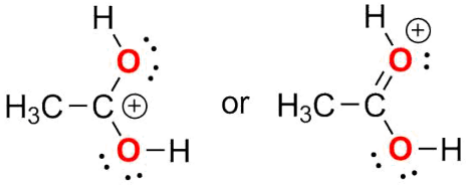
Square around OH-H
Circle around CO-O

Benzoic Acid Dimer

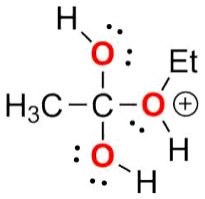


(b) Ethyl acetate H_3C–CO–O–CH_2–CH_3 can be made by Fischer esterification of acetic acid and ethanol. Consider the mechanism of **ethyl acetate** formation catalyzed by a strong mineral acid. Draw the structural formulas of the species indicated (show all lone pairs and formal charges). You may abbreviate the **methyl** group as "H_3C–" or as "Me–" and the **ethyl** group as "H_5C_2–" or as "Et–". (8 points)

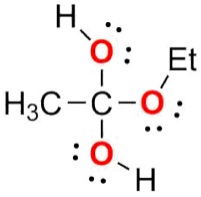
1: Protonated carboxylic acid, i.e., the activated substrate for alcohol addition



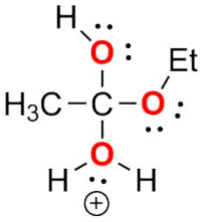
2: Product formed by addition of alcohol to the protonated carboxylic acid



3: Neutral gem tri-functional intermediate



4: Protonated gem tri-functional intermediate that will lead to water elimination



(c) Nomenclature, Preparation, and Reactions. (11 points)

Draw the complete structure of **malonic acid**. (2 p.)

HOOC-CH_2-COOH
drawn in more detail

Draw the complete structures of thionyl chloride and of the product formed by reaction of **benzoic acid with thionyl chloride**. (3 p.)

$O{=}SCl_2 + Ph{-}COOH \rightarrow Ph{-}CO{-}Cl + SO_2 + HCl$
drawn in more detail

Draw structures of **ethyl acetate and methylamine** and of their reaction product. Name the product. (6 p.)

$H_3C{-}CO{-}O{-}C_2H_5 + H_2N{-}CH_3 \rightarrow H_3C{-}CO{-}NH{-}CH_3 + Et{-}OH$
drawn in more detail
N-methylacetamide