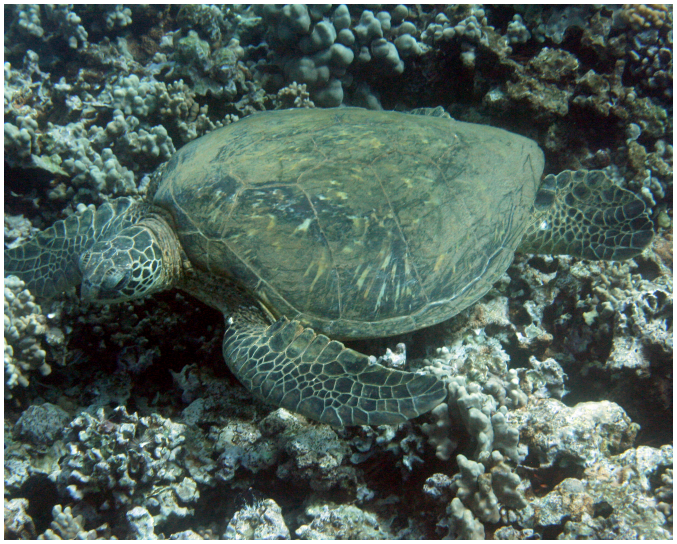


Important takeaways from the contributing structures

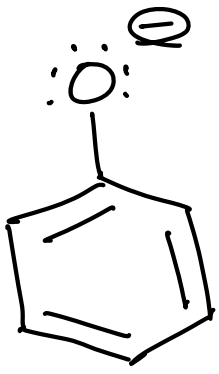
1) Benzene rings stabilize anions, cations and radicals

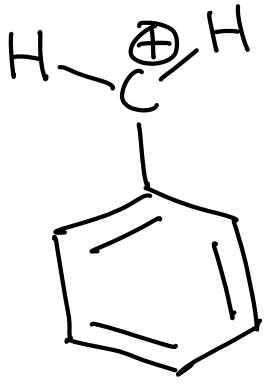
Golden Rules 5, 6 and 7

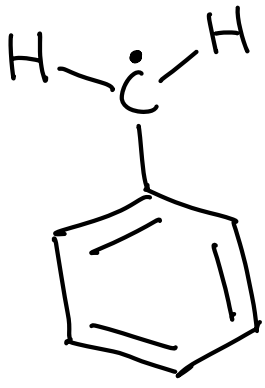
2) Molecules can have electrons on an atom outside the ring delocalized into the π system and the "extra" electrons do not count against the 4n+2 number of π electrons

Quantum Mechanics!

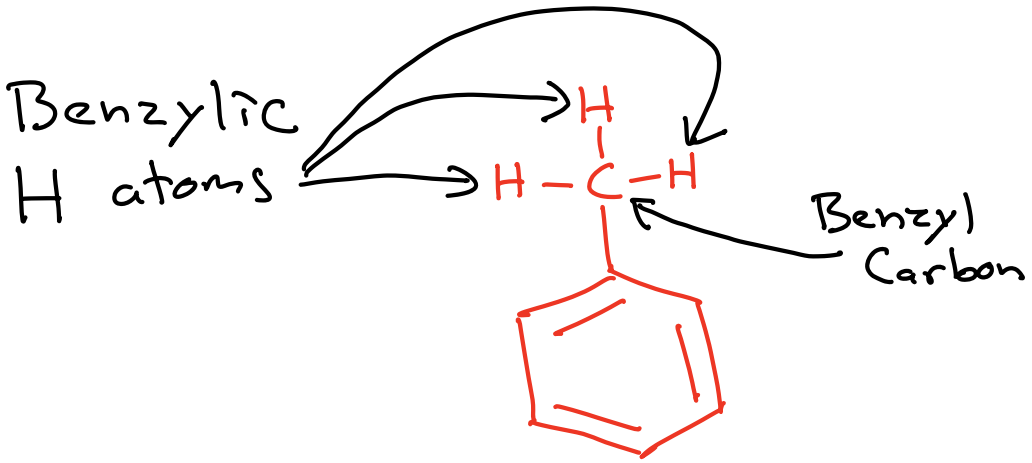
Summary → Molecules below are stabilized by delocalizing the charge/unpaired electron into the aromatic ring.



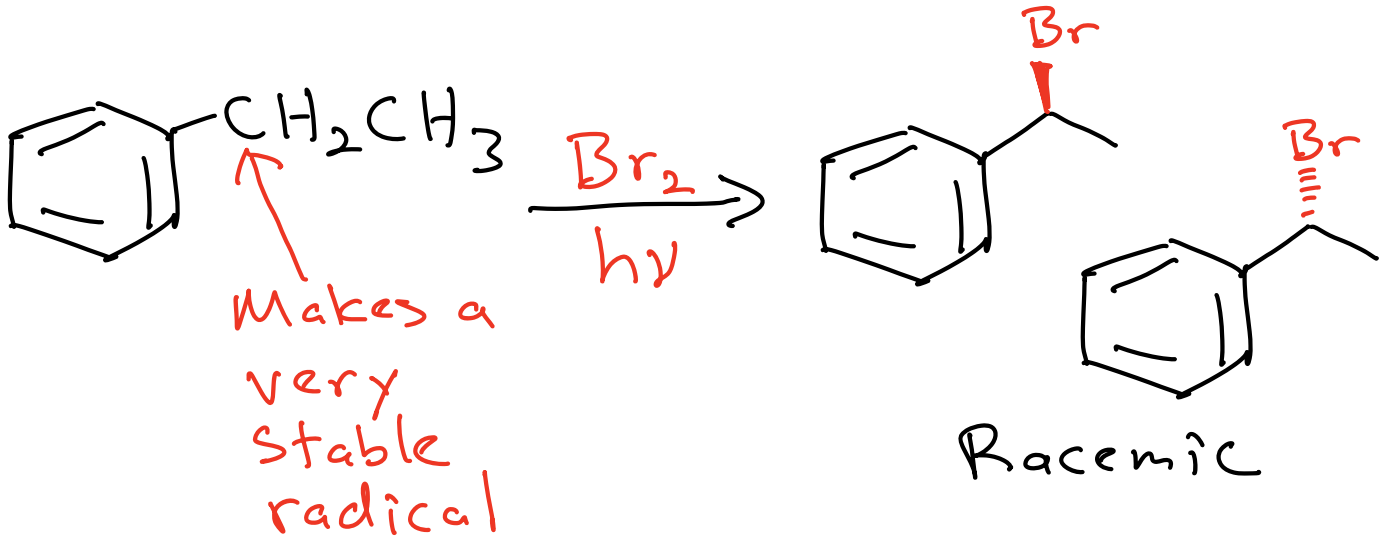




A carbon attached to a benzene ring has special reactivity so it has a special name – the benzyl carbon

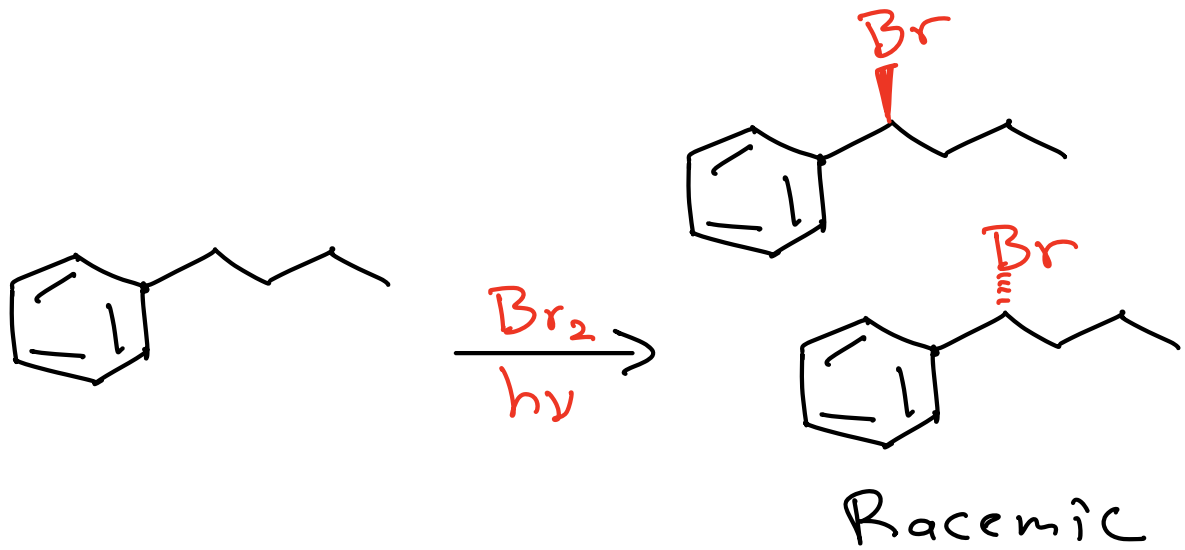


Free radical halogenation



Radical Stability

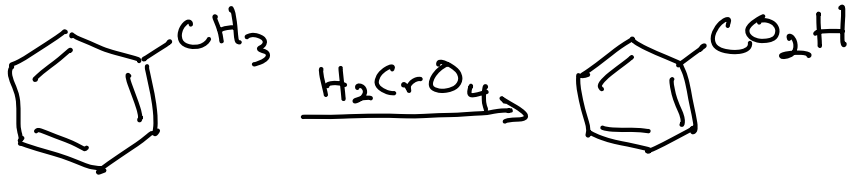
Methyl < 1° < 2° < 3° < Benzyl Radical

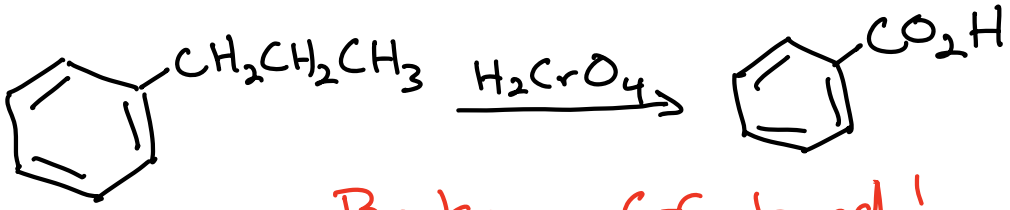


Oxidation

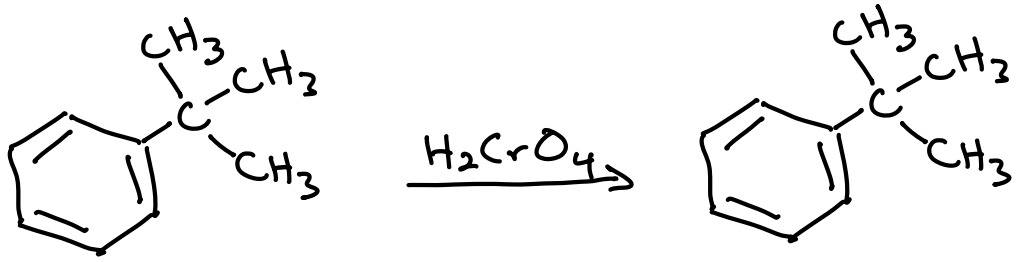
The benzylic carbon is easy to oxidize all the way to a carboxylic acid — even breaking C-C bonds!

The benzylic carbon needs at least one H atom for the reaction to occur



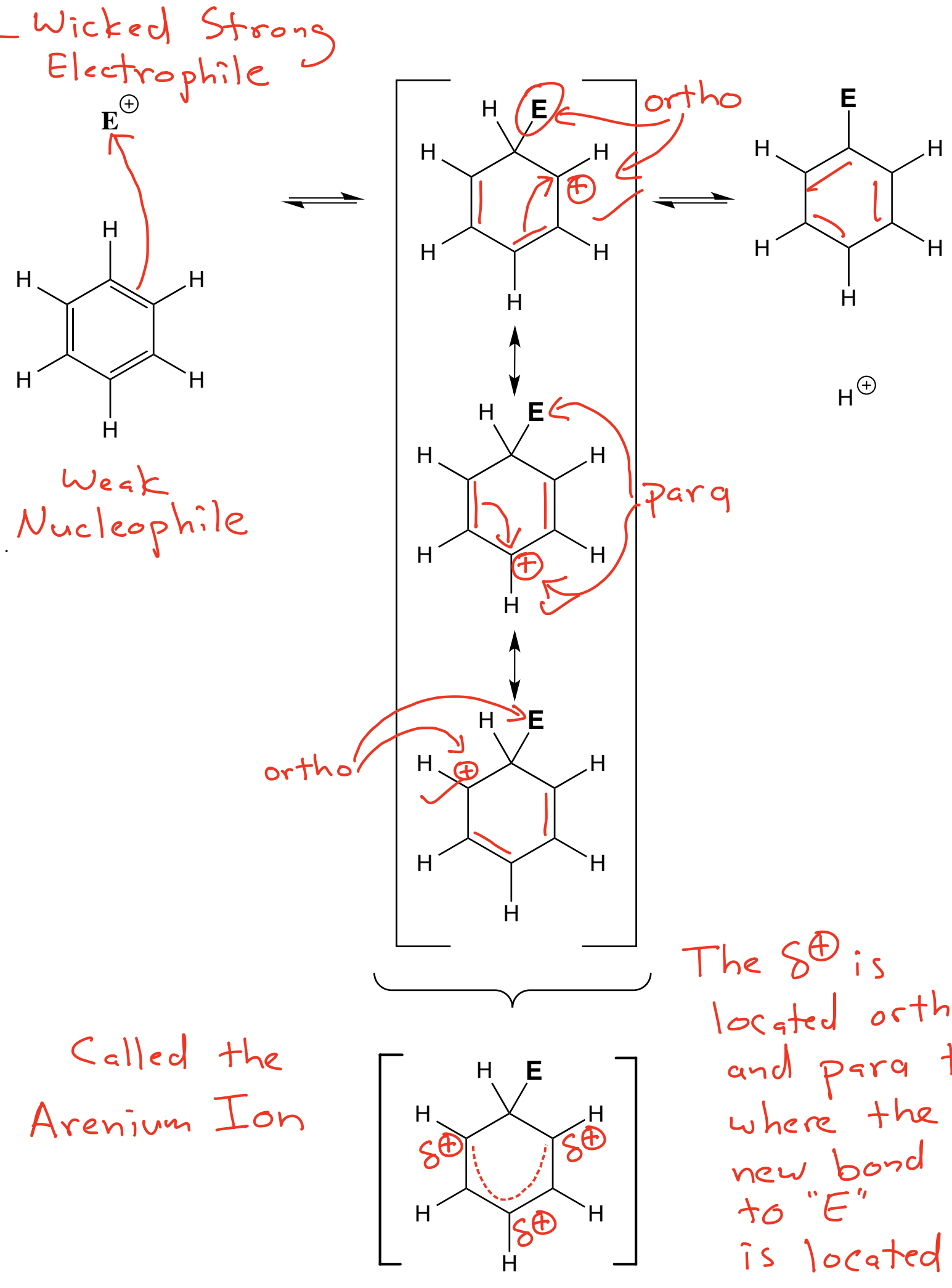


Broke a C-C bond!



No C-H bond on benzylic C atom

(NO REACTION)


Wicked Strong Electrophile
E⊕
Weak Nucleophile
ortho
para
ortho
H⊕
Called the Arenium Ion
The δ⊕ is located ortho and para to where the new bond to "E" is located

Summary → Wicked strong electrophile reacts with the benzene π electron density to make a resonance delocalized arenium ion intermediate that loses a proton to give a substituted benzene

The arenium ion intermediate has partial ⊕ charge ortho and para to the new bond to E

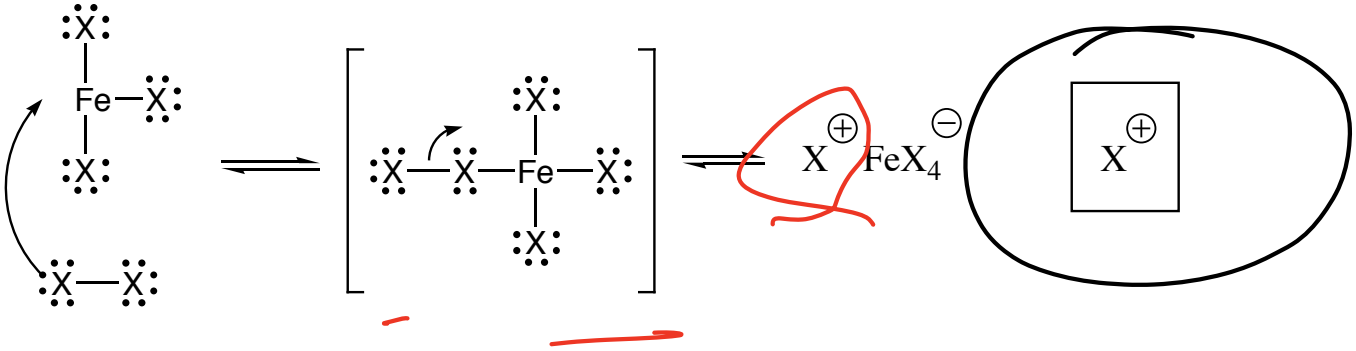
This reaction is called "Electrophilic Aromatic Substitution (EAS)"

Reagents

Wicked strong electrophile

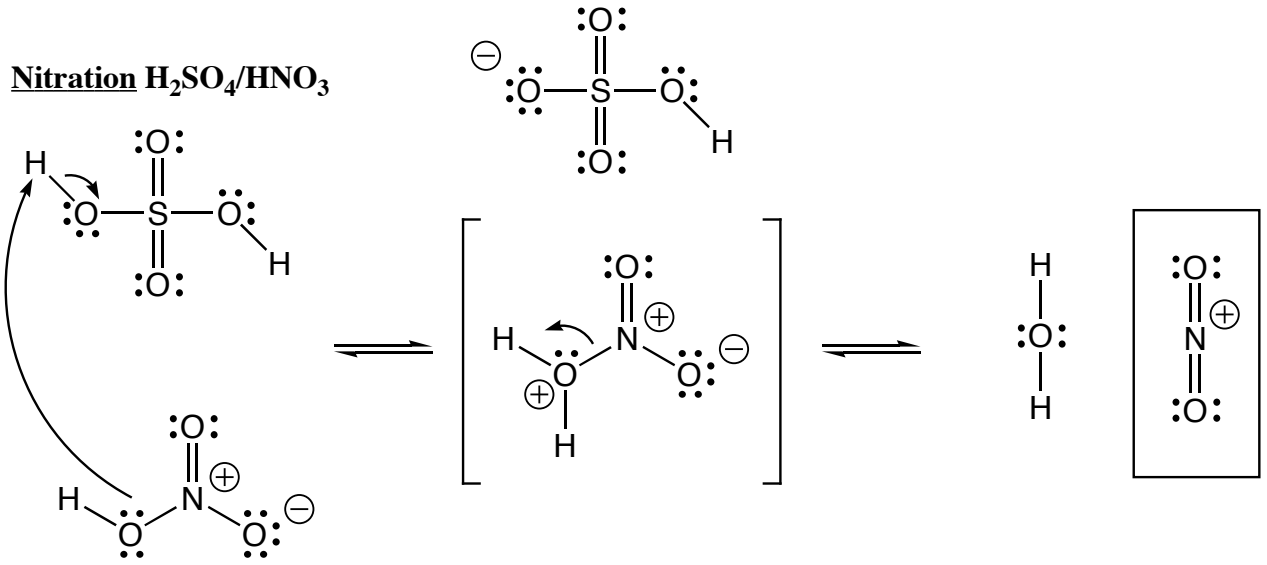
$E^{\oplus}$

Halogenation X_2, FeX_3



X = Br, Cl

Nitration H_2SO_4/HNO_3



Sulfonation H_2SO_4/SO_3

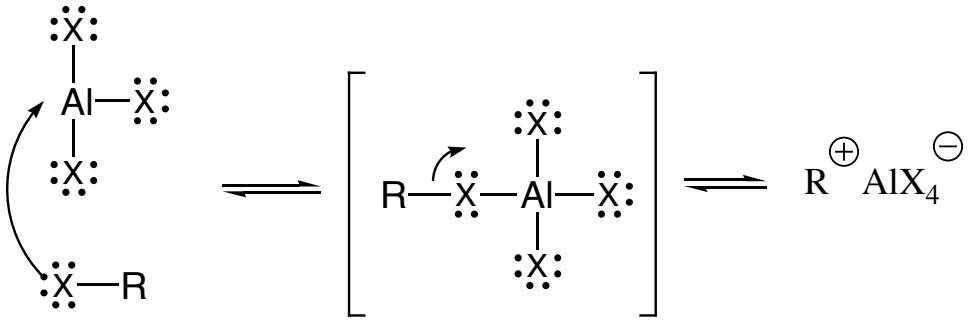
Fuming sulfuric acid contains both of the above reagents, the SO_3 is the important one

Reagents

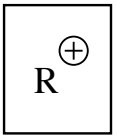
Wicked strong electrophile

$\underline{\mathbf{E}^{\oplus}}$

Friedel-Crafts Alkylation **R-X, AlX_3**

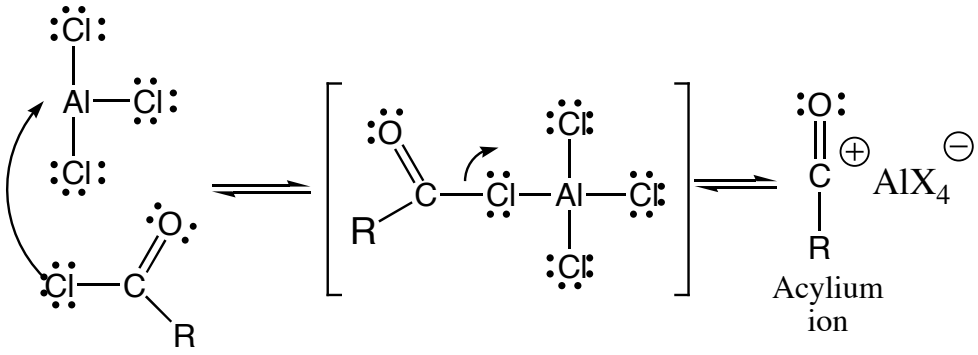


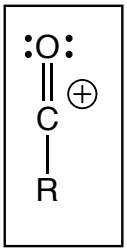
X = Br, Cl



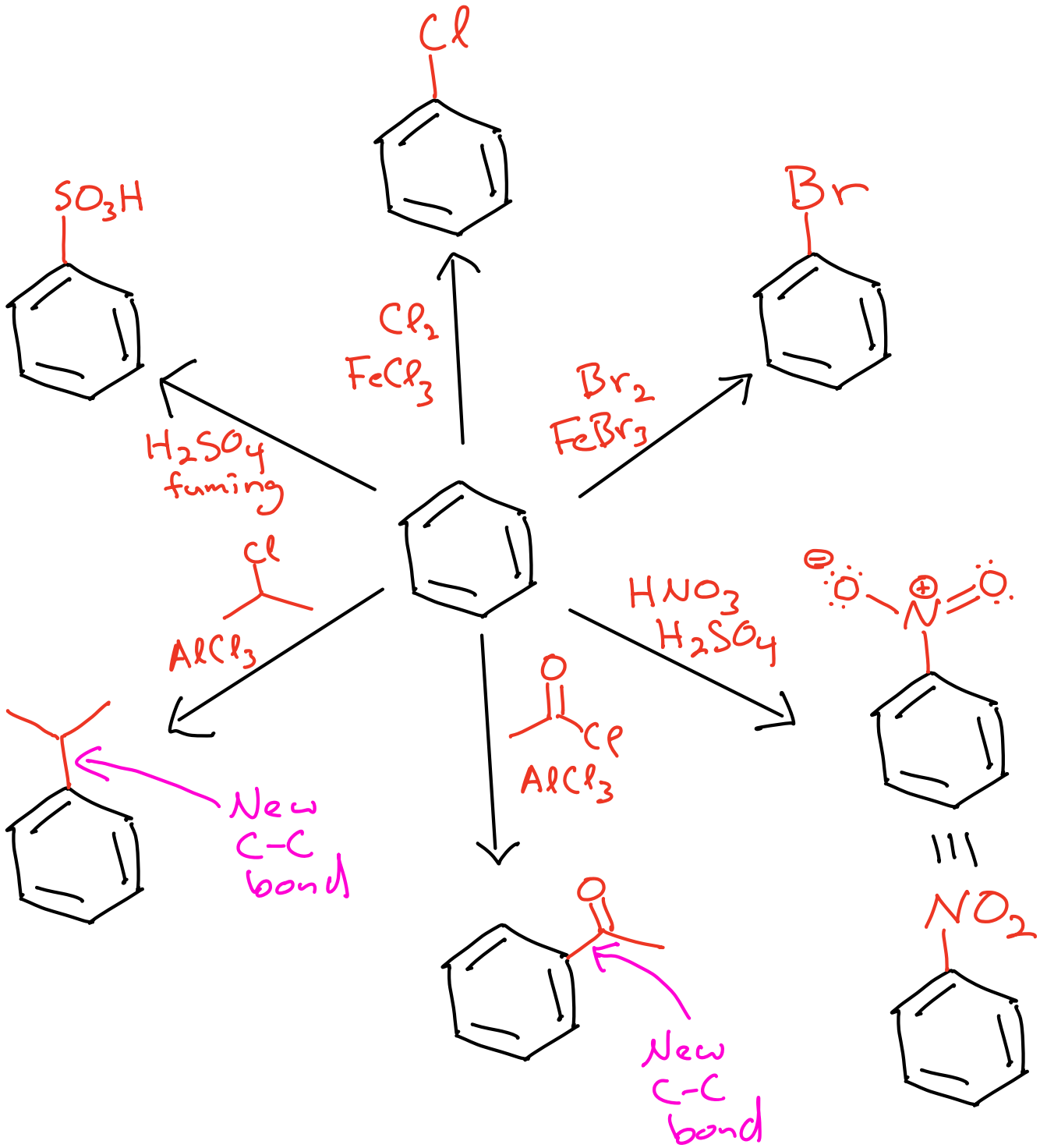
Note this is a carbocation, so it will rearrange if it is a primary or a rearrangment-prone secondary cation

Friedel-Crafts Acylation **RCOCl, $AlCl_3$**





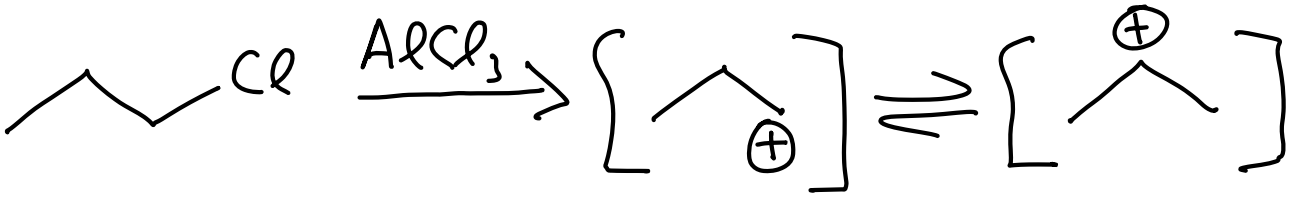
Other notes: 1) It is hard to stop the Friedel-Crafts alkylation after one alkyl group adds (because alkyl groups are "good", that is, activating), but it can be done. 2) Neither Friedel-Crafts reaction works if there is already an electron withdrawing (bad) group on the ring.


Cl
Cl_2
$FeCl_3$
SO_3H
H_2SO_4
fuming
Br
Br_2
$FeBr_3$
Cl
$AlCl_3$
HNO_3
H_2SO_4
O
Cl
$AlCl_3$
New
C-C
bond
O
New
C-C
bond
NO_2

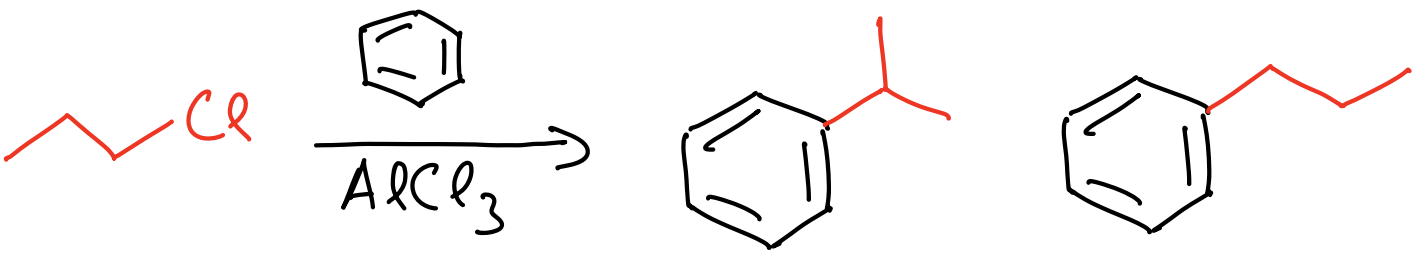
Friedel-Crafts Alkylations

Issue #1 → Carbocations rearrange!

Cannot use primary haloalkanes — they always rearrange!



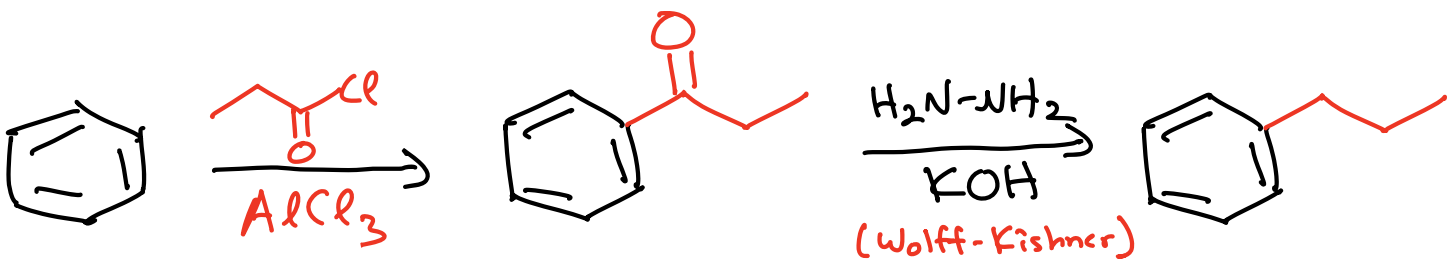
More Stable



Major Product

Minor Product

Workaround for primary alkyl group

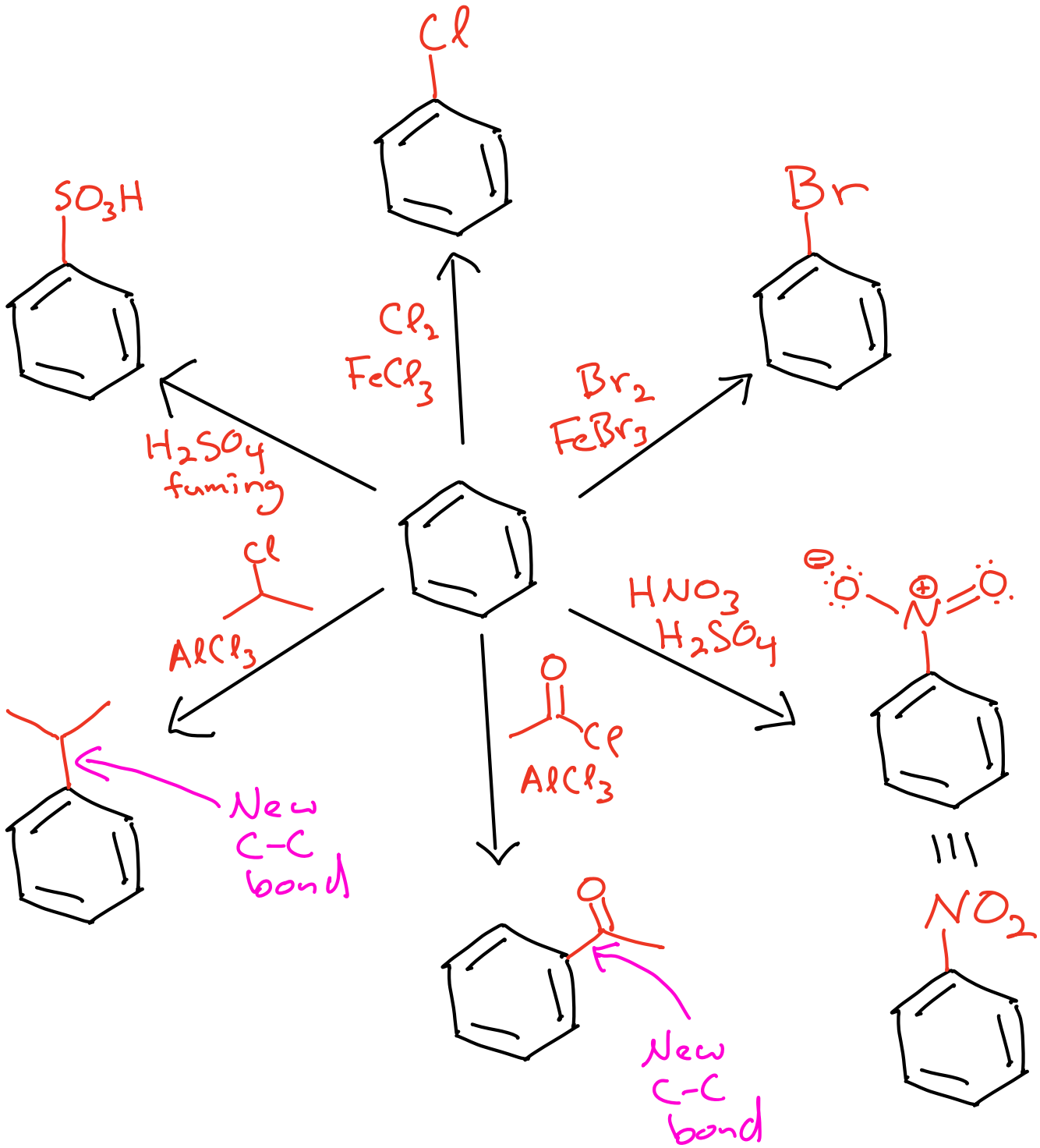


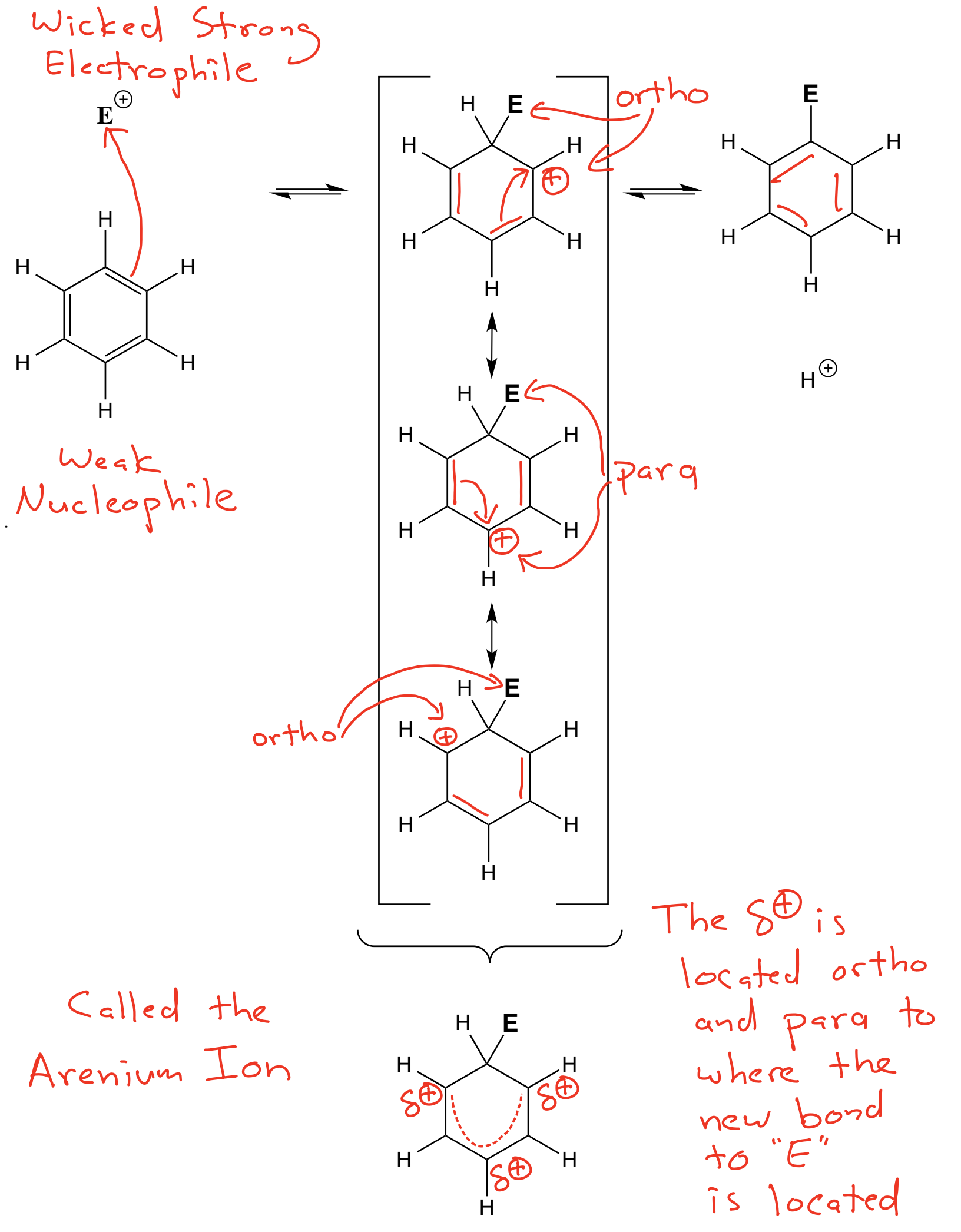
* Acylium ions do NOT rearrange!

Issue #2 → Time capsule: Alkyl groups are GOOD groups, so it is difficult (but not impossible) to stop at the addition of one alkyl group.

Issue #3 → Time capsule: Neither the Friedel-Crafts alkylation or acylation will work if there is a BAD (deactivating) group already on the ring

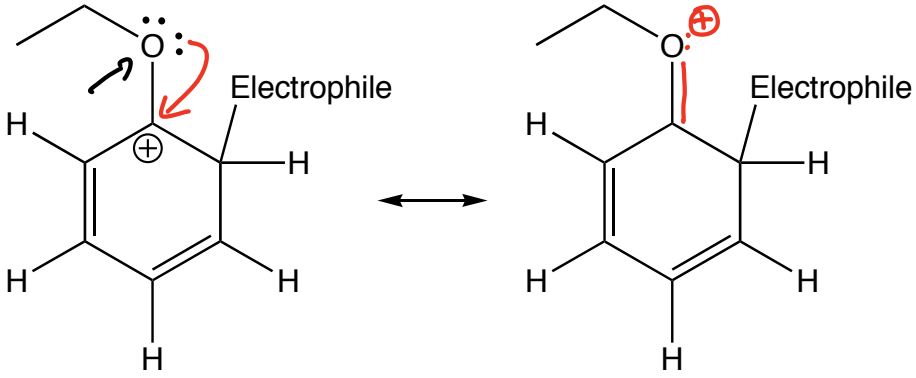
THE GOOD, THE BAD AND THE UGLY (1966)


Cl
Cl_2
$FeCl_3$
SO_3H
H_2SO_4
fuming
Br
Br_2
$FeBr_3$
Cl
$AlCl_3$
HNO_3
H_2SO_4
O
Cl
$AlCl_3$
New
C-C
bond
O
New
C-C
bond
NO_2


Wicked Strong Electrophile
E⊕
Weak Nucleophile
ortho
para
ortho
H⊕
Called the Arenium Ion
δ⊕
The δ⊕ is located ortho and para to where the new bond to "E" is located

Arenium ion ***stabilizing*** interactions ← GOOD

A) **Pi donation**, a resonance effect for atoms with lone pairs attached to the ring

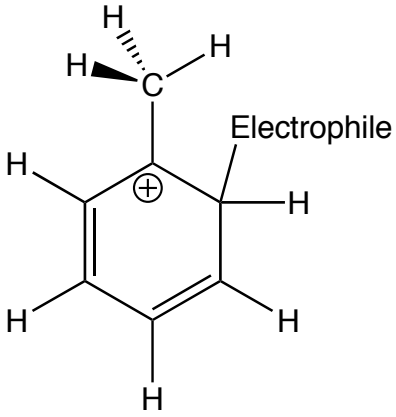


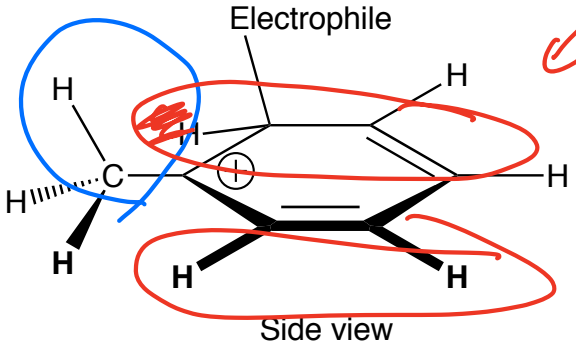
← "pi-pi"

The "Greek interactions"

"sigma-pi"

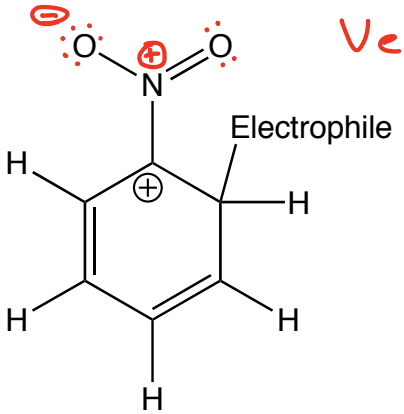
B) **Hyperconjugation** for alkyl groups attached to the ring





Arenium ion ***destabilizing*** interaction ← BAD

A) **Inductive effect** of electronegative atoms or groups attached to the ring



Very electron withdrawing

GOOD → Through pi donation or hyperconjugation the arenium ion is stabilized

↓

Activating
Ortho-Para
Directing

Most effective ortho and para

Atoms attached to the ring have a lone pair of electrons or alkyl groups

BAD → Through the inductive effect – electron withdrawing groups – the arenium ion is destabilized

↓

Deactivating
Meta directing

"Least bad" meta

Mostly when the atom attached to the ring has a π bond or $-CX_3$ in which X is halogen

UGLY

↓

Deactivating

Ortho-Para

Directing

→ Both GOOD and BAD at the same time

→ Through pi donation the arenium ion is stabilized.

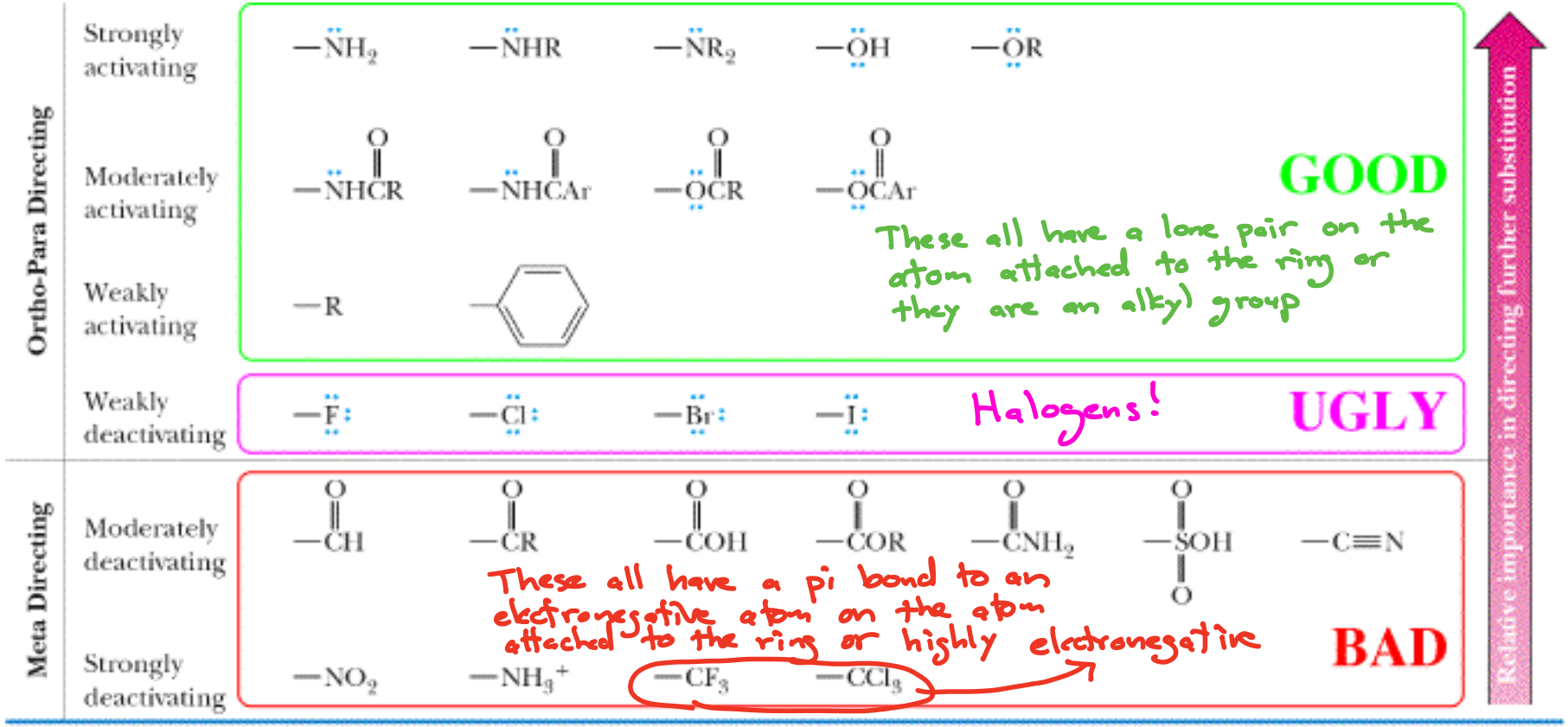
Most effective ortho and para

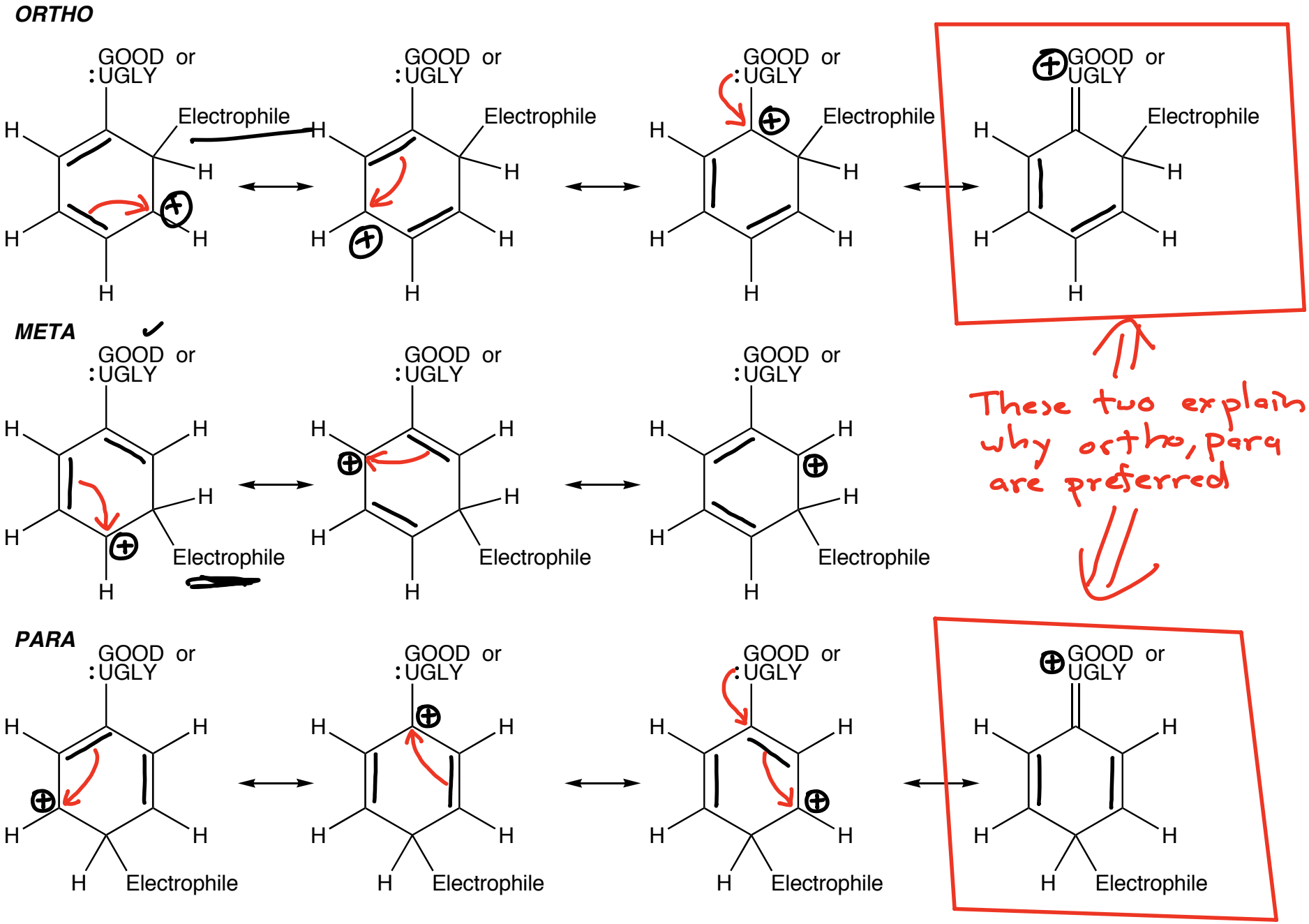
A pi electron effect

→ Through the inductive effect – electron withdrawing groups – the arenium ion is destabilized

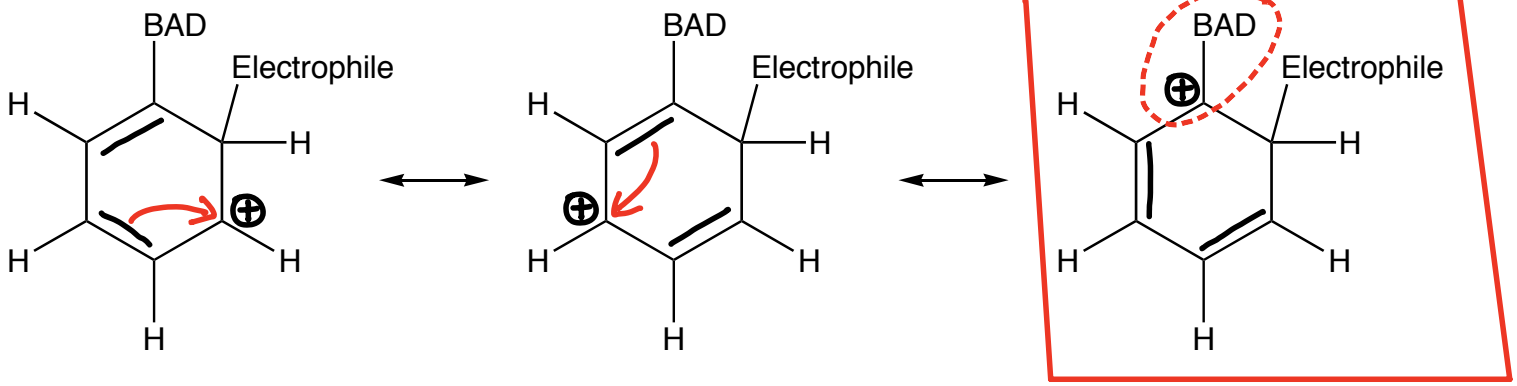
A sigma bond effect

$-\ddot{F}:$, $-\ddot{Cl}:$, $-\ddot{Br}:$, $-\ddot{I}:$

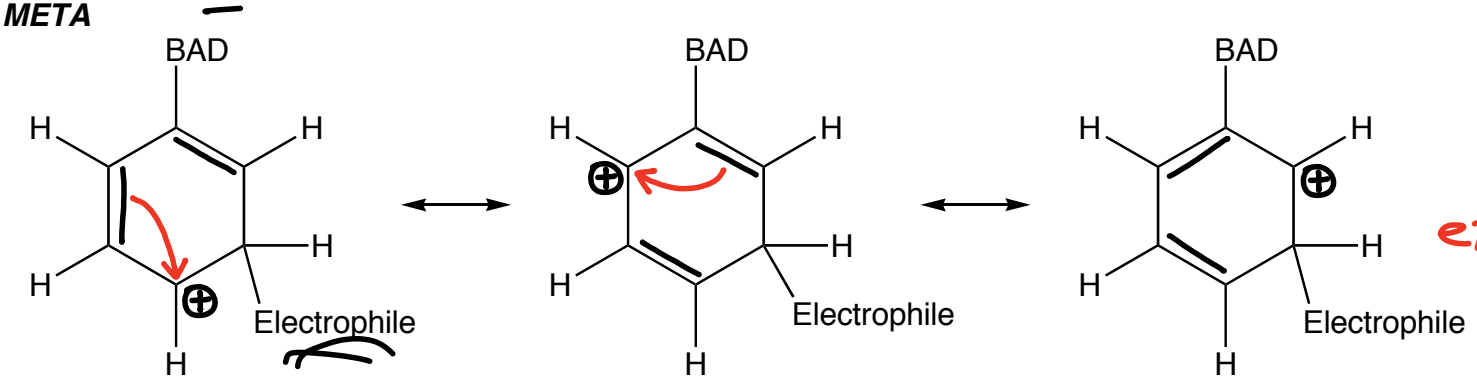

Ortho-Para Directing
Strongly activating
—NH2
—NHR
—NR2
—OH
—OR
Moderately activating
—NHCR
—NHCAr
—OCR
—OCAr
Weakly activating
—R
GOOD
These all have a lone pair on the atom attached to the ring or they are an alkyl group
Weakly deactivating
—F:
—Cl:
—Br:
—I:
Halogens!
UGLY
Meta Directing
Moderately deactivating
—CH
—CR
—COH
—COR
—CNH2
—SOH
—C≡N
These all have a pi bond to an electronegative atom on the atom attached to the ring or highly electronegative
Strongly deactivating
—NO2
—NH3+
—CF3
—CCl3
BAD
Relative importance in directing further substitution


ORTHO
GOOD or
:UGLY
Electrophile
META
PARA
These two explain why ortho, para are preferred

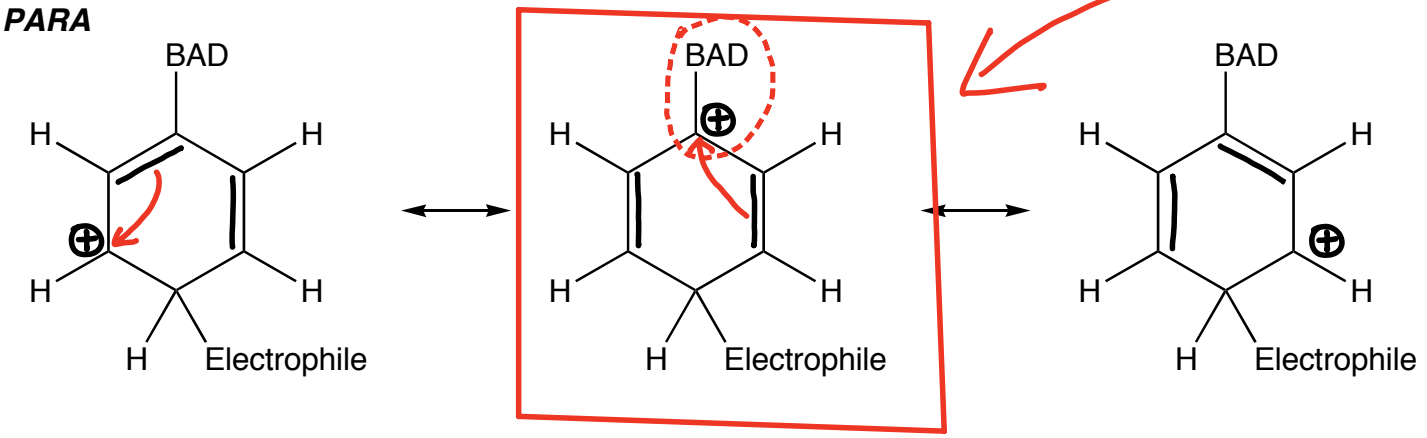
ORTHO



META



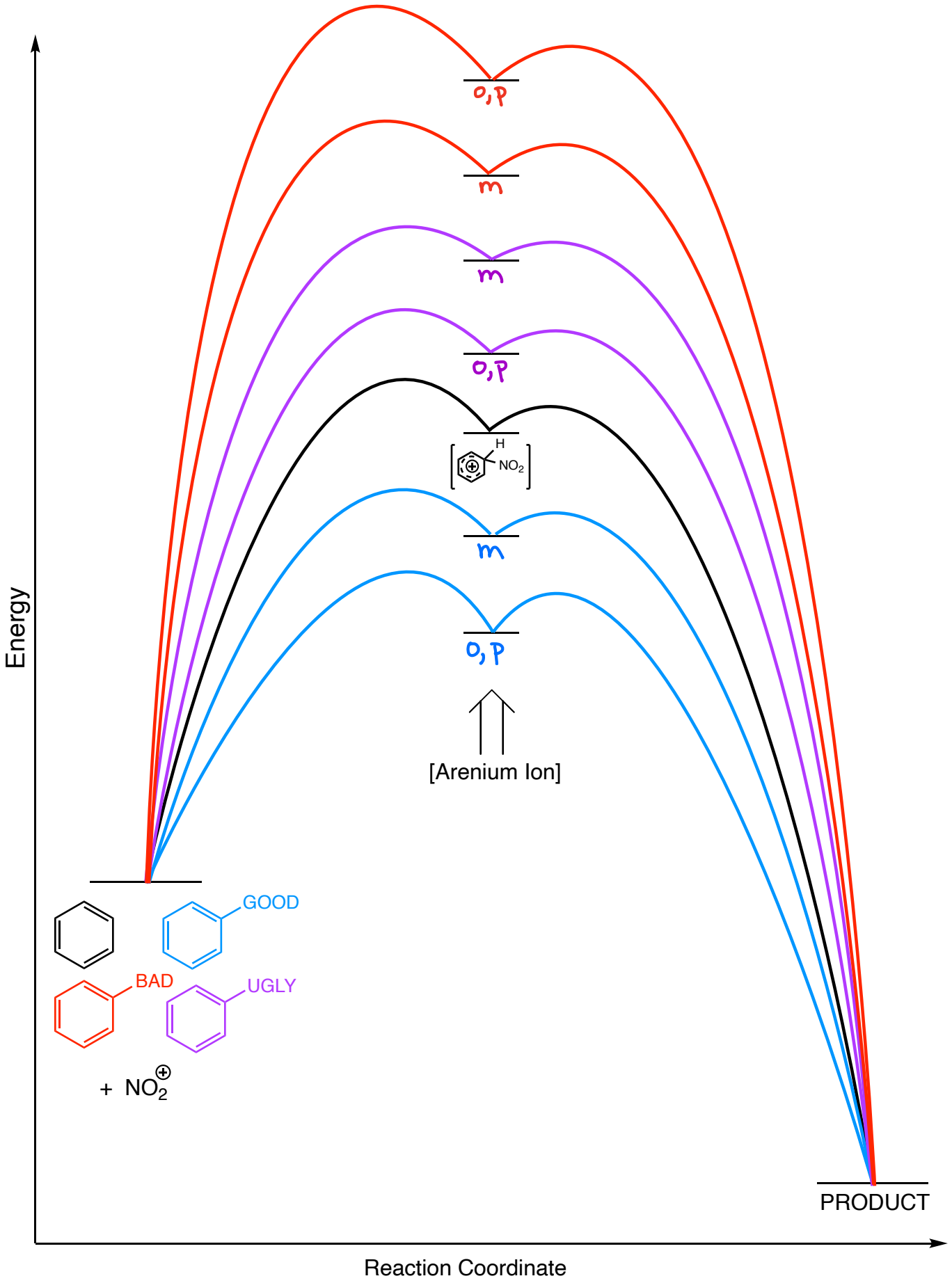
PARA



Very destabilizing explaining why for BAD groups

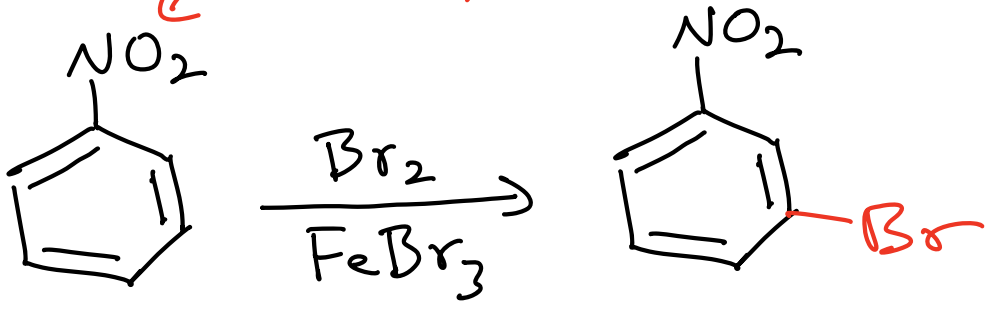
"meta is betta"

No terrible interaction meta like there is ortho, para

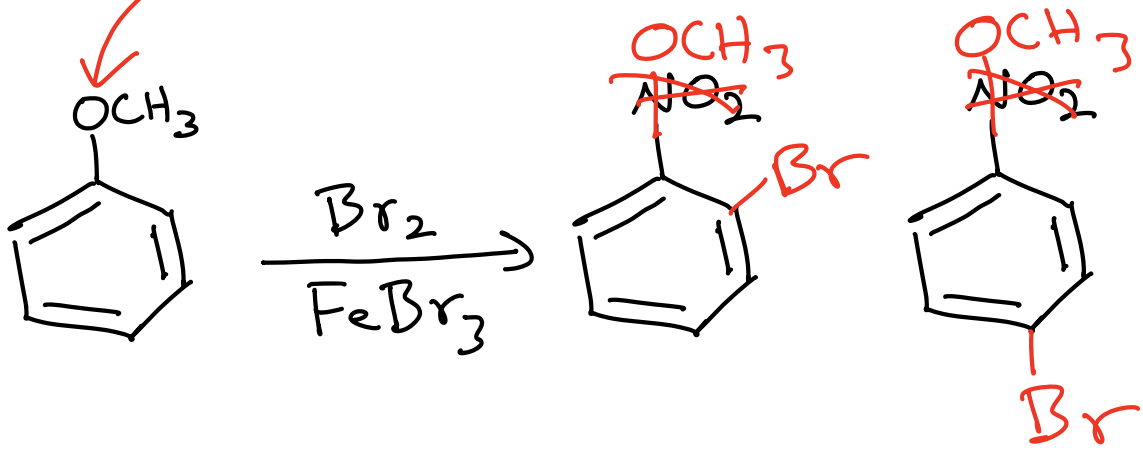

o,p
m
m
o,p
H
NO2
m
o,p
[Arenium Ion]
GOOD
BAD
UGLY
+ NO2⊕
PRODUCT
Energy
Reaction Coordinate

Examples

BAD, meta directing



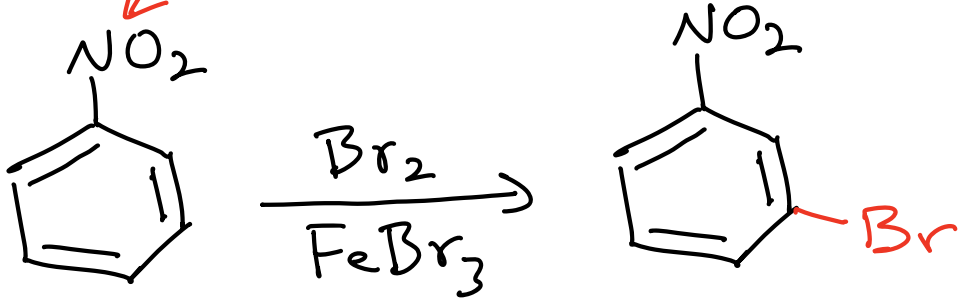
GOOD, ortho, para directing



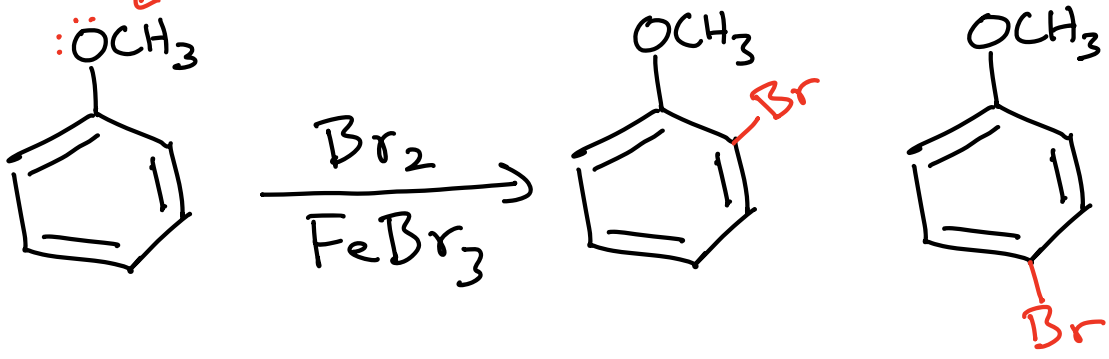
OOPS! In class I did not notice an error in the notes → The notes incorrectly had an $-NO_2$ group on the two product rings. Shoud be $-OCH_3$. Below it is drawn correctly.

Examples

BAD → Meta directing



GOOD → Ortho, Para directing



The order in which you add groups matters!