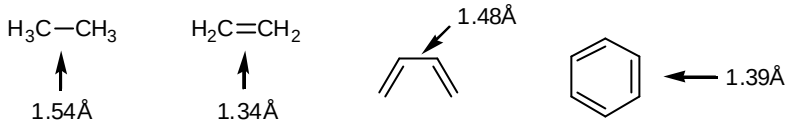
1) Zum Mechanismus der elektrophilen aromatischen Substitution

Aromatischer Charakter

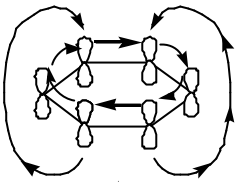
(4 n + 2)π-Elektronen

Antiaromatischer Charakter

4 nπ e⊖

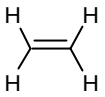


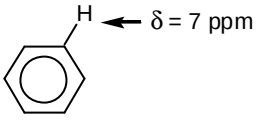
Ringstrom-Effekte



induziertes Feld

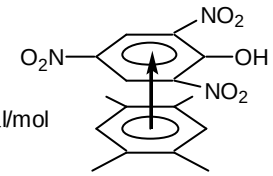
Äußeres Magnetfeld





<u>Reaktion des aromatischen Ringes:</u>

Bildung von π-Komplexen

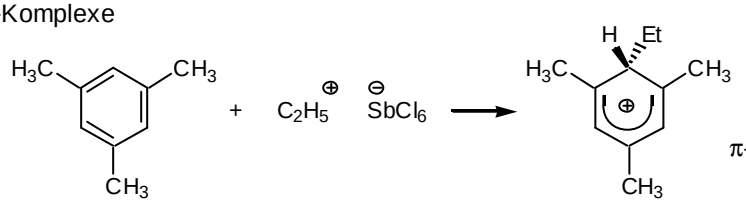


Pikrinsäure

Charge-Transfer Komplexe

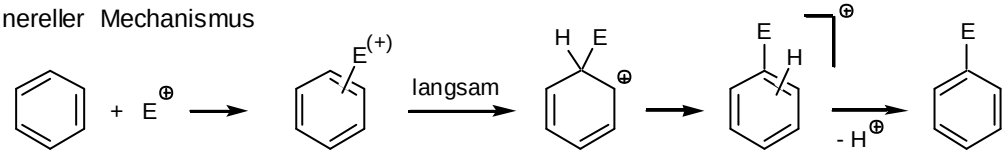
Schwache Komplexe: 3-10kcal/mol

π-Komplexe

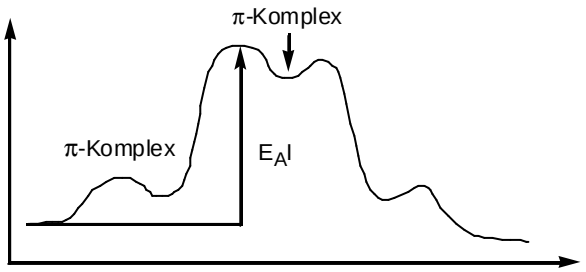


π-Komplex (bei -15°C haltbar)

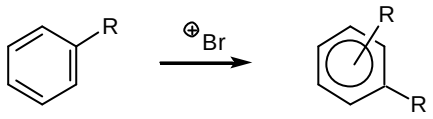
Genereller Mechanismus



π-Komplex — σ–Komplex — π-Komplex



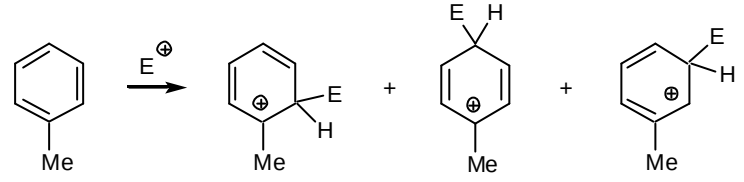
Einfluß der Erstsubstituenten auf die Geschwindigkeit der Bromierung von monosubstituierten Benzolen.

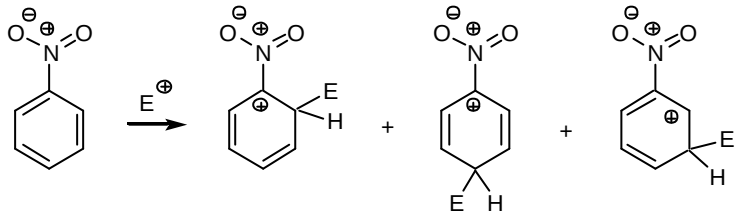


R	k_{rel}	R	k_{rel}	R	k_{rel}	R	k_{rel}
Me_2N	10^{18}	CH_3	340	H	1.0	F	1.2
OH	10^{11}	C_2H_5	290	CH_2Cl	0.8	Cl	0.1
OMe	10^{9}	Me_2CH	180	CO_2H	10^{-4}	Br	0.08
HNCOMe	10^{8}	t-Bu	110	NO_2	10^{-6}	I	0.18

+ I, + M beschleunig und dirigiert o, p

- I, - M verlangsamt und dirigiert m





Sterische Effekte begünstigen Para-Substitution

2) Beispiele für elektrophile aromatische Substitutionen

2.1. Elektrophiler Stickstoff

Nitrierung $HO{-}NO_2 + 2\ H_2SO_4 \longrightarrow \overset{\oplus}{N}O_2 + H_3\overset{\oplus}{O} + 2\ \overset{\ominus}{HSO_4}$

Nitronium-ion

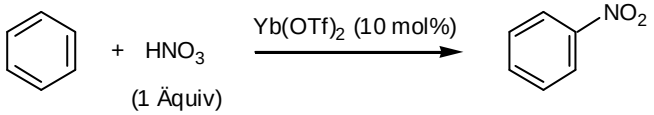
Nitrierung mit konz. HNO_3

$HNO_3 + H_2SO_4$

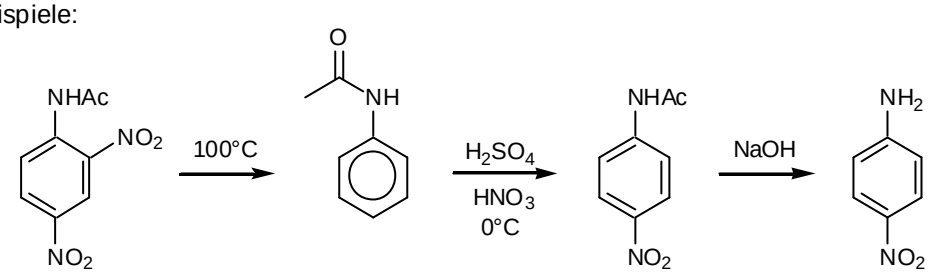
HNO_3 in $AcOH/Ac_2O \rightleftharpoons AcONO_2 \rightleftharpoons \overset{\oplus}{N}O_2 + \overset{\ominus}{AcO}$

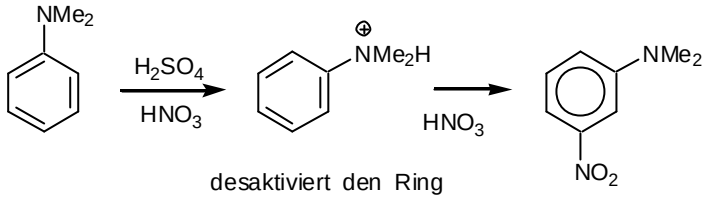
$\overset{\oplus}{N}O_2\ \overset{\ominus}{BF_4}$ Acylnitrat

A. G. M. Barrett



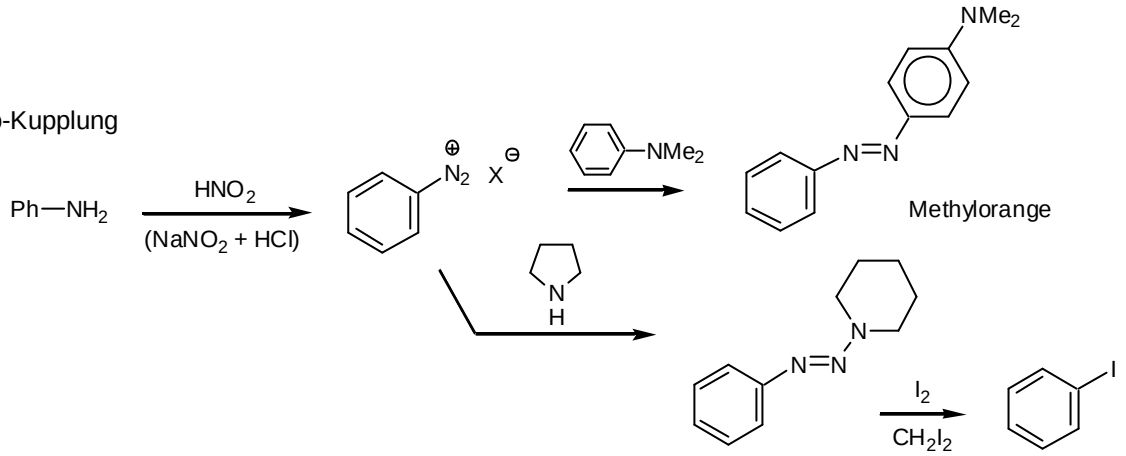
Beispiele:



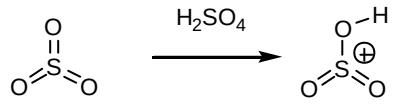


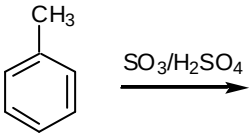
desaktiviert den Ring

Azo-Kupplung

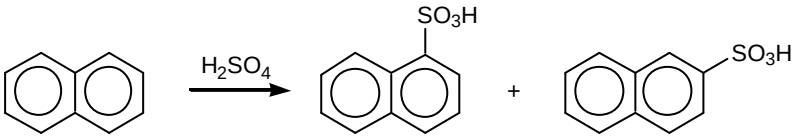


2.2. Elektrophiler Schwefel



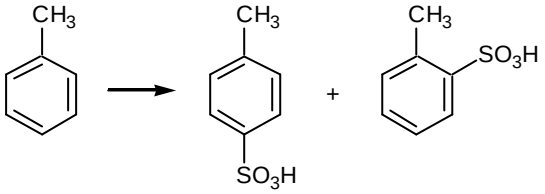


	o	m	p	
0°C	43	4	53	kinetische Kontrolle
> 100°C			>> 90	thermodynamische Kontrolle

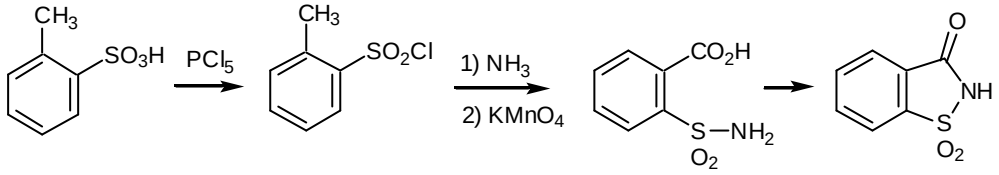


80°C	96%	4%
165°C	15%	85%

Saccharin-Synthese:

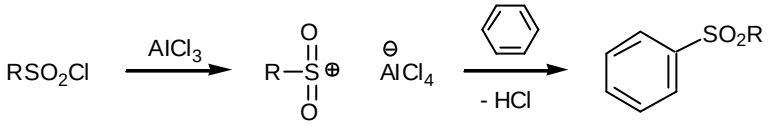


Das kinetische Gemisch wird getrennt



Na-Salz

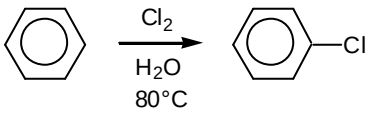
500 x süßer als Zucker



2.3. Elektrophile Halogenierung

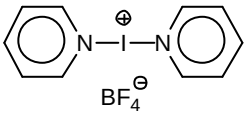
Chlorierung mit Cl_2 + $AlCl_3$; Bromierung mit Br_2 + $FeBr_3$

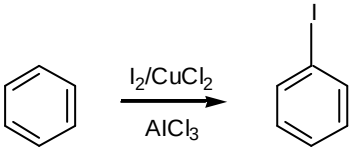
Die Verwendung von $Yb(OTf)_3$, $Sc(OTf)_3$ oder $Bi(OTf)_3$ erlaubt die Durchführung von Reaktionen mit katalytischen Mengen an Katalysatoren (Lewissäure)



Chlorierungsmittel: HOCl

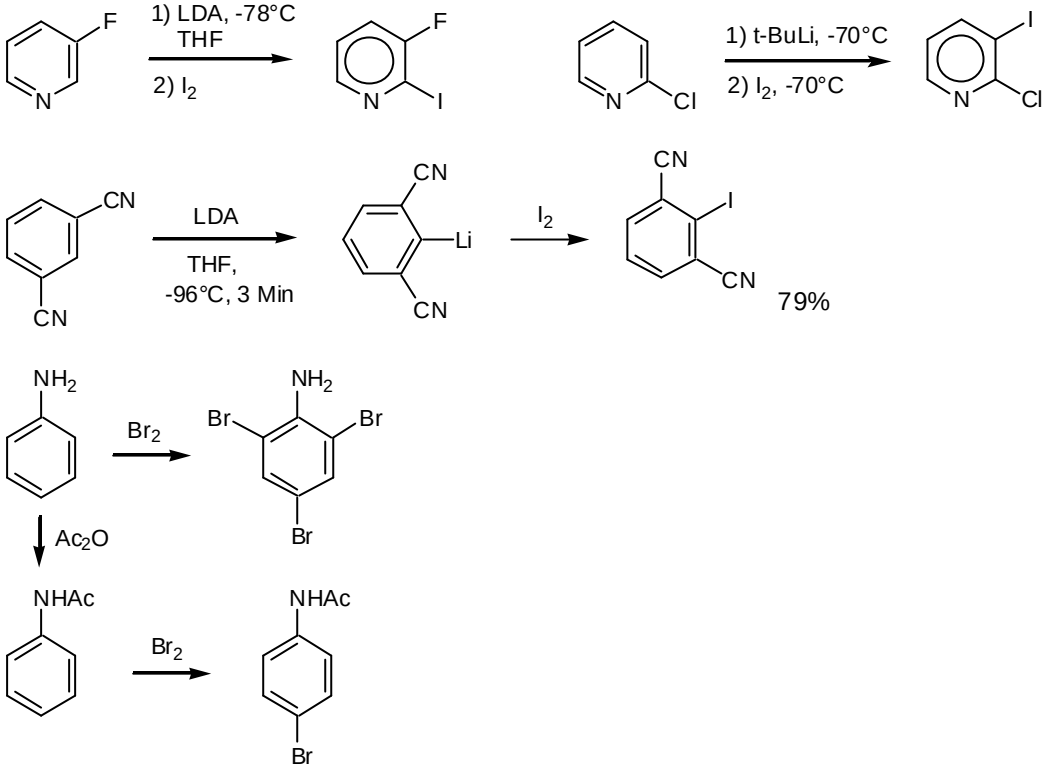
Iodierung ist reversibel: ICl, $I_2/AgClO_4$ oder



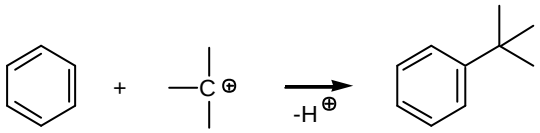


86%

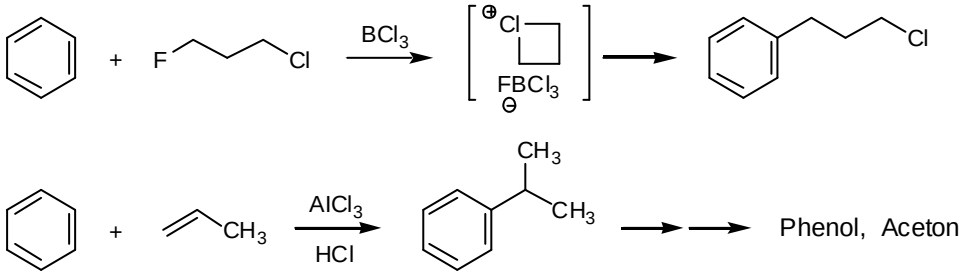
Alternative Synthesen:



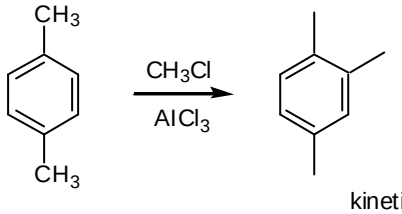
2.4. Elektrophiler Kohlenstoff: Friedel-Crafts-Reaktion



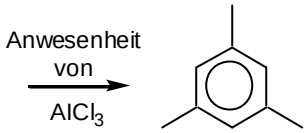
Kat.: $AlBr_3$ > $AlCl_3$ > $FeCl_3$ > $SnCl_4$ > BF_3 > $TiCl_4$



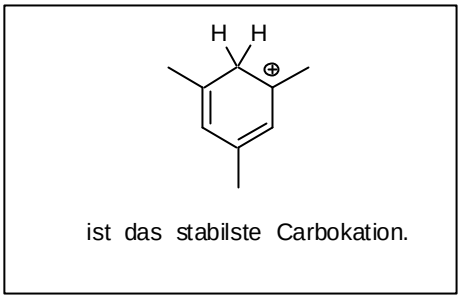
Die Fiedel-Crafts-Reaktion ist reversibel.



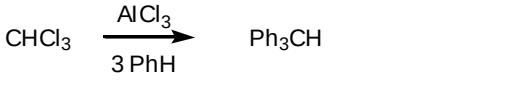
kinetisches Produkt

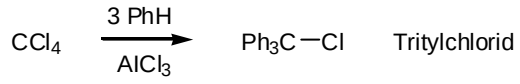


thermodynamisches Produkt

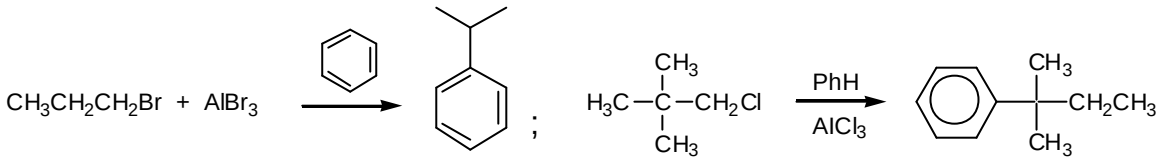


ist das stabilste Carbokation.

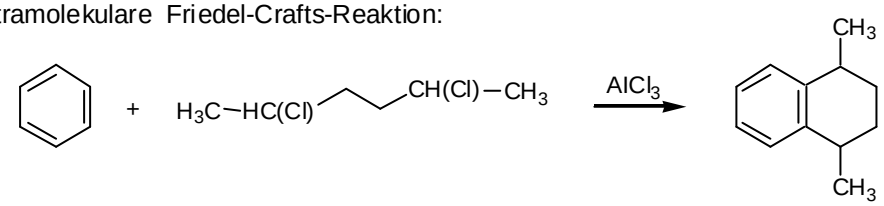




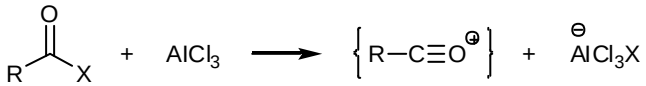
Umlagerungen werden oft beobachtet:



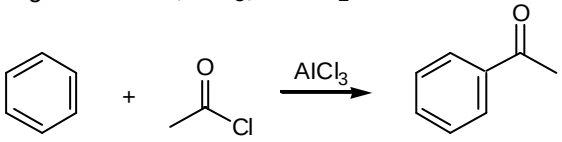
Intramolekulare Friedel-Crafts-Reaktion:



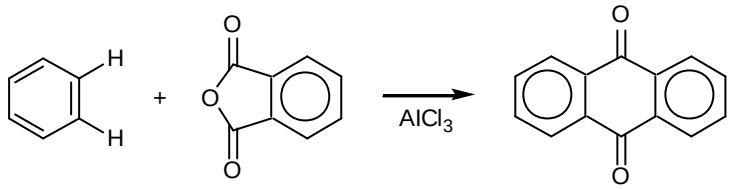
Friedel-Crafts-Acylierung

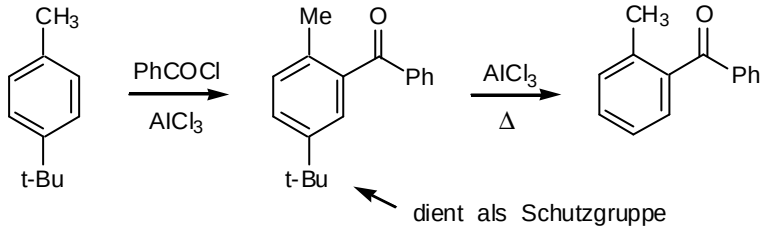


Lösungsmittel: CS, CH_3, $PhNO_2$

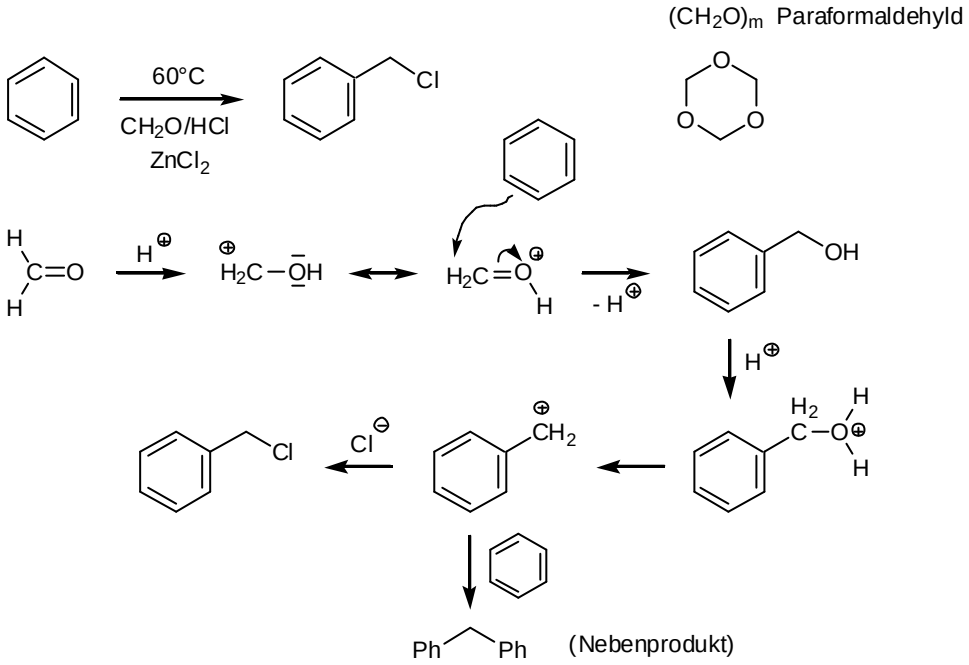


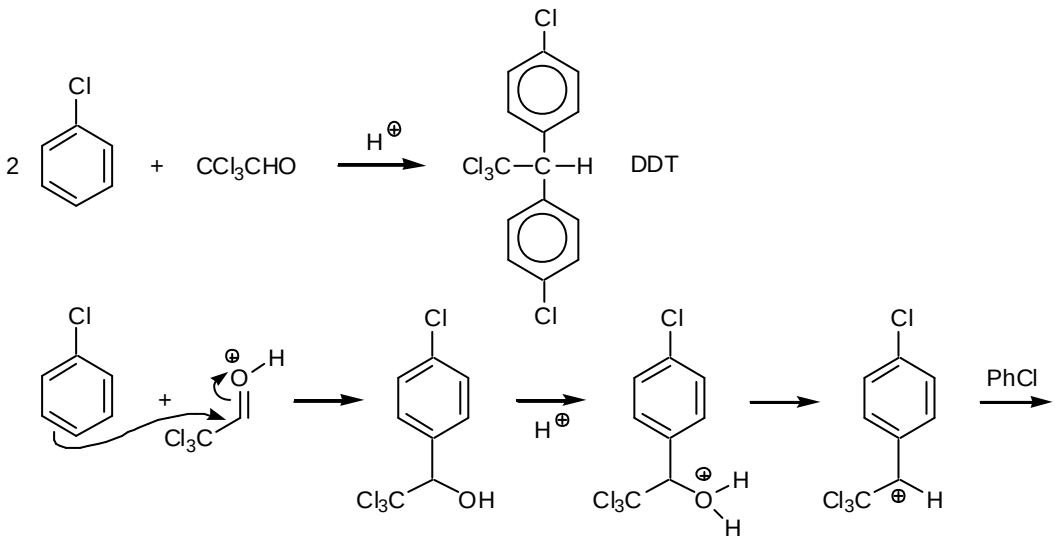
reaktives Intermediat: $H_3C-\overset{\oplus}{C}=O$

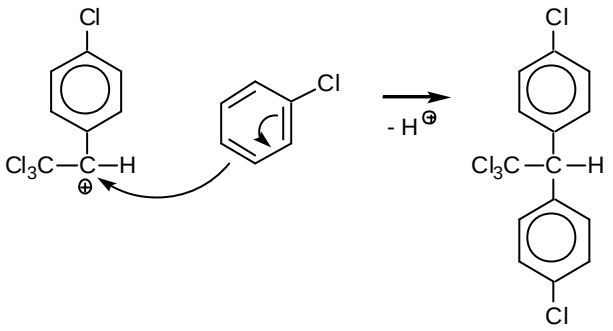




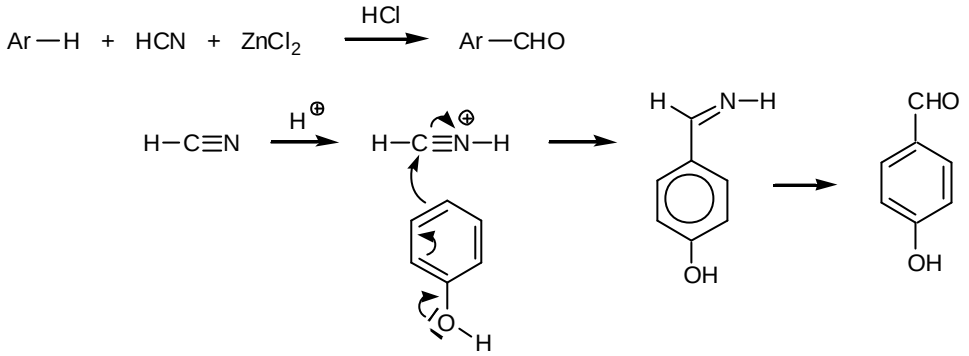
Die Chlormethylierung



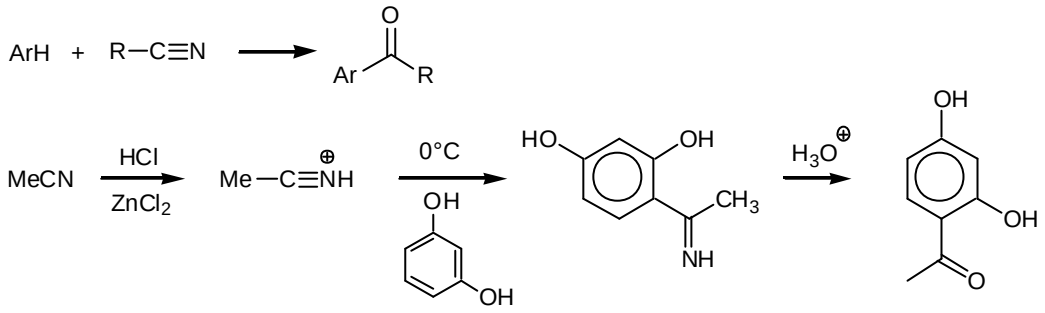




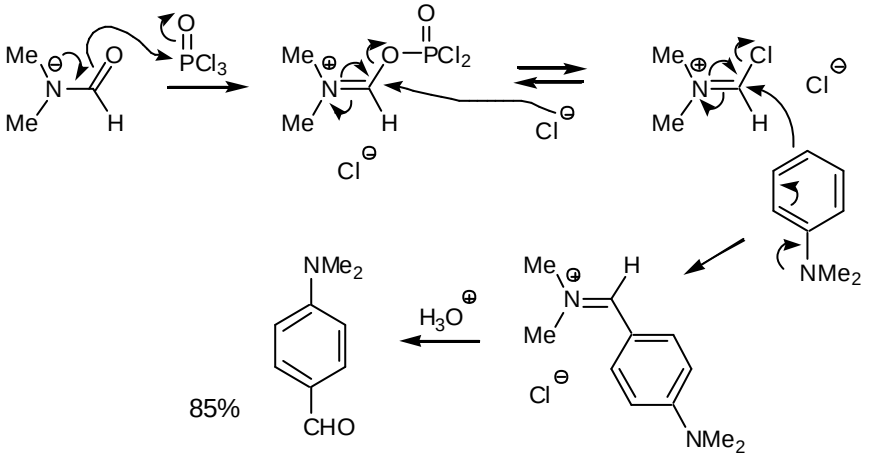
Gattermann-Hoesch-Reaktion:



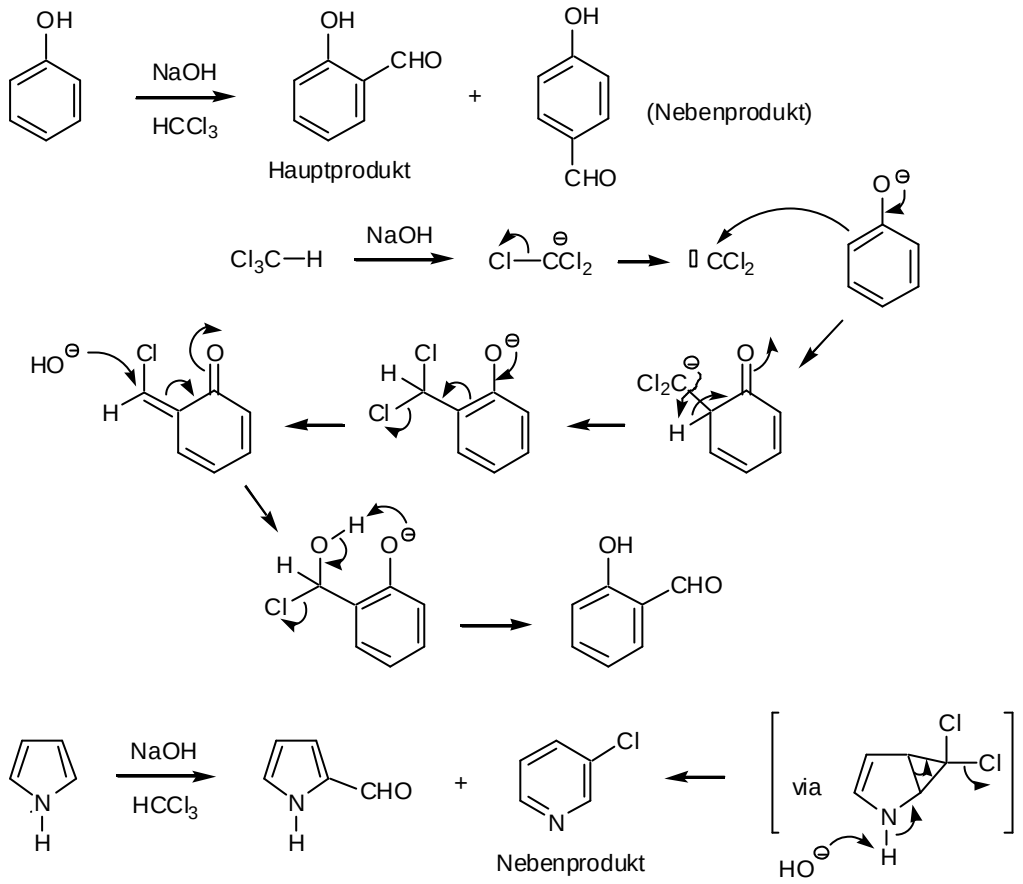
Hoesch-Synthesen:



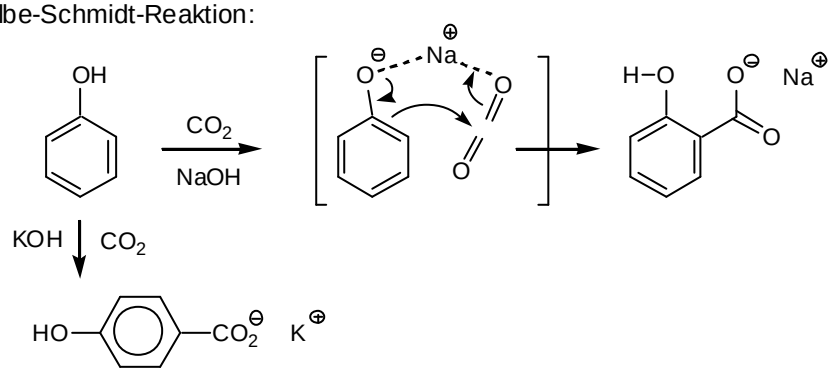
Vilsmeier-Hack-Reaktion:



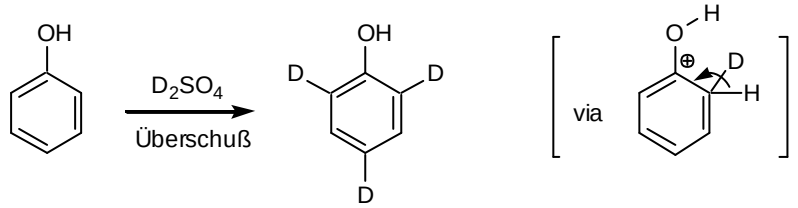
Reimer-Tiemann-Reaktion:



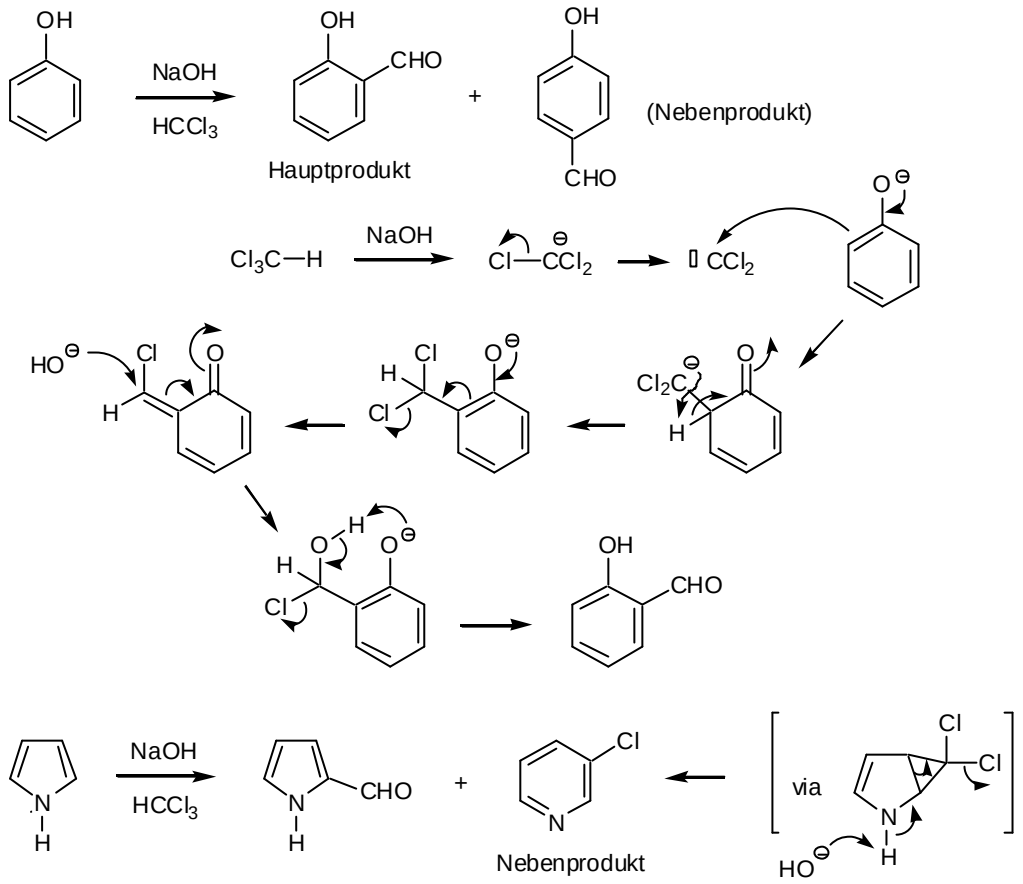
Kolbe-Schmidt-Reaktion:



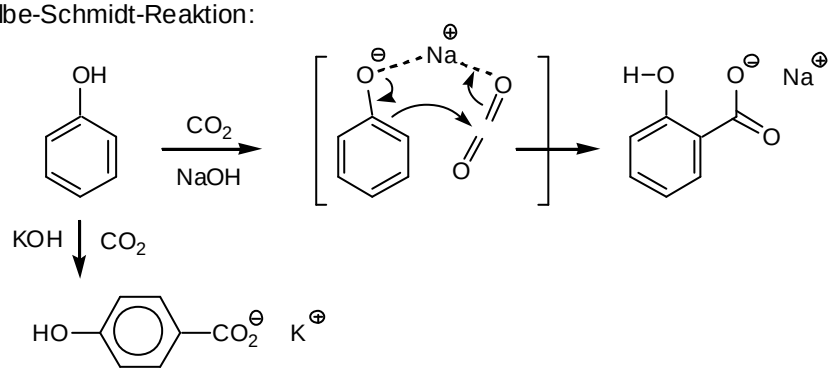
Substitution mit Deuterium



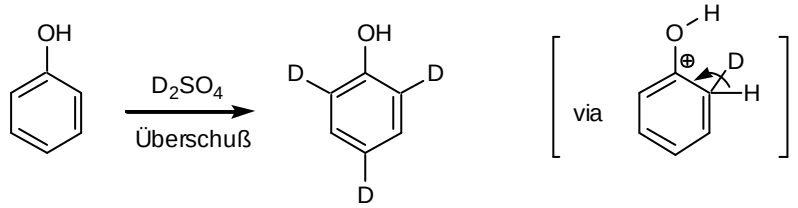
Reimer-Tiemann-Reaktion:



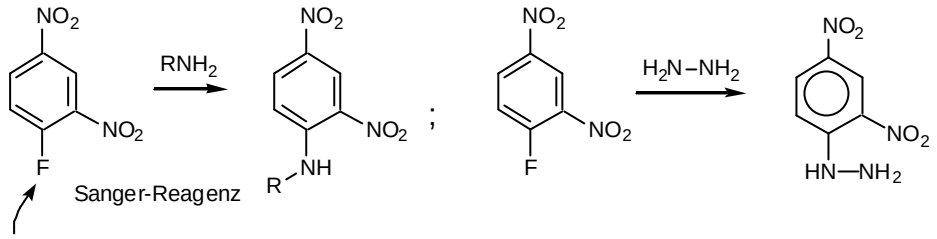
Kolbe-Schmidt-Reaktion:



Substitution mit Deuterium

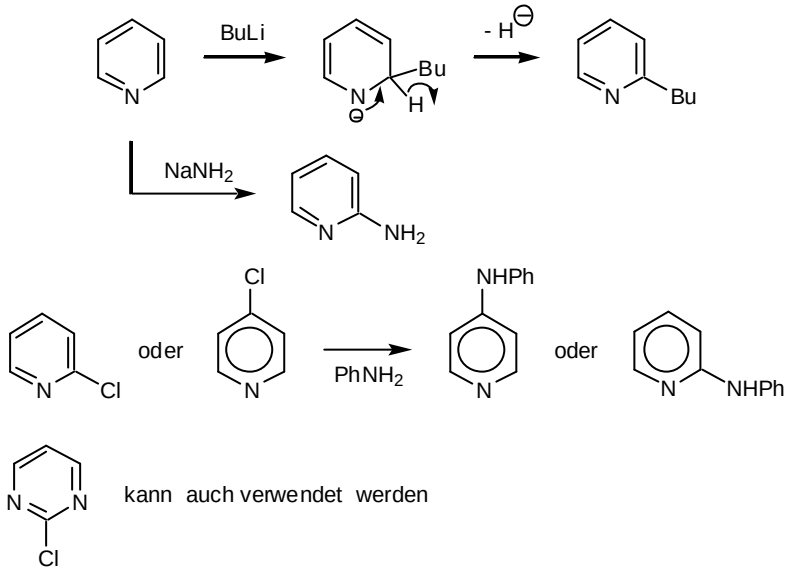


A: Akzeptorfunktion: NO_2, CN, SO_2R, CO_2R, ...



Fluor ist die beste Abgangsgruppe (elektronärmster Aromat)

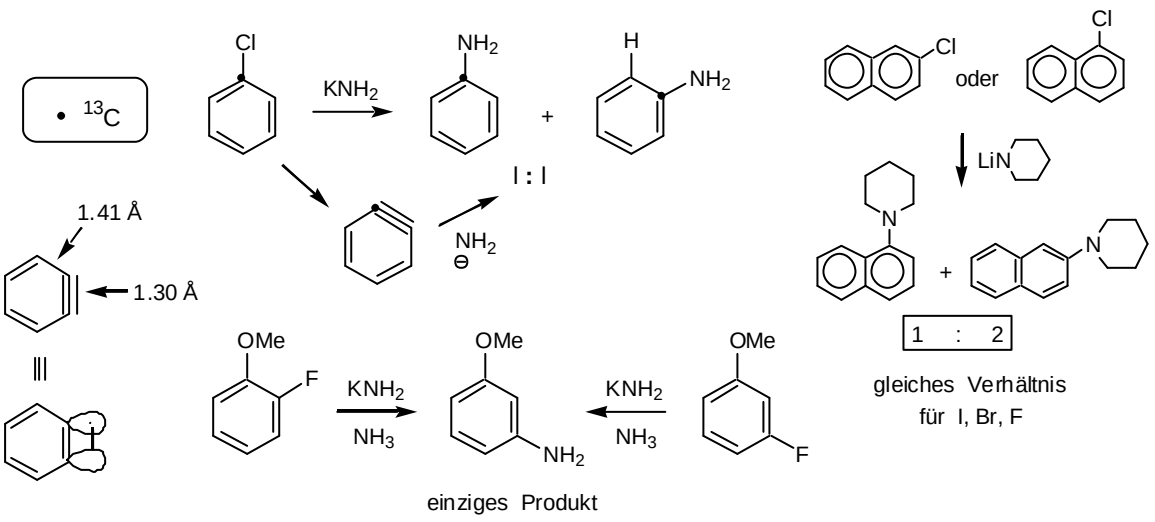
Chichibabin-Reaktion:



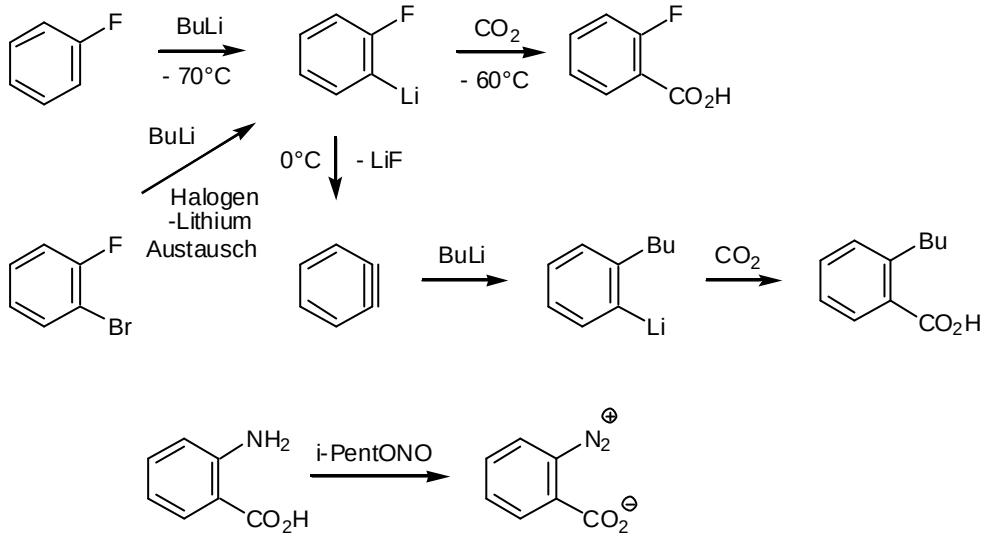
kann auch verwendet werden

4) Benzine (Arine) als Intermediate

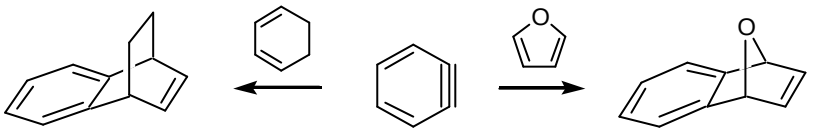
R. Huisgen



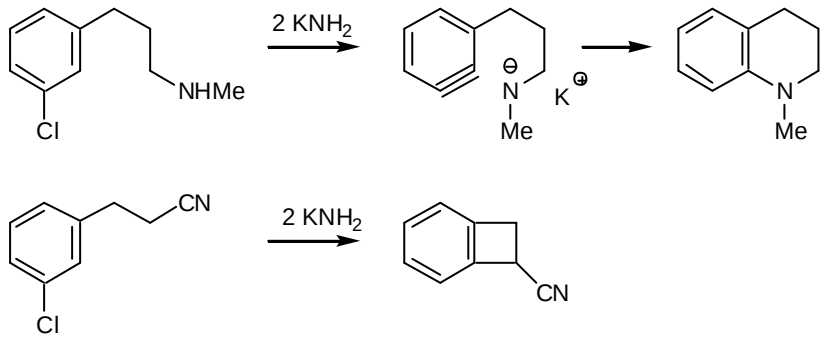
Arin-Quellen:



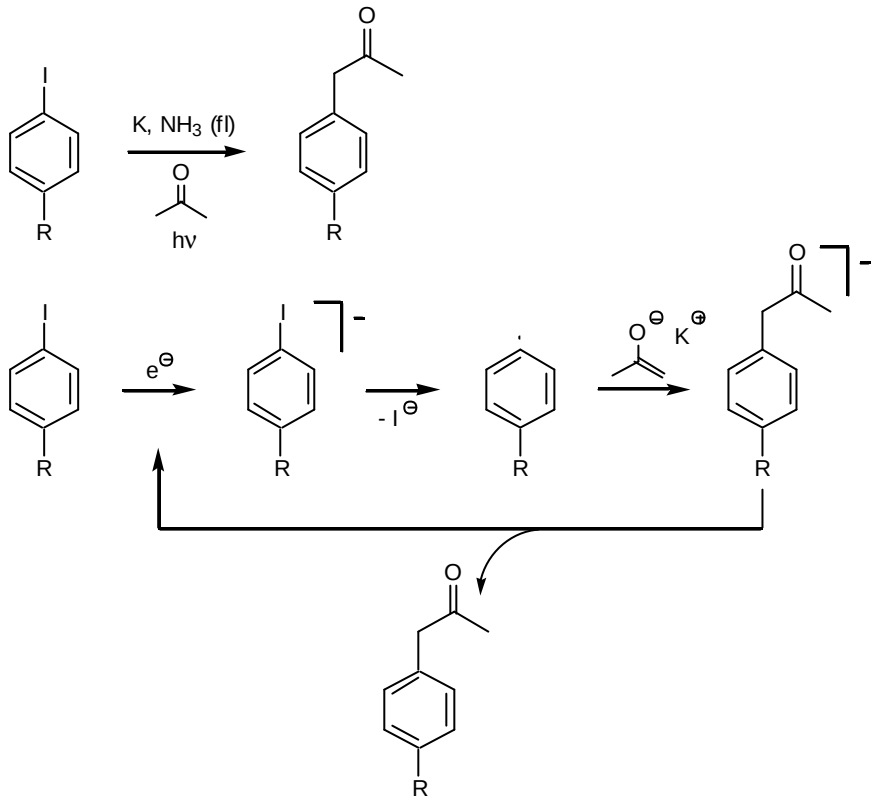
Anthranilinsäure:



Intramolekulare Reaktionen:

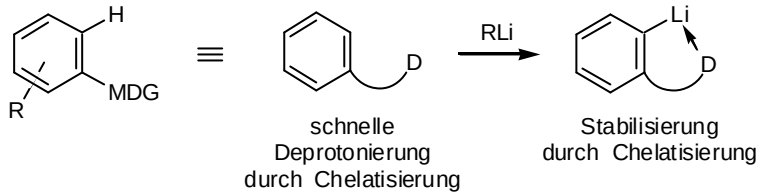


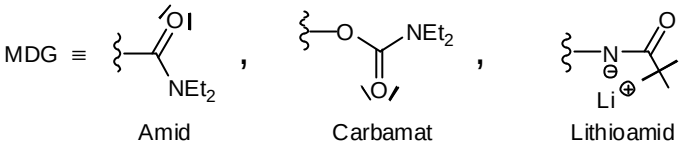
5) Radikalische nucleophile Substitution ($S_{RN}1$)

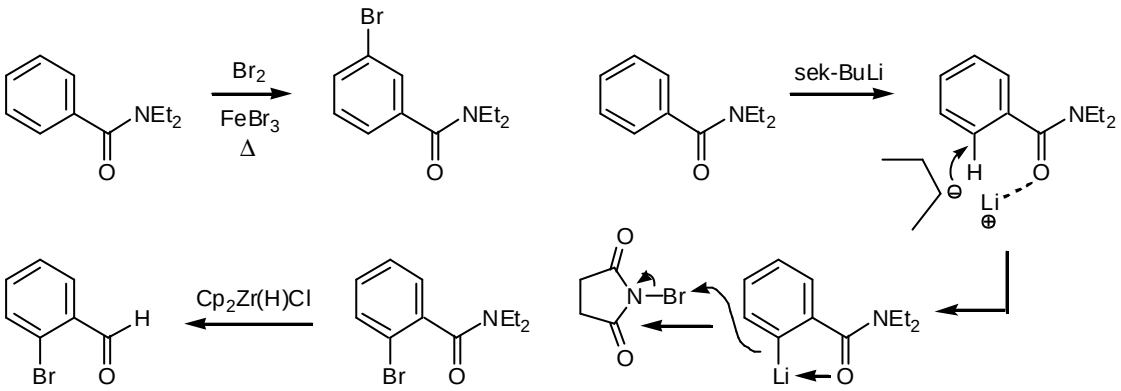


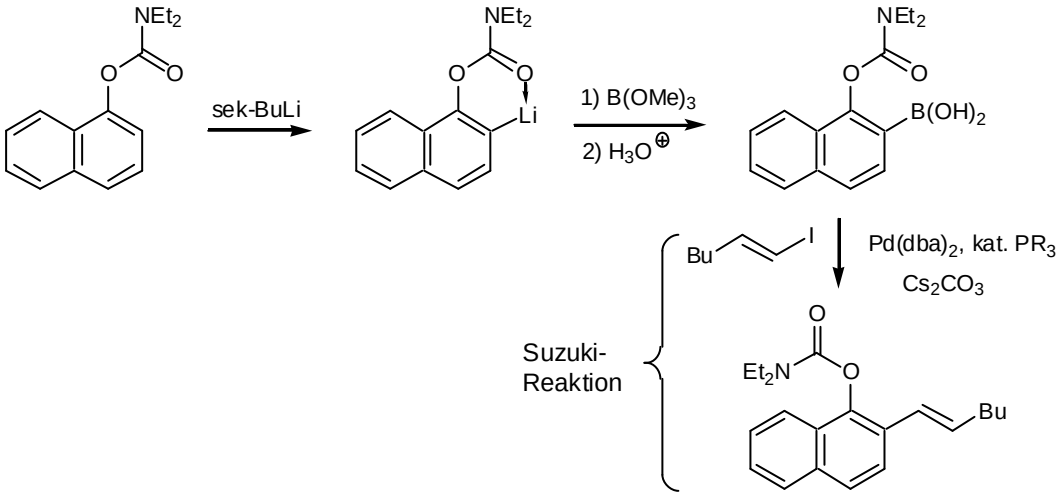
6) Moderne Metall-vermittelte Funktionalisierung von Aromaten

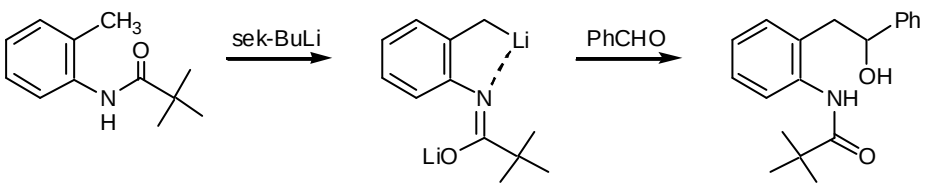
6.1. Verwendung von MDG (metallierungsdirigierenden Gruppen)





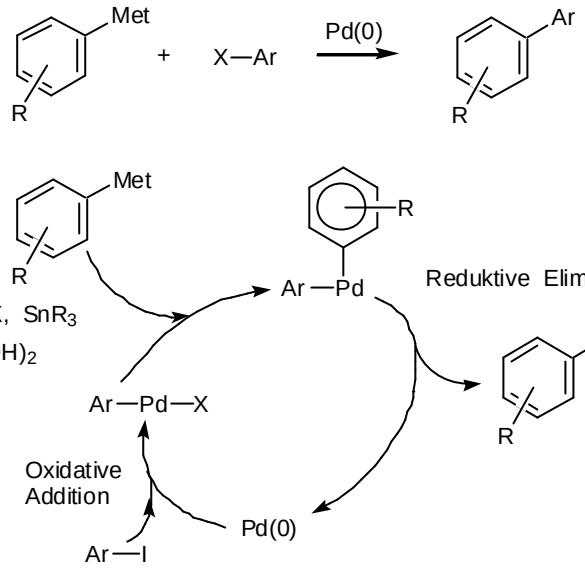






6.2. Pallodium katalysierte Funktionalisierung von Aromaten

-Kreuzkupplungsreaktionen

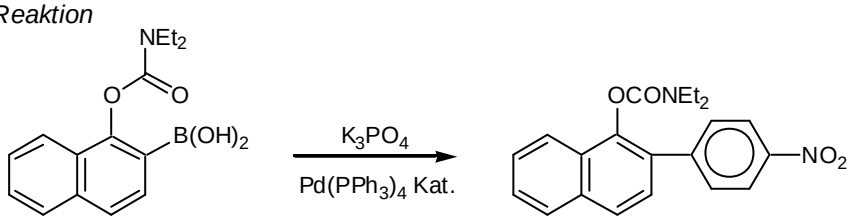


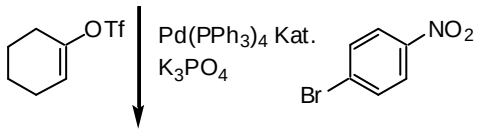
Met = ZnX : Negishi-Reaktion Met = $B(OH)_2$: Suzuki-Reaktion

Met = SnR_3 : Stille-Reaktion Met = Mg (mit Ni-Kat): Kumada-Reaktion

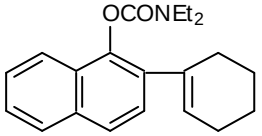
Beispiele:

Suzuki-Reaktion

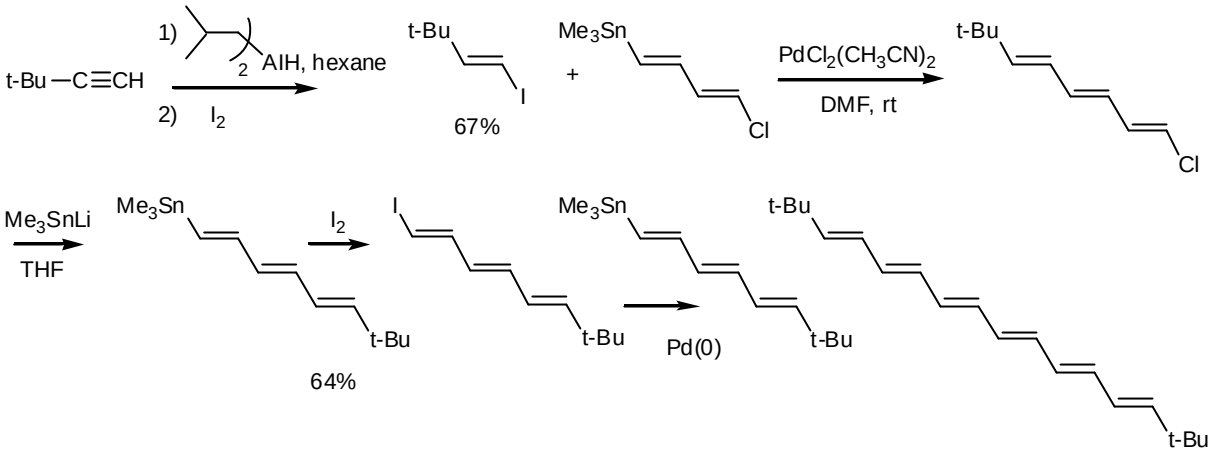




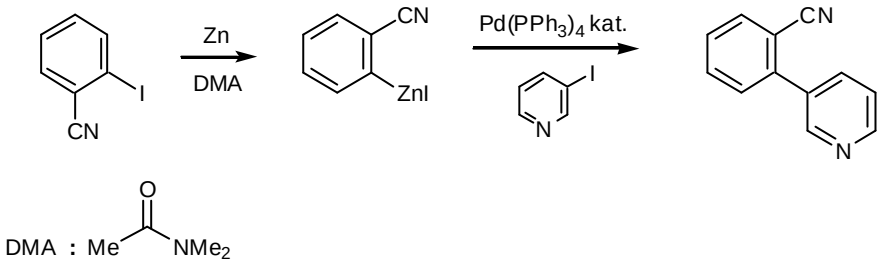
Tf = SO_2CF_3



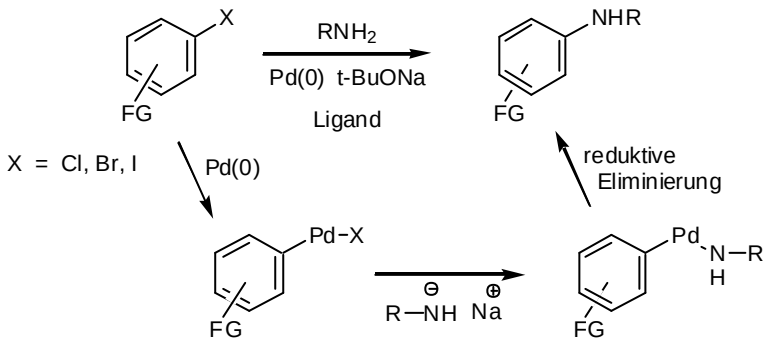
Stille-Reaktion



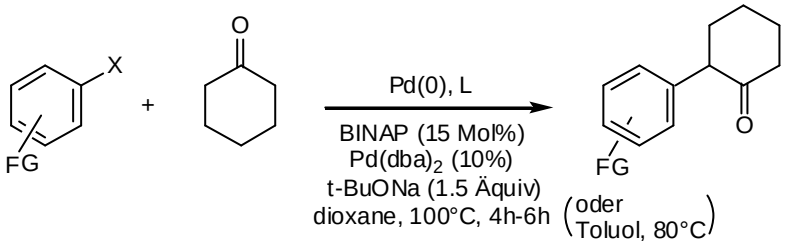
Negishi-Kreuzkupplung



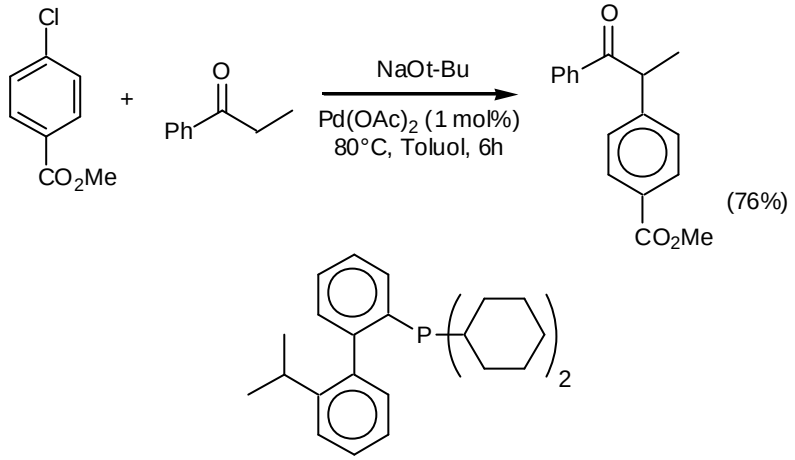
-Hartwig-Buchwald Aminierung von Aromaten



Buchwald Keton-Arylierung

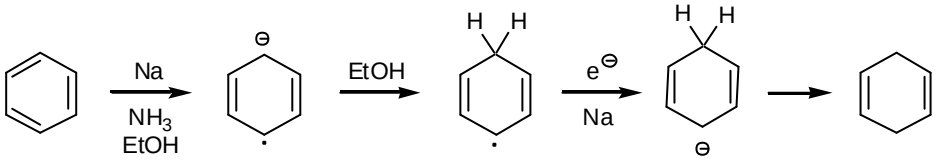


Beispiele:



S.L. Buchwald, *J. Am. Chem. Soc.* **2000**, *122*, 1360

Birch-Reduktion



Regioselektivität