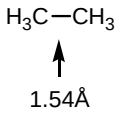
1) Zum Mechanismus der elektrophilen aromatischen Substitution

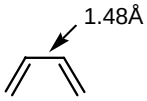
Aromatischer Charakter

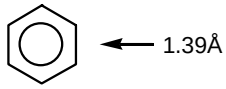
(4 n + 2)π-Elektronen

Antiaromatischer Charakter

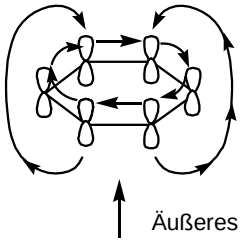
4 nπ $e^{\ominus}$



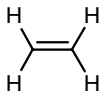




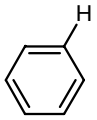
Ringstrom-Effekte



^{1}H-NMR-Verschiebung:



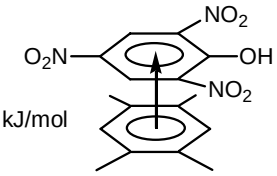
δ = 5 ppm



δ = 7 ppm

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

Bildung von π-Komplexen

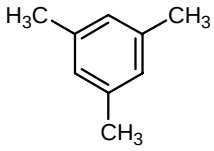


Pikrinsäure

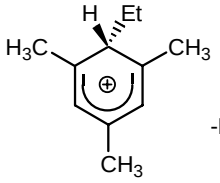
Charge-Transfer Komplexe

Schwache Komplexe: 12 - 40 kJ/mol

σ-Komplexe



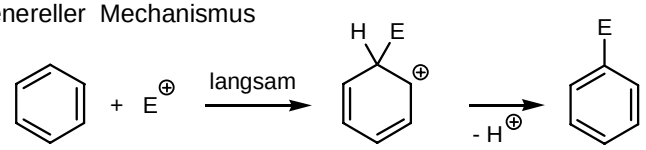
+ $C_2H_5Cl / SbCl_5$ →



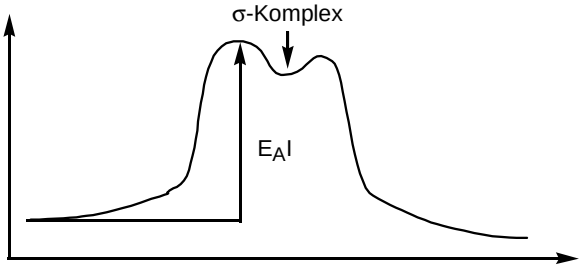
$SbCl_6^{\ominus}$

-Komplex (bei -15°C haltbar)

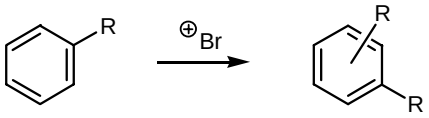
Genereller Mechanismus



σ–Komplex



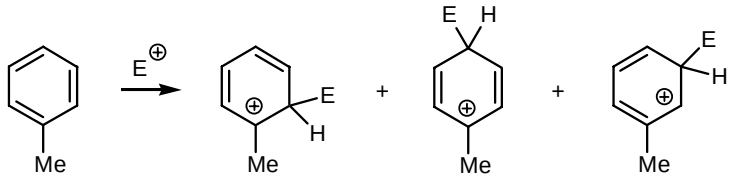
Einfluß der Erstsubstituenten auf die Geschwindigkeit der Bromierung von monosubstituierten Benzolen.



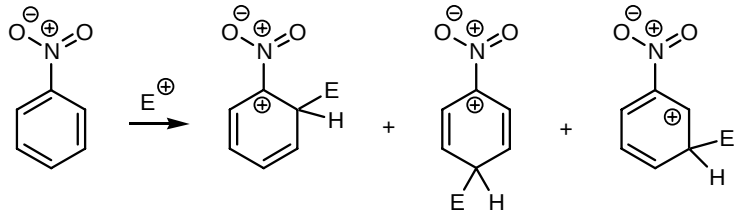
R	k_{rel}	R	k_{rel}	R	k_{rel}	R	k_{rel}
Me_2N	10^{18}	CH_3	340	H	1.0	F	1.2
OH	10^{11}	C_2H_5	290	CH_2Cl	0.8	Cl	0.1
OMe	10^{9}	Me_2CH	180	CO_2H	10^{-4}	Br	0.08
HNCOMe	10^{8}	t-Bu	110	NO_2	10^{-6}	I	0.18

+ I, + M beschleunigt und dirigiert *o*, *p*

- I, - M verlangsamt und dirigiert *m*



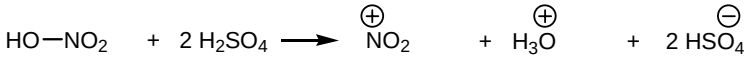
Sterische Effekte begünstigen para-Substitution gegenüber ortho



→ Furane, Thiophene und Pyrrolen reagieren schneller
Pyridine reagieren langsamer

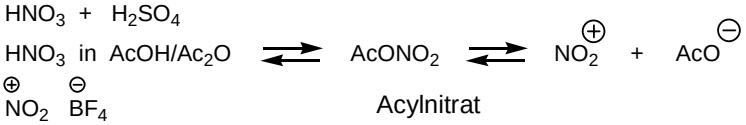
2) Beispiele für elektrophile aromatische Substitutionen

2.1. Elektrophiler Stickstoff

Nitrierung 

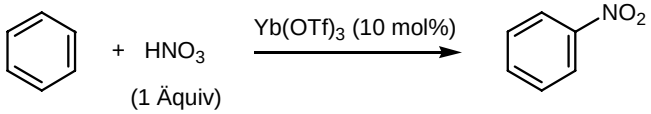
Nitronium-ion

Nitrierung mit konz. HNO_3

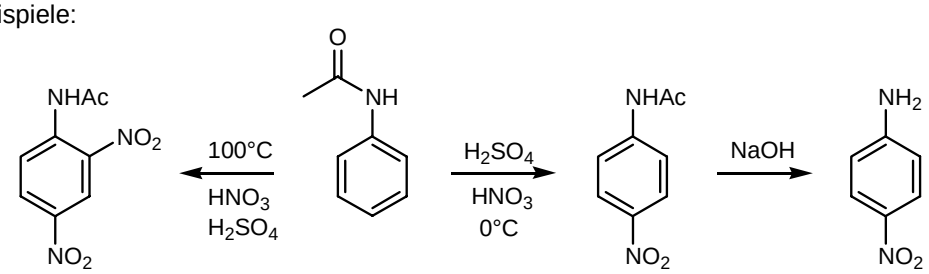


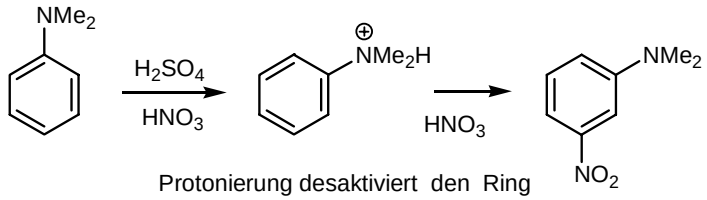
$\overset{\oplus}{NO_2}\ \overset{\ominus}{BF_4}$ Acylnitrat

A. G. M. Barrett



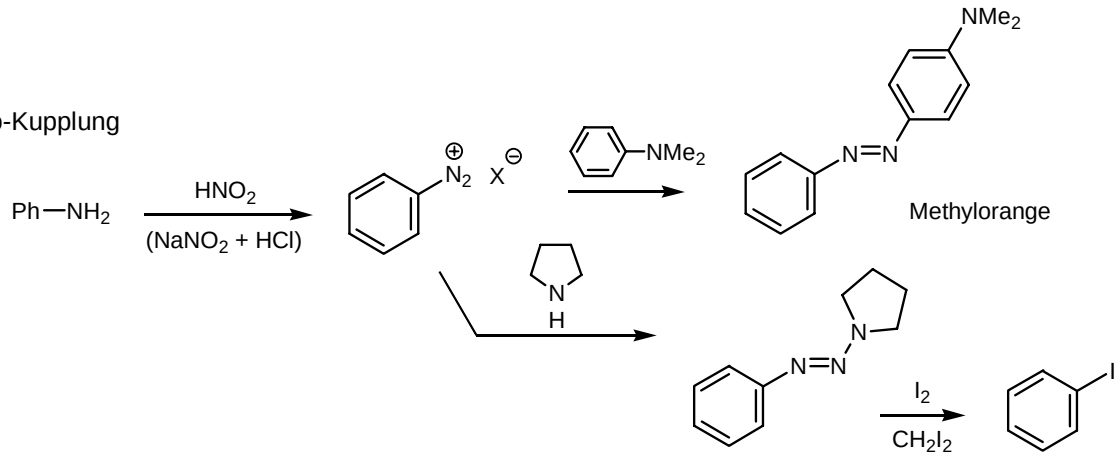
Beispiele:



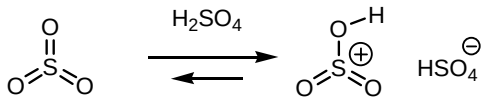


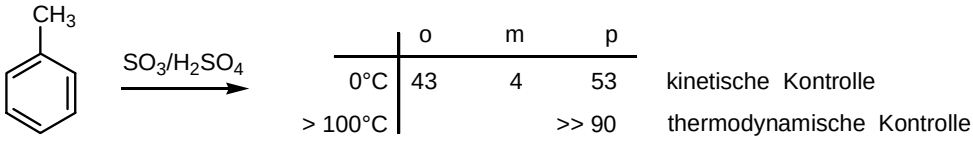
Protonierung desaktiviert den Ring
und dirigiert in meta-Stellung

Azo-Kupplung

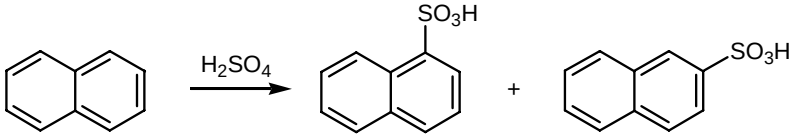


2.2. Elektrophiler Schwefel



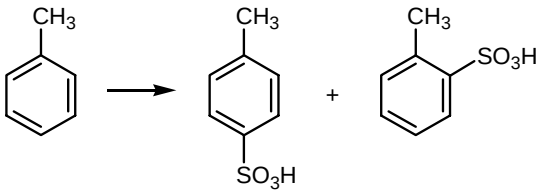


	o	m	p	
0°C	43	4	53	kinetische Kontrolle
> 100°C			>> 90	thermodynamische Kontrolle

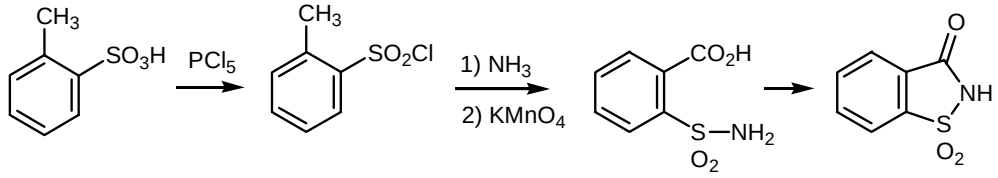


80°C	96%	4%
165°C	15%	85%

Saccharin-Synthese:

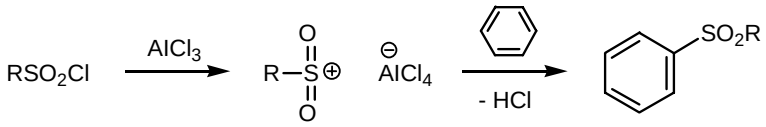


Das kinetische Gemisch wird getrennt



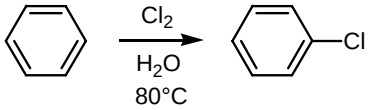
Na-Salz

500 x süßer als Zucker



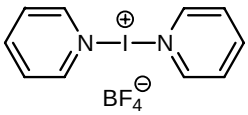
2.3. Elektrophile Halogenierung

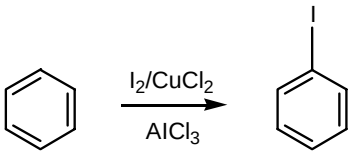
Chlorierung mit Cl_2 + $AlCl_3$; Bromierung mit Br_2 + $FeBr_3$



Chlorierungsmittel: HOCl

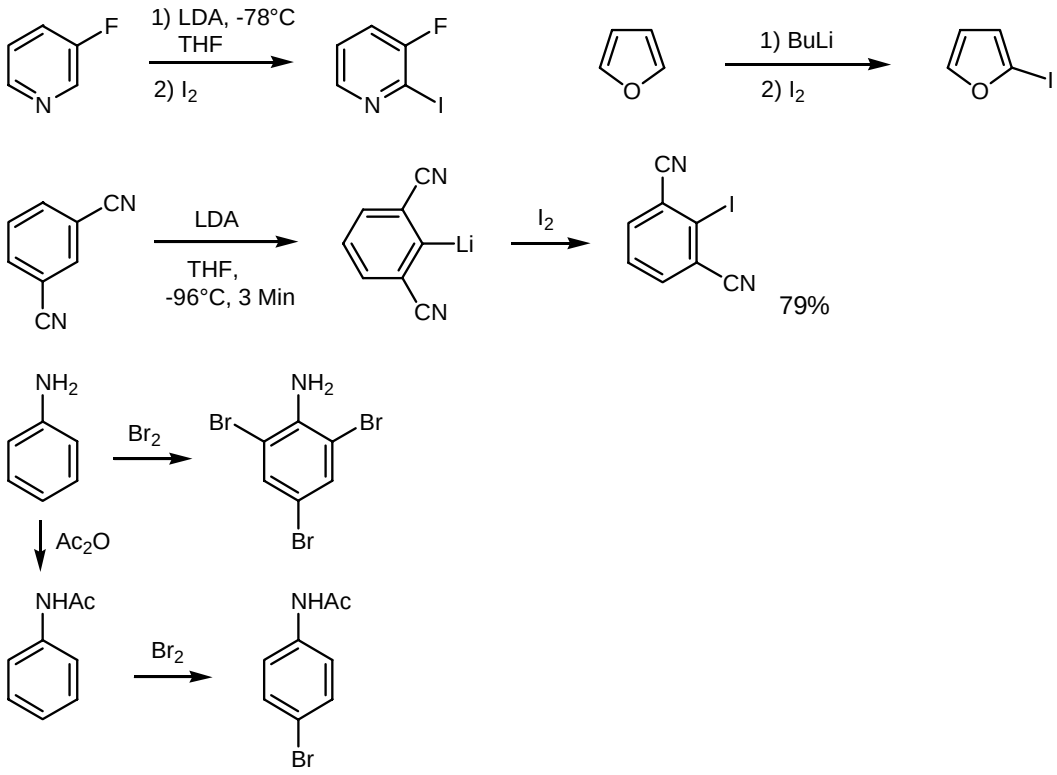
Iodierung ist reversibel: ICl, $I_2/AgClO_4$ oder



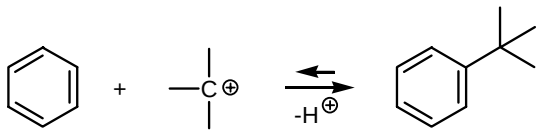


86%

Alternative Synthesen:

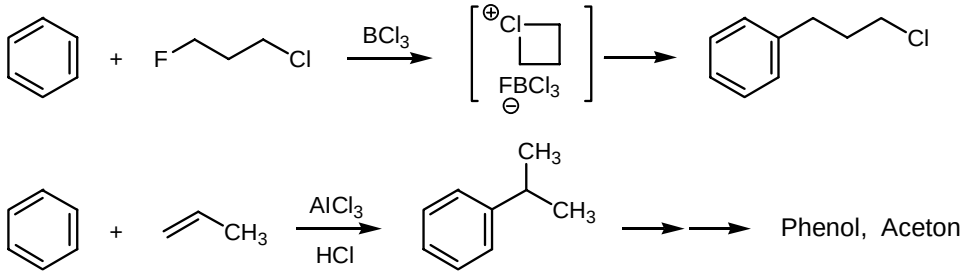


2.4. Elektrophiler Kohlenstoff: Friedel-Crafts-Reaktion

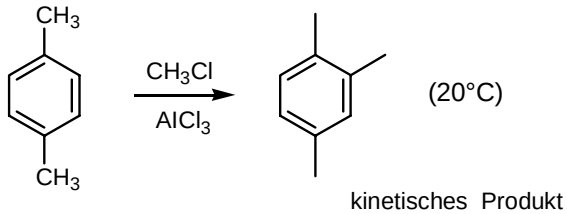


Die Friedel-Crafts-Reaktion kann reversibel sein

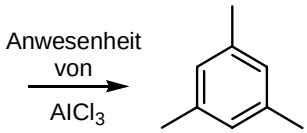
Kat.: $AlBr_3$ > $AlCl_3$ > $FeCl_3$ > $SnCl_4$ > BF_3 > $TiCl_4$



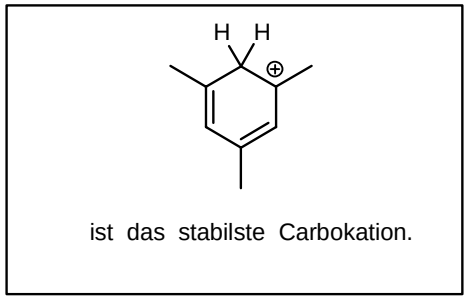
3. Gruppe: Aromatische Substitution



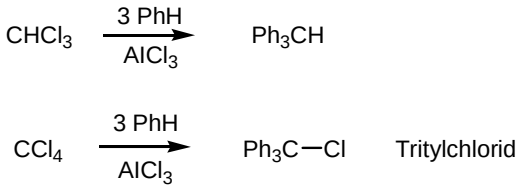
kinetisches Produkt



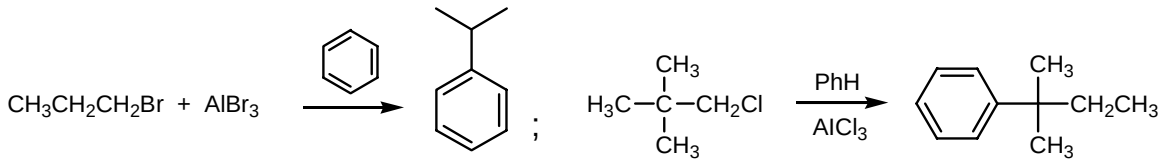
thermodynamisches Produkt



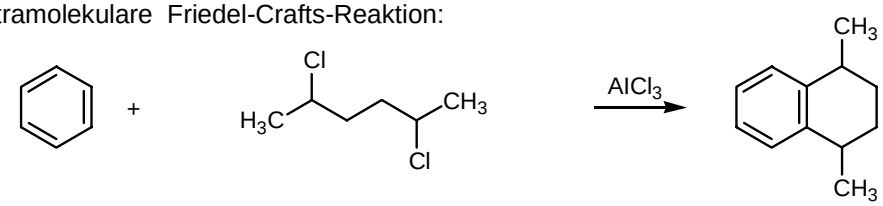
ist das stabilste Carbokation.



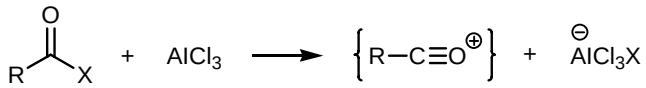
Umlagerungen werden oft beobachtet:



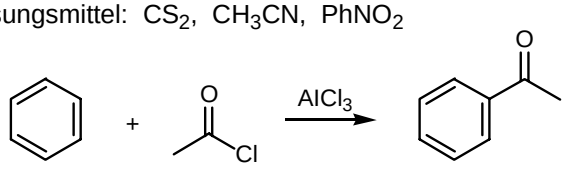
Intramolekulare Friedel-Crafts-Reaktion:



Friedel-Crafts-Acylierung

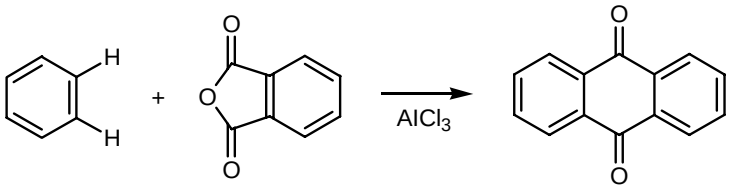


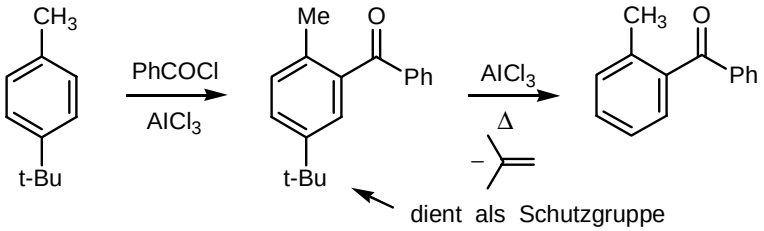
Lösungsmittel: CS_2, CH_3CN, $PhNO_2$



reaktives Intermediat: $H_3C-C\equiv O^{\oplus}$

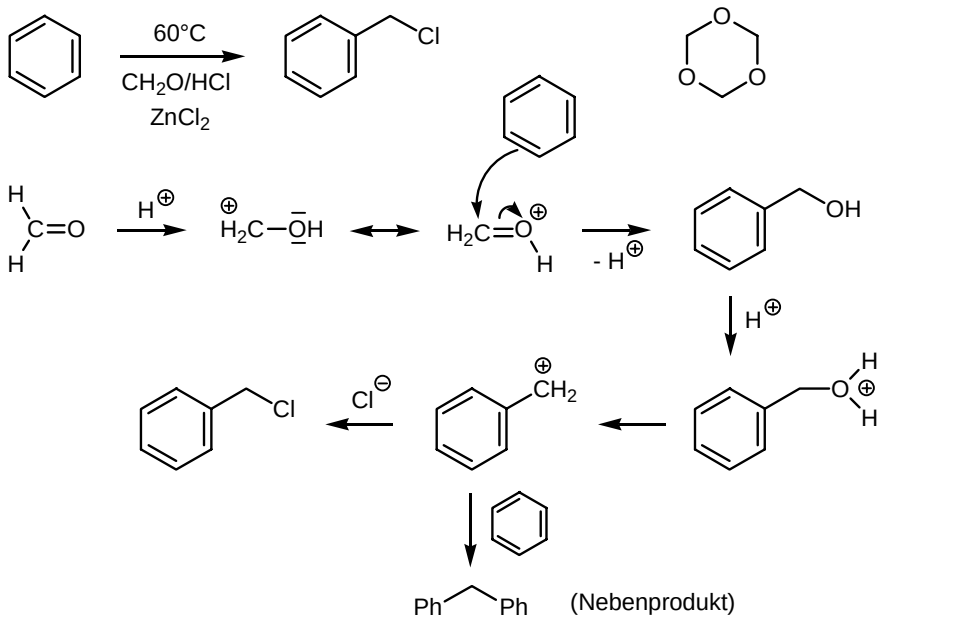
3. Gruppe: Aromatische Substitution

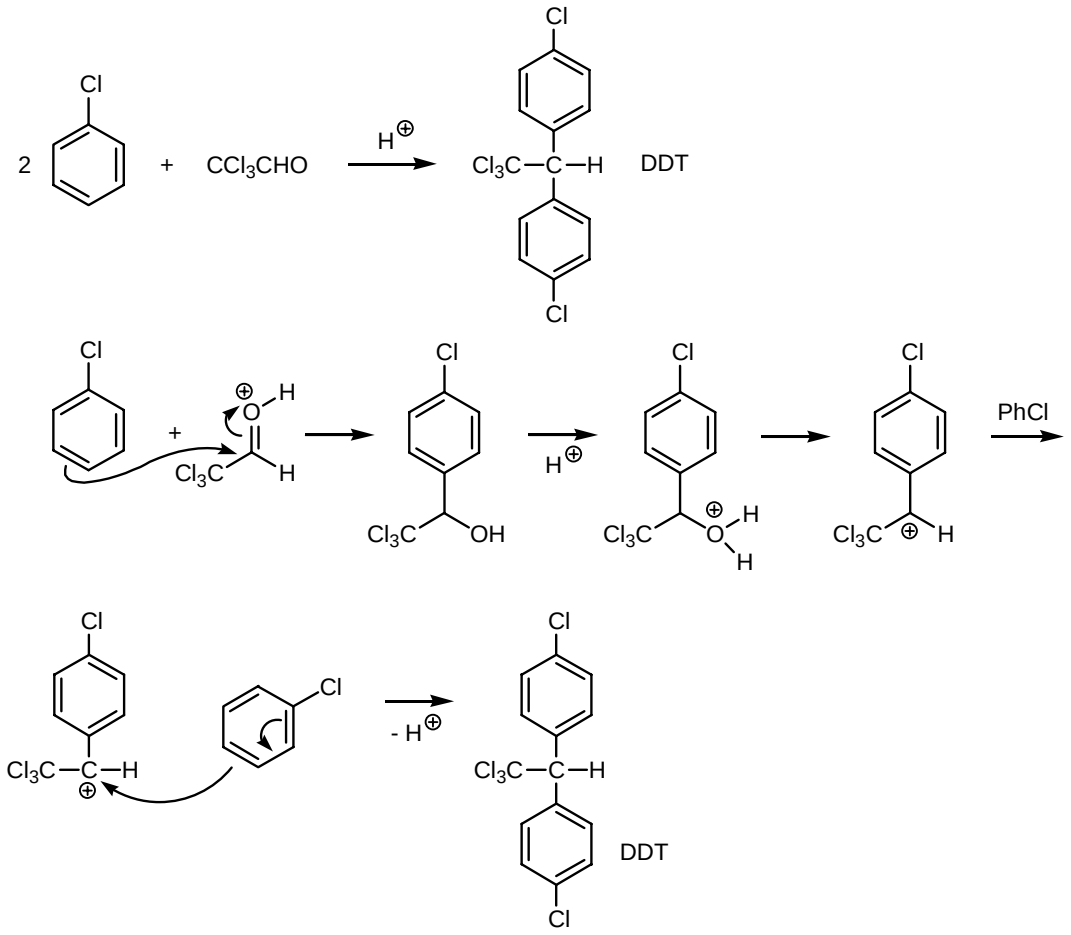




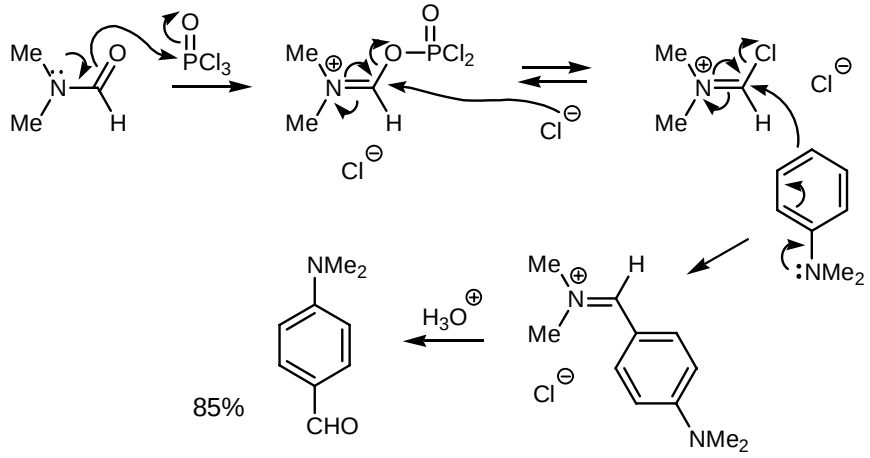
Die Chlormethylierung

$(CH_2O)_m$ Paraformaldehyld

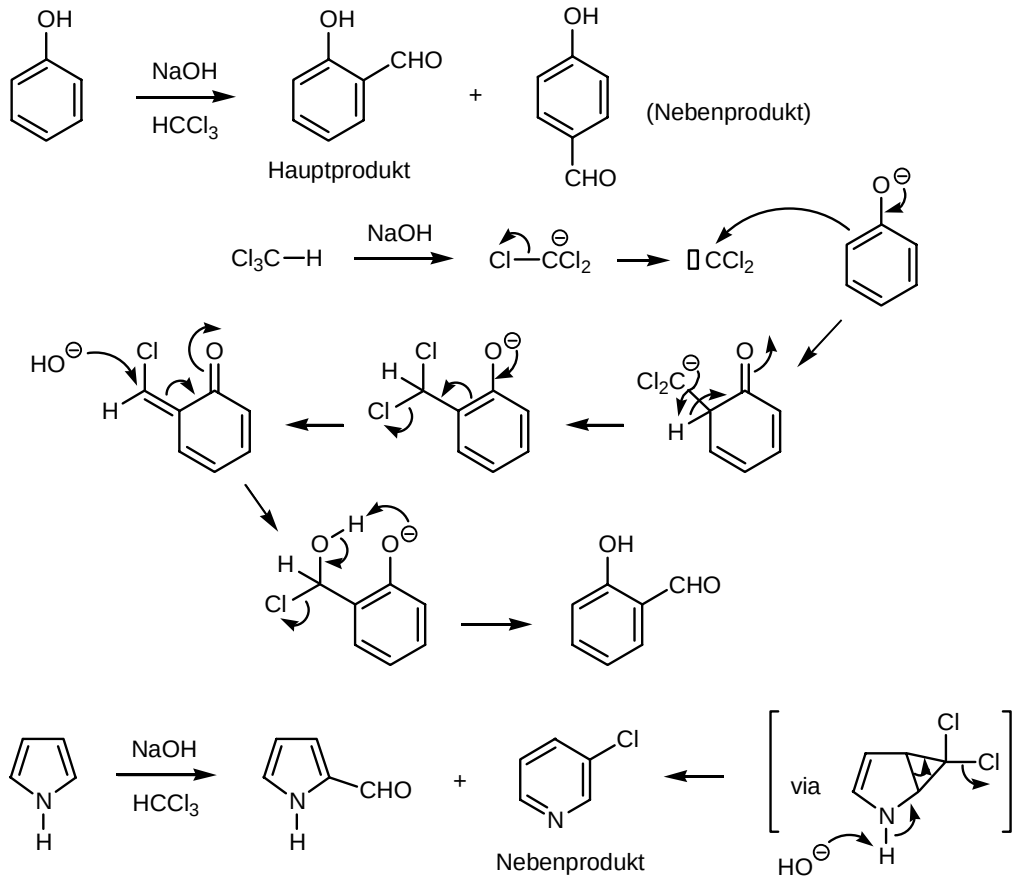




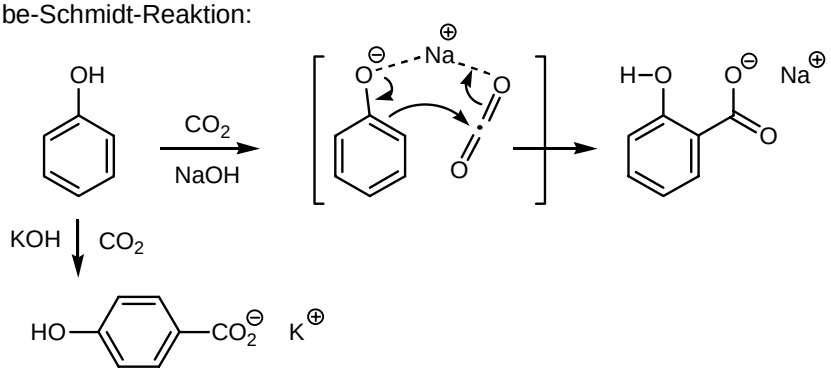
Vilsmeier-Haack-Reaktion:



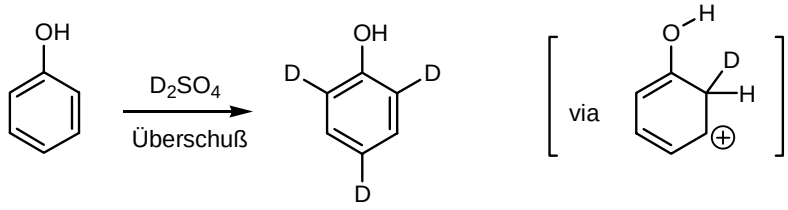
Reimer-Tiemann-Reaktion:



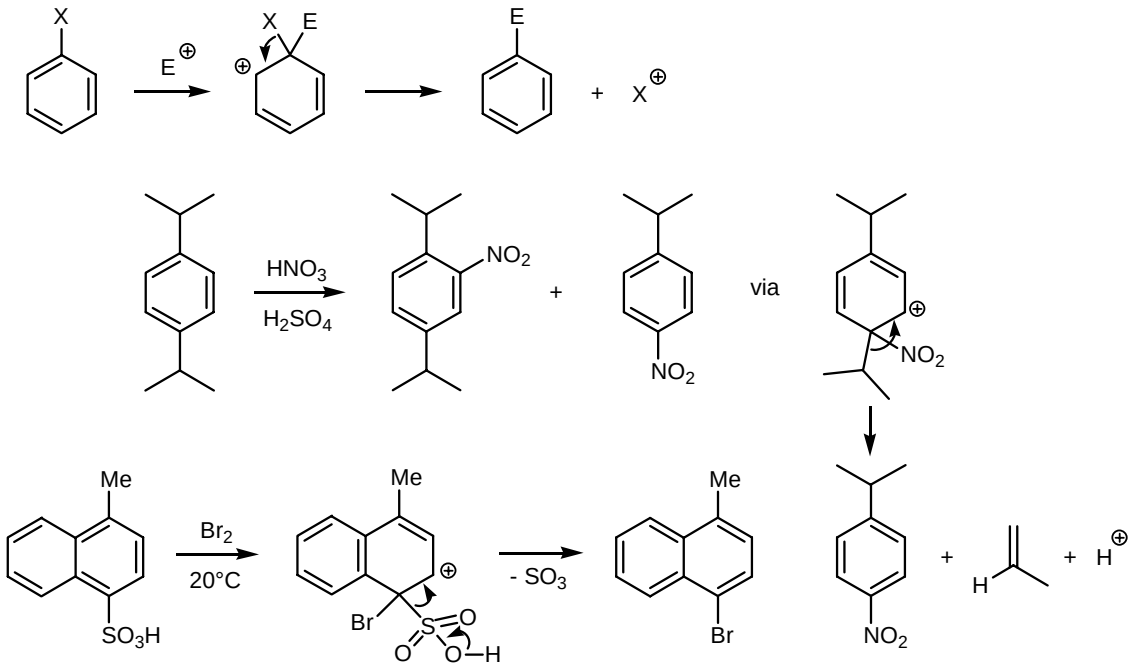
Kolbe-Schmidt-Reaktion:



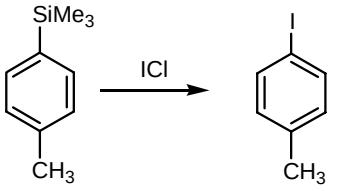
Substitution mit Deuterium



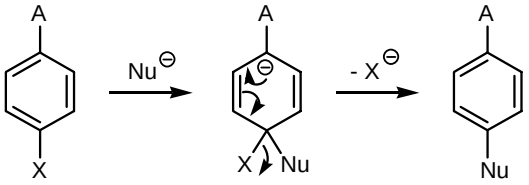
Ipso-Substitution:



Isomerenfreie Reaktion:

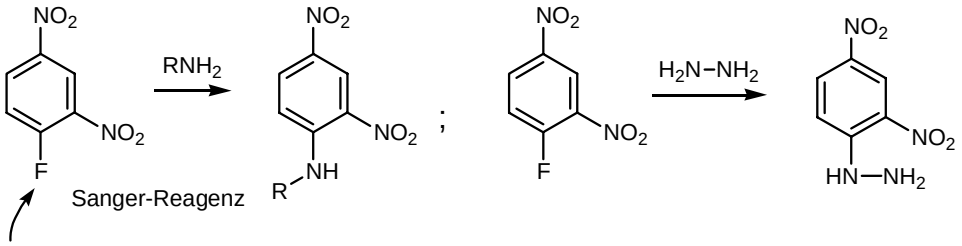


3) Nucleophile aromatische Substitution



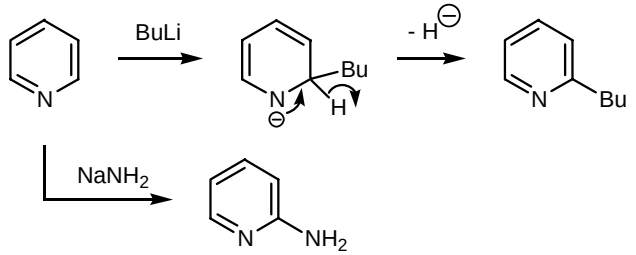
Additions - Eliminierungs - Reaktion

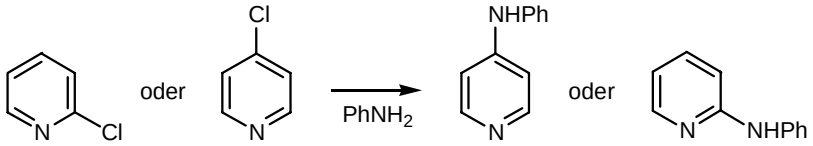
A: Akzeptorfunktion: NO_2, CN, SO_2R, CO_2R, ...

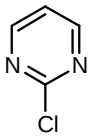


Fluor ist die beste Abgangsgruppe (elektronärmster Aromat)

Chichibabin-Reaktion:

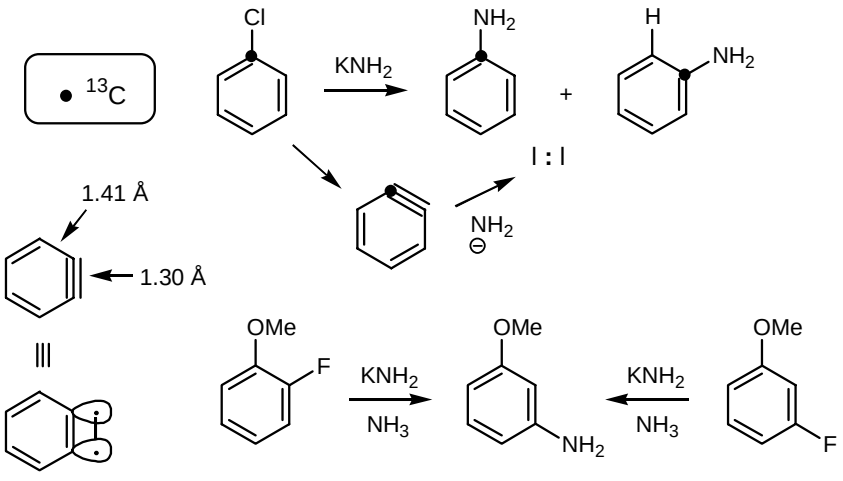






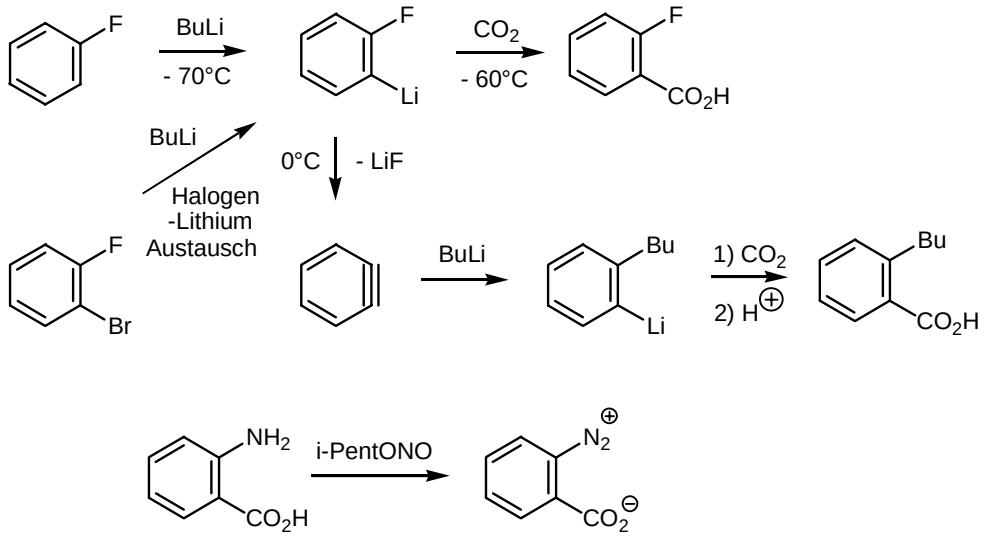
kann auch verwendet werden

4) Benzine (Arine) als Intermediate

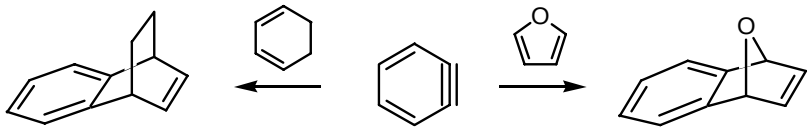


einziges Produkt

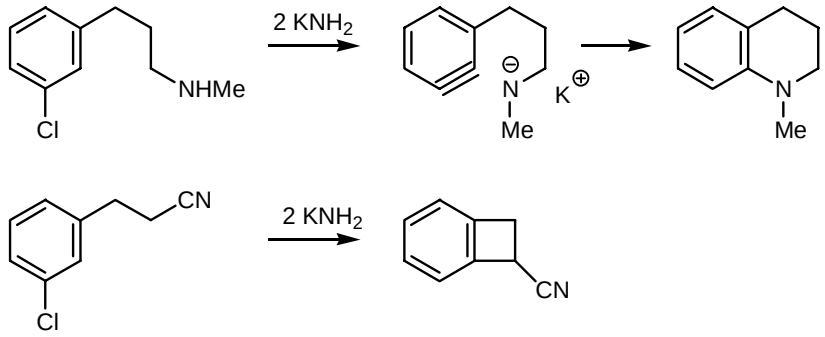
Arin-Quellen:



Anthranilinsäure:

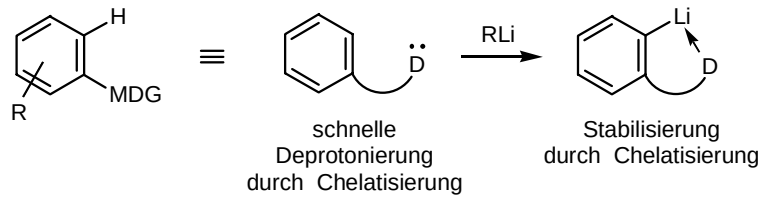


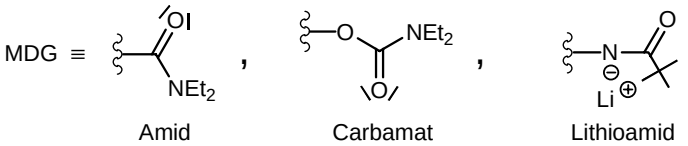
Intramolekulare Reaktionen:

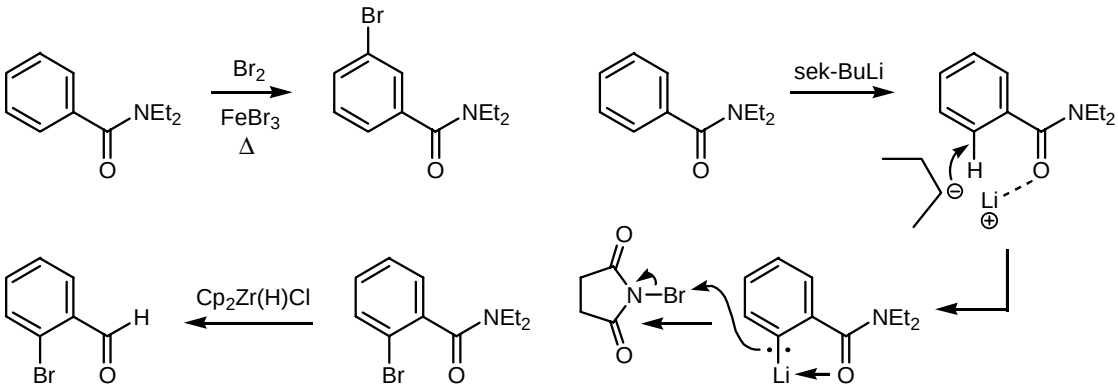


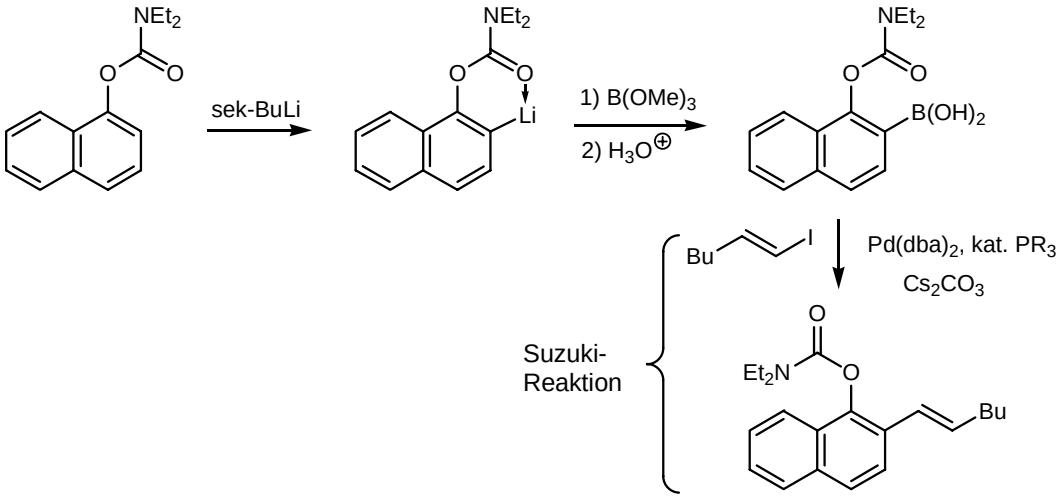
6) Moderne Metall-vermittelte Funktionalisierung von Aromaten

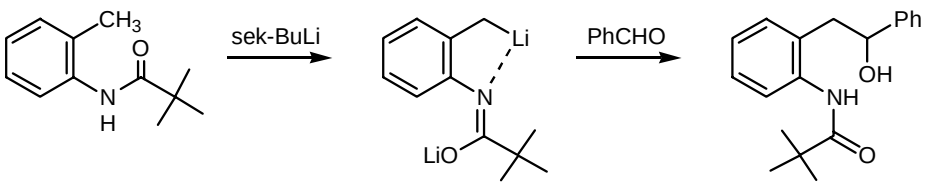
6.1. Verwendung von MDG (metallierungsdirigierenden Gruppen)





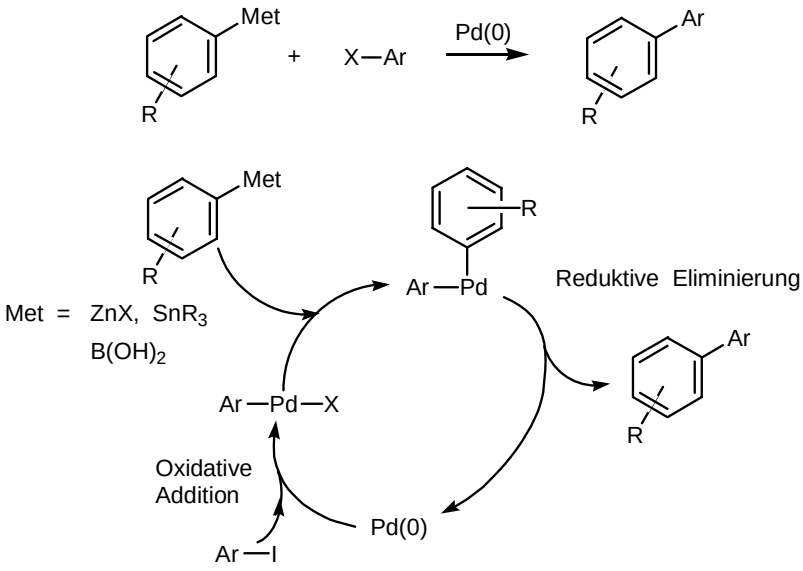






6.2. Palladium katalysierte Funktionalisierung von Aromaten

-Kreuzkupplungsreaktionen

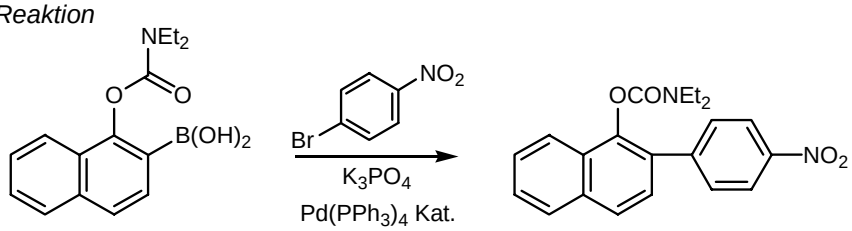


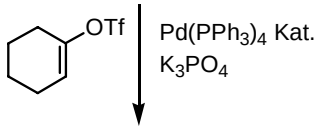
Met = ZnX : Negishi-Reaktion Met = $B(OH)_2$: Suzuki-Reaktion

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

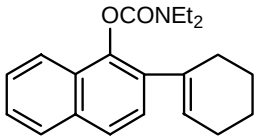
Beispiele:

Suzuki-Reaktion

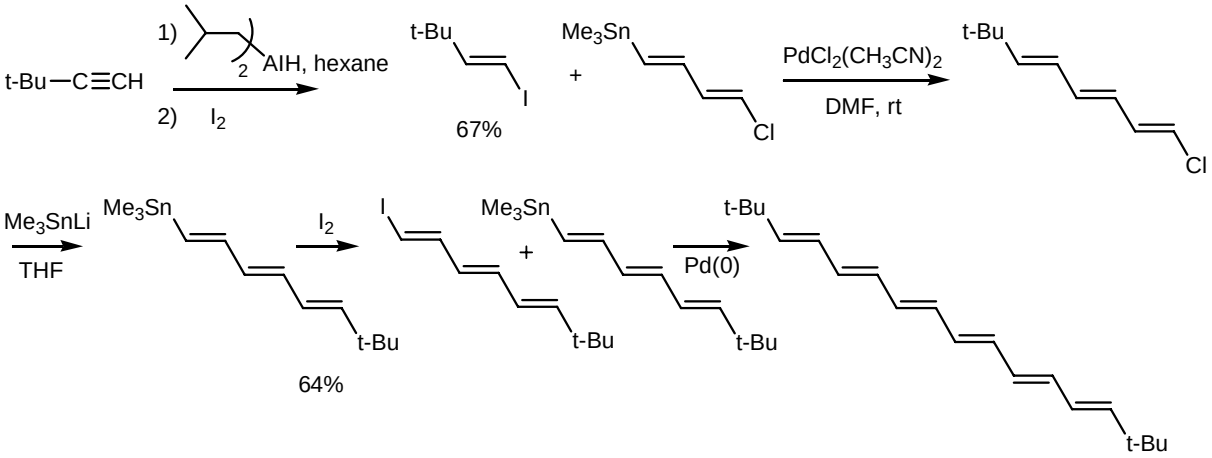




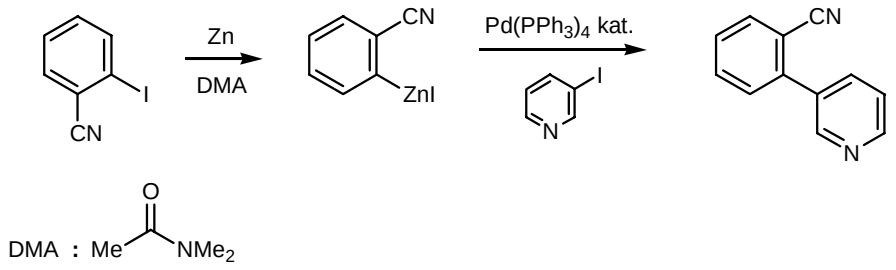
Tf = SO_2CF_3



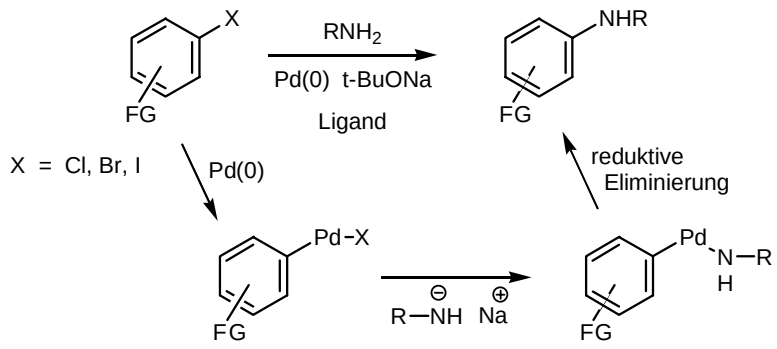
Stille-Reaktion



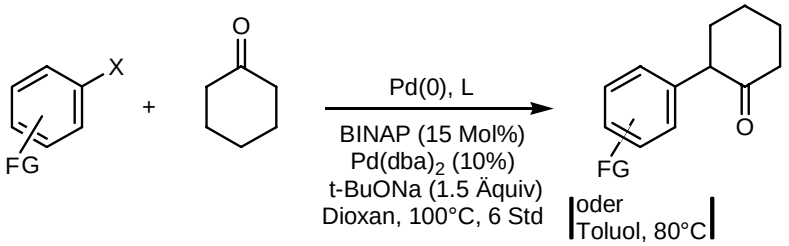
Negishi-Kreuzkupplung



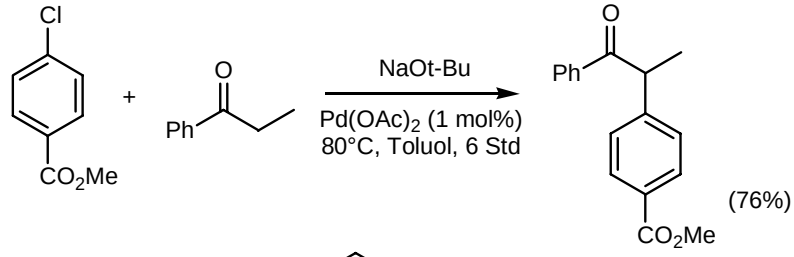
-Hartwig-Buchwald Aminierung von Aromaten



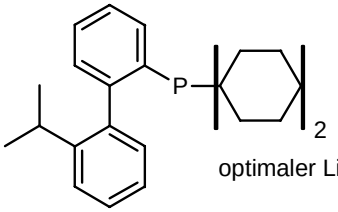
Buchwald Keton-Arylierung



Beispiele:



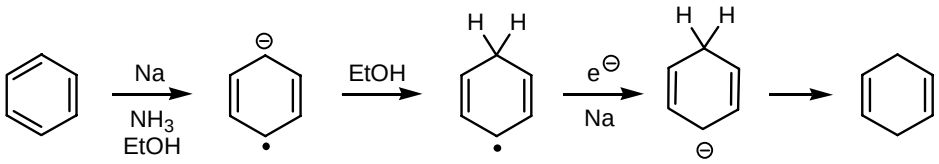
(76%)



optimaler Ligand für diese Pd-Katalyse

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

Birch-Reduktion



Regioselektivität