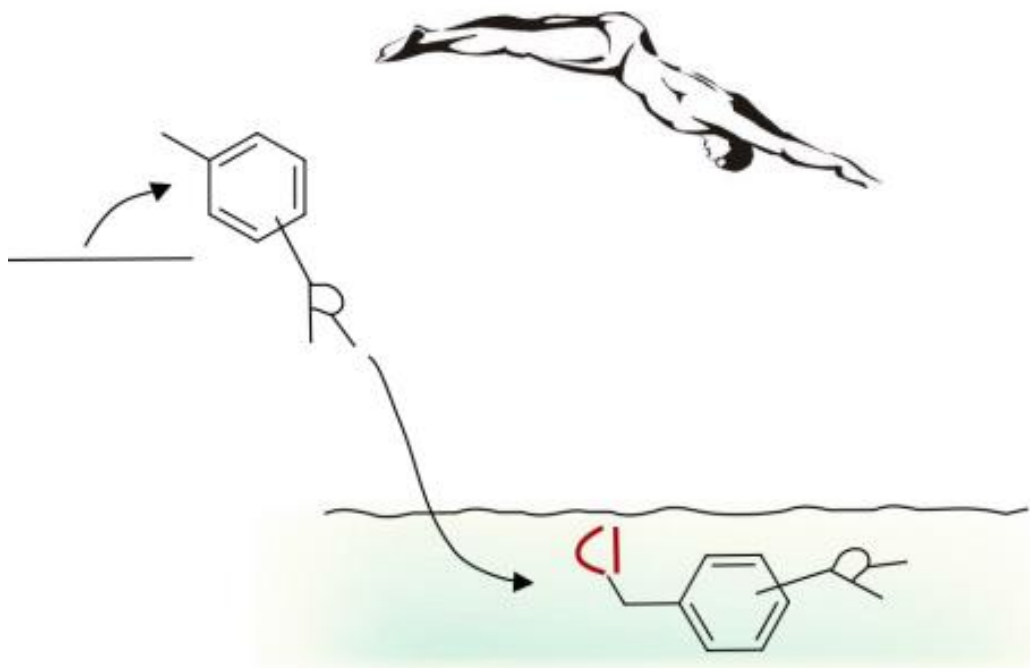


Toluenes and hydrocarbons in the swimming pool

Seminar talk presented by
Sascha Combe

April 24th, 2014

*Institute of Organic Chemistry
Justus-Liebig-University Giessen*





- Introduction
- Idea
- Screening/Optimization
- Substrates
- Summary and outlook

Introduction: Use of chlorine



Solvents (3.1%)

Metal degreasing, adhesives, dry cleaning, plastics

Epichlorohydrin (5.6%)

Pesticides, epoxy resins, printed circuits, fishing rods

Isocyanates and oxygenates (27.2%)

Upholstery, insulation, footwear, plastics, pesticides, car paints

Inorganics (14.0%)

Disinfectants, water treatment, paint pigments

Chloromethanes (5.7%)

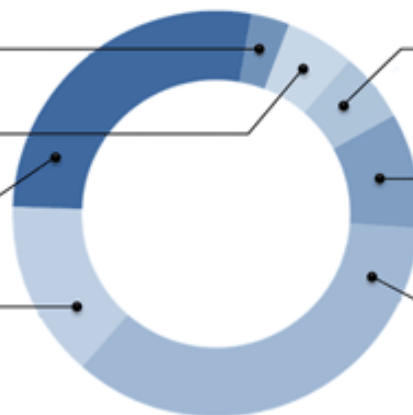
Silicon rubbers, descaffeinator, Teflon®, paint strippers, cosmetics

Other organics (9.2%)

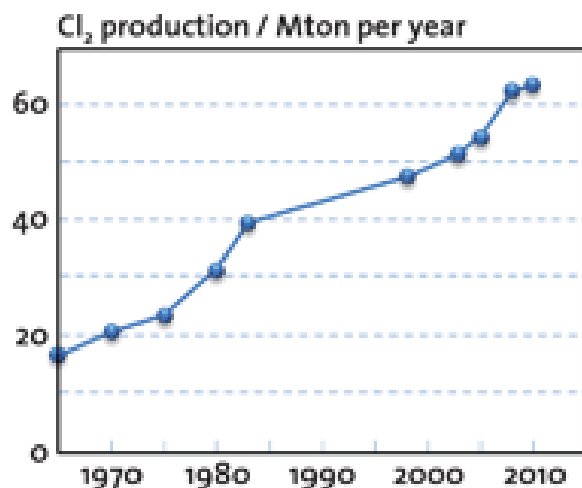
Detergents, ship and bridge paints, lubricants, wallpaper adhesives, herbicides, insecticides

PVC (35.2%)

Door and window frames, pipes, flooring, medical supplies, clothing



European chlorine applications in 2009



Worldwide Cl₂ production since 1965

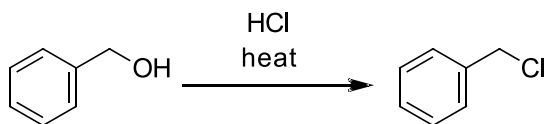
- European chlorine production was about 9 Mton. Germany main producer (~44%)

Introduction: Beginnings of side chain chlorination

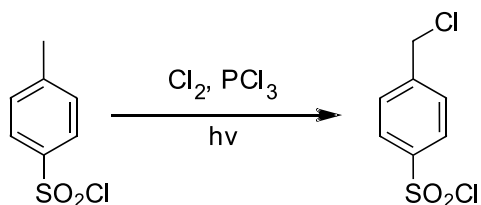
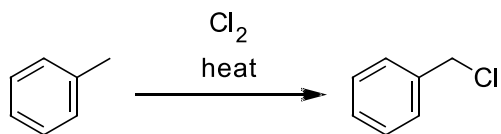


The side-chain chlorinated alkyl aromatics, particularly those based on toluene and xylene, have an exceptional place because of their role as chemical intermediates. Indeed, they are used in the manufacture of chemical products of almost all kinds, including dyes, plastics, pharmaceuticals, flavors and perfumes, pesticides, catalysts, inhibitors, and so forth.

Karl-August Lipper, Bayer AG, Krefeld, Germany; Eckhard Löser, Bayer AG, Wuppertal, Germany

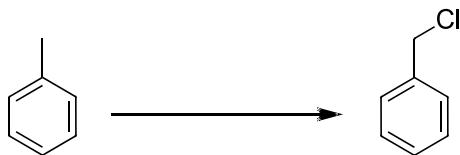


Cannizzaro 1853



BASF 1910

Introduction: Different methods – brief overview (most important)

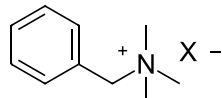


SO₂Cl₂ Highly corrosive; SO₂(g), HCl(g)

- BPO, reflux, 30 min., **80%**
- Pd(PPh₃)₄, reflux, 2-5 h, **82%** (conv.)
- AIBN, reflux, 15 min., **70%**
- Zeolite, hv, 30 min., **81%**
- TBHP, THF, 60 °C, 30 min., **88%**

Kharasch, Matsumoto, Ford, Laszlo, Kurdyukov

BTMA



- AIBN, ICCL₄, CCl₄, reflux, 4 h, **65%** (+11% Benzal)

Kajigaeshi

TCCA

CCl₄, **forbidden in Europe & America**

- BPO, CCl₄, 78 °C, 3 h, **44%**

Juenge

^tBuOCl

Explosive, forbidden in Germany

- 100 °C, time, yield: not given
- BPO, time, yield: not given, (Cyclohexene possible substrate)
- AIBN, 40 °C or hv, N₂, run until consumption, **84%** (+ 5% Benzal)

Clark, Kenner, Jacknow

NaOCl

Explosive

- Mn(TPP)Cl (2 mol%, PTC (4 mol%), DCM, N₂, **38%** (also tested Cyclopentane (69%), Cyclohexane (57%), Cyclooctane (74%), Neopentane (31%)) → + two patents

Groves

Et₄NCl

- *m*CPBA, MeCN, N₂, r.t., 3 min., **11%** (Cyclohexane 33% , 5 min)
- Peracetic acid, 22 °C, 8 h, **6%** (mostly core substitution)

Kojima, Goldsmith

Kharasch, M. S.; Brown, H. C. *J. Am. Chem. Soc.* **1939**, 61 (8), 2142–2150; Ford, M. C.; Waters, W. A. *J. Chem. Soc.* **1951**, No. 0, 1851–1855; Matsumoto, H.; Nakano, T.; Kato, M.; Nagai, Y. *Chem. Lett.* **1978**, 7 (2), 223–226; Delaude, L.; Laszlo, P. *J. Org. Chem.* **1990**, 55 (18), 5260–5269; Kurdyukov, A. M. *Russ. J. Appl. Chem.* **2007**, 80 (9), 1566–1569; B. F. Clark, Jr., *Chcm. News* **1931**, 265; Kenner, J. *Nature* **1945**, 156 (3960), 369–370; Walling, C.; Jacknow, B. B. *J. Am. Chem. Soc.* **1960**, 82 (23), 6108–6112; Liu, W., Groves, J. T. *J. Am. Chem. Soc.* **2010**, 132 (37), 12847–12849; Kojima, T.; Matsuo, H.; Matsuda, Y. *Chem. Lett.* **1998**, 27 (11), 1085–1086; He, Y.; Goldsmith, C. R. *Synlett* **2010**, 09, 1377–1380; Kajigaeshi, S.; Kakinami†, T.; Moriwaki, M.; Tanaka, T.; Fujisaki, S. *Tetrahedron Lett.* **1988**, 29 (45), 5783–5786; Juenge, E. C.; Beal, D. A.; Duncan, W. P. *J. Org. Chem.* **1970**, 35 (3), 719–722.



- Often use of radical starters (AIBN, BPO, TBHP)
- Corrosive chlorine agents, toxic waste, toxic chemicals (costs for safety)
- Air sensitive (radical scavenger, oxygenated products)
- Moisture sensitive

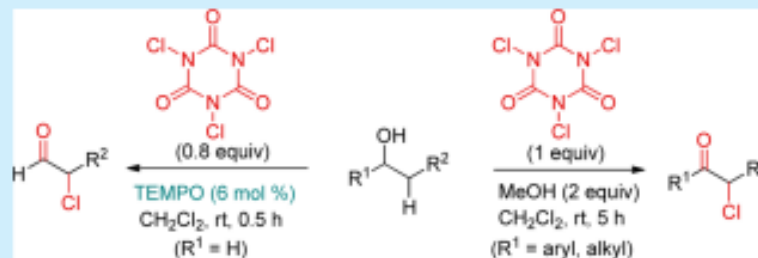
Direct Conversion of Alcohols to α -Chloro Aldehydes and α -Chloro Ketones

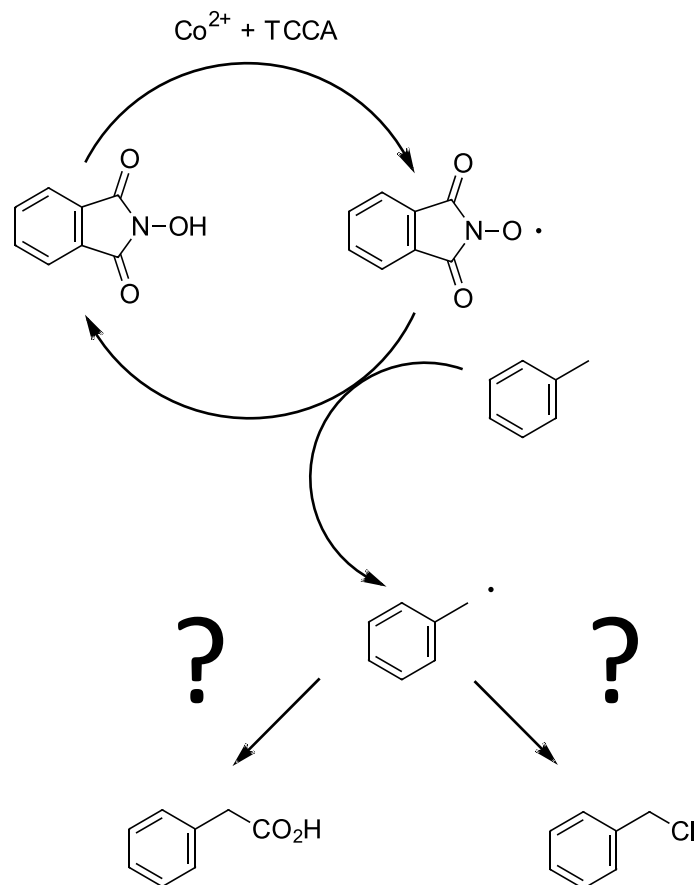
Yuanyuan Jing, Constantin G. Daniliuc, and Armido Studer*

Institute of Organic Chemistry, Westfälische Wilhelms-University, Corrensstraße 40, 48149 Münster, Germany

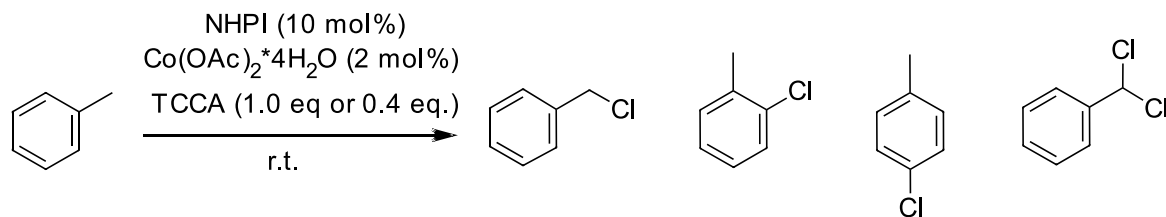
S Supporting Information

ABSTRACT: Direct conversion of primary and secondary alcohols into the corresponding α -chloro aldehydes and α -chloro ketones using trichloroisocyanuric acid, serving both as stoichiometric oxidant and α -halogenating reagent, is reported. For primary alcohols, TEMPO has to be added as an oxidation catalyst, and for the transformation of secondary alcohols (TEMPO-free protocol), MeOH as an additive is essential to promote chlorination of the intermediary ketones.





- Minisci chlorination of alkanes with NHPI, HNO₃, O₂, stoichiometrically CuCl₂, AcOH, 100 °C



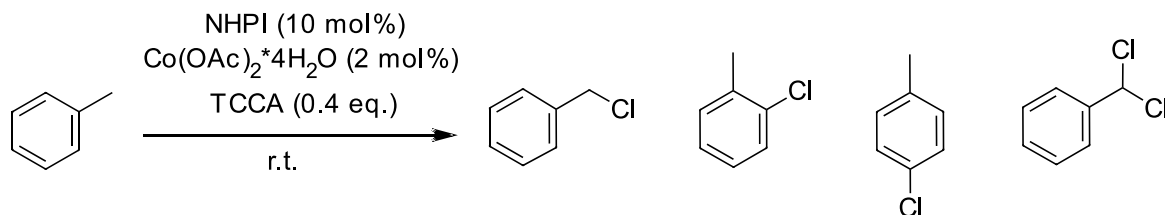
t [h]	solvent	BnCl [%]	ortho [%]	para [%]	BnCl ₂ [%]
16	DCM	24	4	5	—
19 ^[1]		33	20	28	—
18 ^[2]	DCM	28	2	2	trace
120		72	10	7	10
16	AcOH	23	40	15	—
19 ^[1]		20	45	20	—

Cl[•]

Polymerization

Cl⁺

[1] After 16 h was added MeOH (2 eq.). [2] TBHP (0.1 eq.); TCCA (0.4 eq.).



- polar, aprotic: DMSO, DMF -> explosion

t [h]	solvent	BnCl [%]	ortho [%]	para [%]	BnCl ₂ [%]
5	MeCN	13	29	38	—

Side products

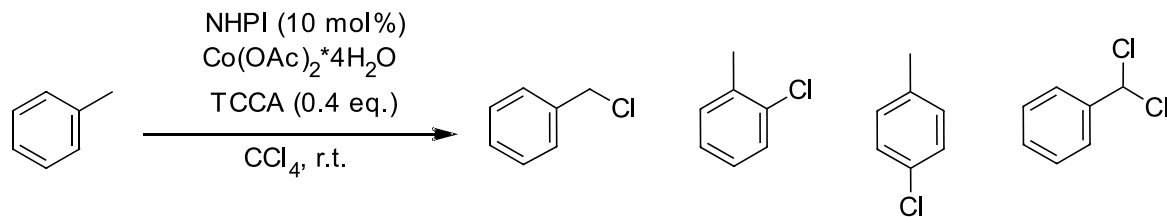
16	CHCl ₃	47	1	1	—
40 ^[1]		45	1	1	—

16	1,2-DCE	46	—	—	—
40		35	—	—	—

Trace of CHO

16	CCl ₄	45	—	—	—
40		76 (45) ^[2]	—	—	17 (13) ^[2]

[1] Additionally TCCA (0.4 eq.) added -> after 6 d 53% BnCl [2] Isolated yield.



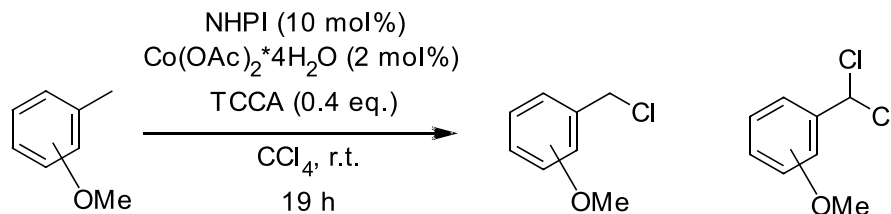
t [h]	Co [mol%]	BnCl [%]	BnCl ₂ [%]
24	1	50	2
48		80	11

16	2	45	—
40		76 (45) ^[1]	17 (16)

24	5	73	8
48		73	16

Polymerization

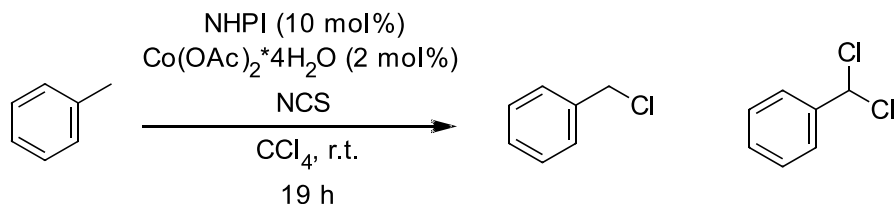
24	10	11	—
48		51	—



Substitution	BnCl [%]	BnCl ₂ [%]	BDE [kcal*mol ⁻¹]
<i>o</i>	58	—	
<i>m</i>	94	6	90.5
<i>p</i>	—	—	86.6

BDE PhMe = 89.6 kcal*mol⁻¹

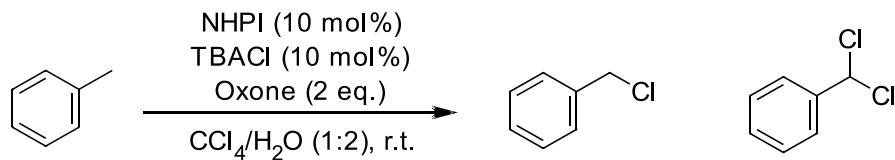
BDE NHPI/PINO = 88 kcal*mol⁻¹



t [h]	NCS [eq.]	BnCl [%]	BnCl ₂ [%]
21	0.4	—	—
48		—	—

21	1	—	—
48		—	—

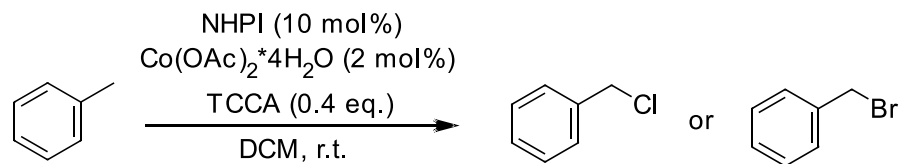
- TCCA seems to act as oxidizer; NCS not
- Are •CCl₃ radicals involved? If Co activates NHPI somehow – it does (O₂)! → 10% conv. to product or even more



- works for Ad-H; why not for PhMe?

t [h]	BnCl [%]	BnCl ₂ [%]
24	—	—
48	—	—
6 d	—	—

Mechanism?



t [h]	CBr ₄ [eq.]	BnCl [%]	BnBr [%]
20	1.0	48	5
43		65	—

17	—	31	—
42		64	—

16	0.01	33	—
40		58	—

16	0.05	39	—
40		63	—

16	0.1	69	—
40		79	—

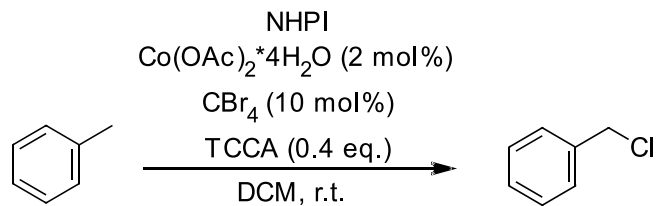
- Is $\bullet\text{CCl}_3$ involved in the reaction? ($\bullet\text{CBr}_3$)
- Cl_2 from TCCA?

t [h]	CHBr ₃ [eq.]	BnCl [%]	BnBr [%]
16	0.5	47	—
40		63	—

16	0.2	30	—
40		55	—

16	0.15	28	—
40		54	—

16	0.1	25	—
40		45	—

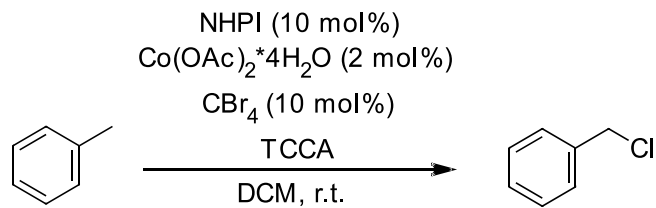


t [h]	NHPI [eq.]	BnCl [%]
16	—	—
40		—

16	0.05	7
40		n.d.

16	0.1	69
40		79

16	0.2	77
40		77

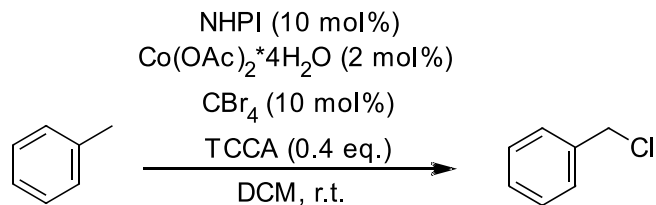


t [h]	TCCA [eq.]	BnCl [%]
16	0.35	60
41		68

16	0.4	69
40		79

16	0.6	18
41		33

16	0.8	17
41		24

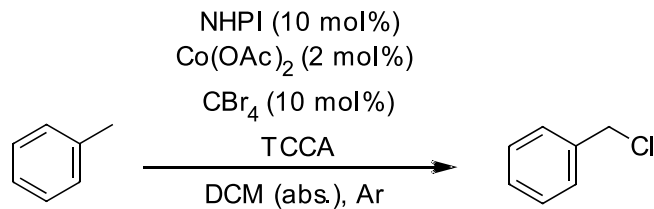


t [h]	H ₂ O [eq.]	BnCl [%]
16	—	69
40		79

16	0.05	11
40		30

16	0.1	16
40		44

16	0.3	1
40		37



- PhMe abs. + degassed
- DCM abs. + degassed

t [h]	T [°C]	BnCl [%]
17	18	45
41		54

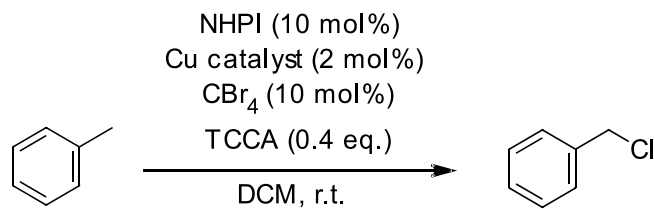
t [h]	T [°C]	BnCl [%]
18	18	44
41		59

17	25	45
41		77

19	25	74
43		74

17	30	53
41		64

Temperature dependent!



t [h]	Catalyst	BnCl [%]
16	Cu(OAc) ₂ *H ₂ O	47
40		75

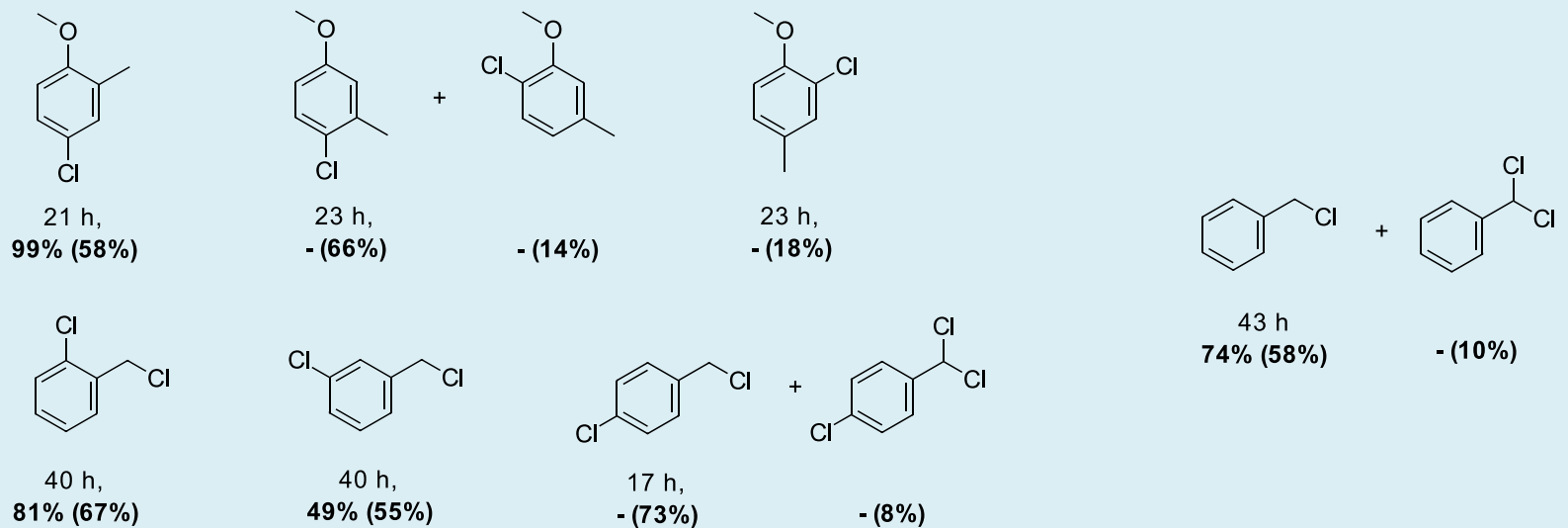
16	Cu(acac) ₂	50
40		62

16	CuCl ₂	34
40		79

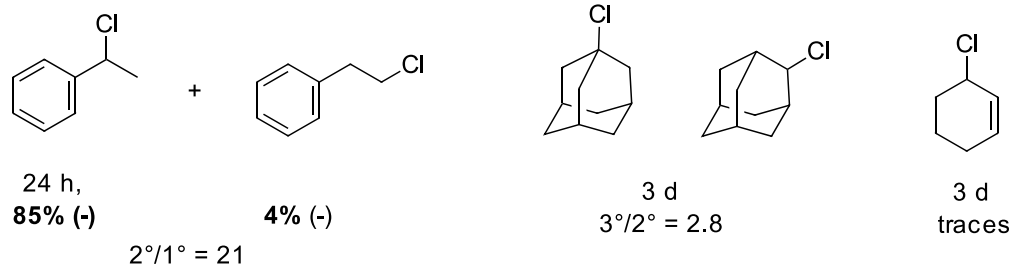
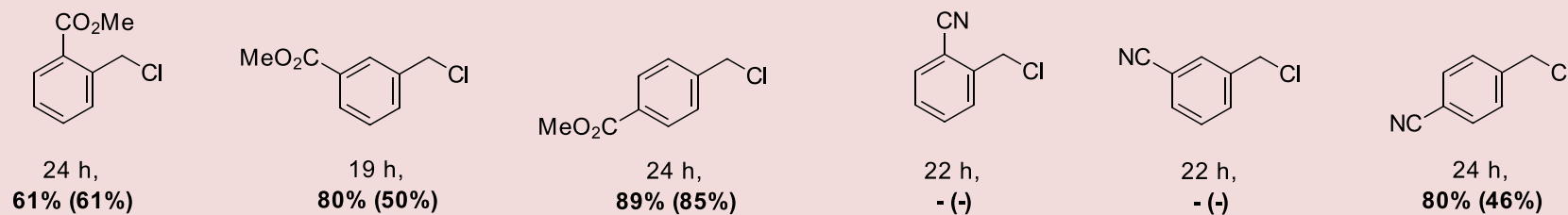
Substrate scope

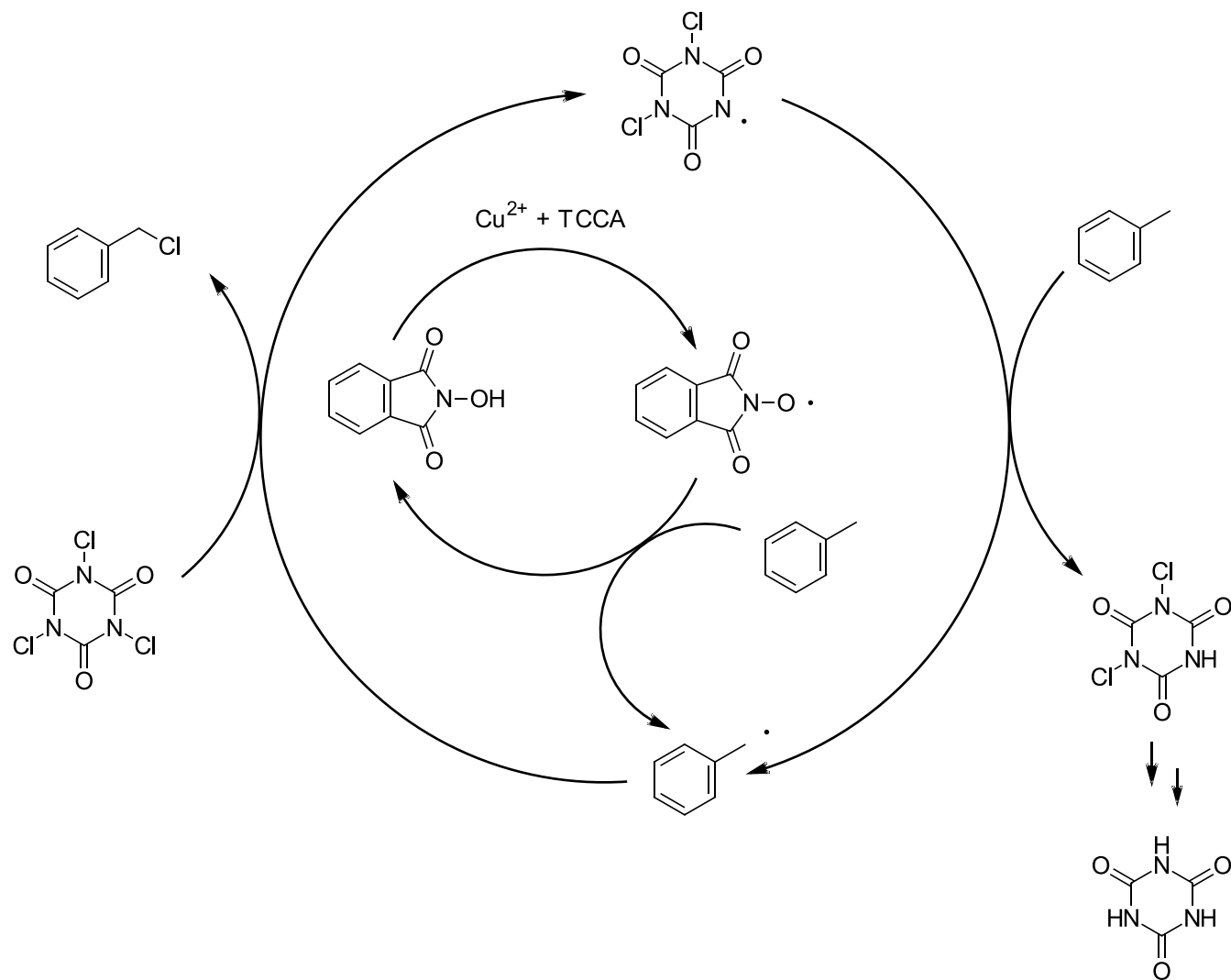


EDG



EWG







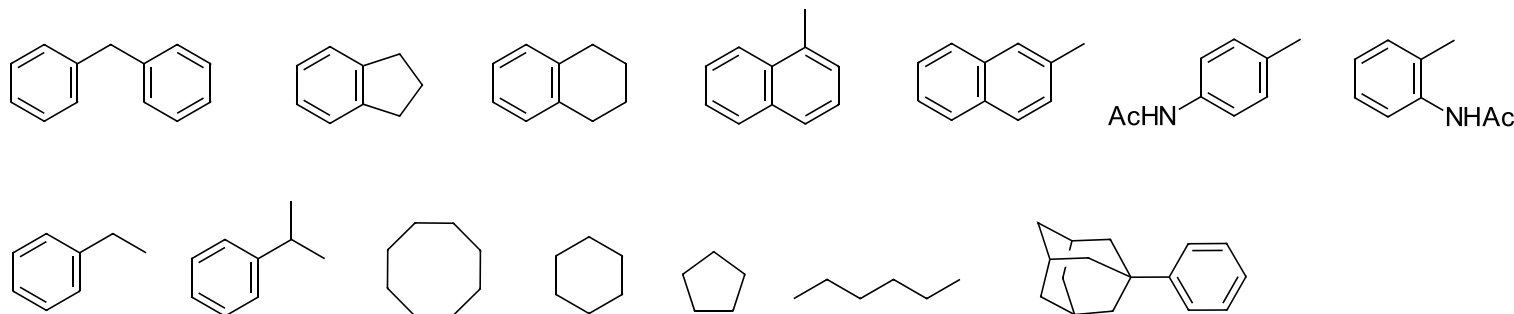
TCCA

- Very cheap
- Easy available
- Safe
- Oxidant and chlorine agent
- Waste is easy renewable (Cyanuric acid → TCCA)

General

- Reaction at 25 °C
- Stable against air and moisture
- High atom economy
- (Cu-catalyst can be filtered and reused - check)

Further Substrates



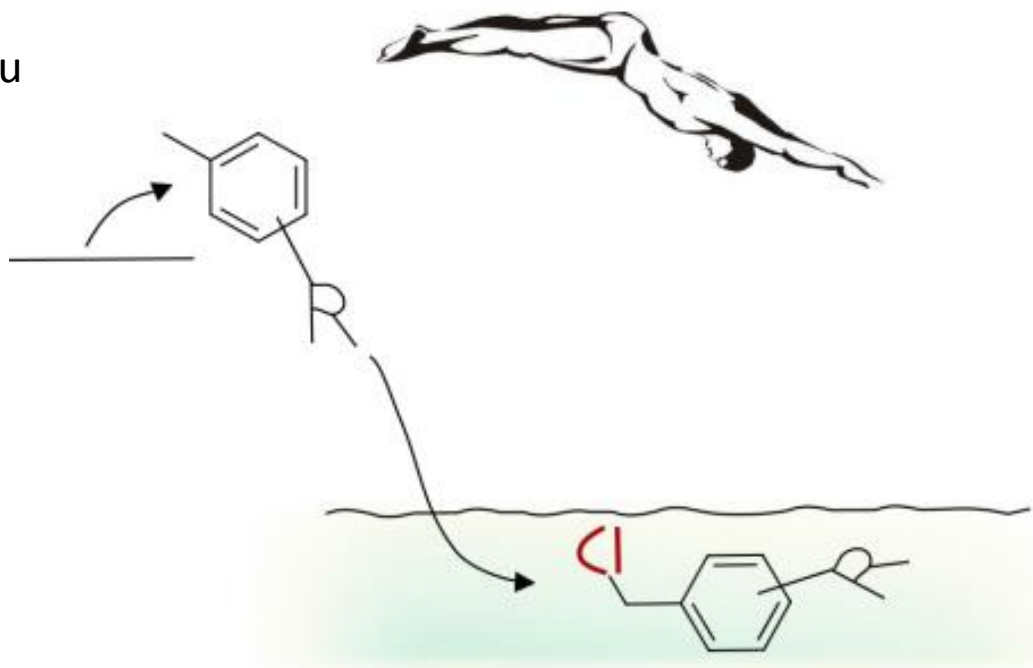


... Prof. Schreiner

... Abolfazl Hosseini, Honman Yau

... Dr. Röcker

... PRS group



Thank you for your attention