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A PROCEDURE FOR QUANTITATIVE REGIOSELECTIVE NITRATION OF AROMATIC HYDROCARBONS IN THE LABORATORY

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Summary : Aromatic hydrocarbons are nitrated by metallic nitrates impregnated on the K10 montmorillonite in the presence of acetic anhydride (Menke conditions). The influence on this stoichiometric reaction of the conditions (metallic cation; solvent; temperature) is studied. With toluene as the test molecule, the reaction is optimized to a 100% yield combined with a 8:1 *para* preference (79 % *para*, 20% *ortho*, 1 % *meta*).

NOVEL reagents consisting of metallic nitrates impregnated on lamellar montmorillonite clays give outstanding results in aromatic nitration[1]. Such success stems from a combination of factors involved in this type of heterogeneous catalysis : high diffusion rates from reduction of dimensionality; high BET specific surfaces; awesome oxidizing power of covalent metallic nitrates; considerable surface acidity; ease of formation of oxidized cationic species; boosted ionic strength next to the charged silicate sheets; etc. We show here how clay-supported cupric nitrate ("claycop"), chosen for the match in softness with the substrates[2], in the presence of acetic anhydride (Menke conditions[3]) so that acetyl nitrate is the likely nitrating species, does a nice job at nitration of normally-activated aromatic hydrocarbons. We examine here the influence of these parameters :

1. Nature of the Metallic Nitrate (Table 1)

	3 h reaction time	20 h reaction time
Aluminum(III)	73 (44,2,54)	81 (44,3,53)
Baryum(II)	0	0
Bismuth(III)	71 (46,0,54)	84 (45,2,53)
Cadmium(II)	52 (45,2,53)	69 (45,2,53)
Cerium(III)	65 (45,3,52)	70 (45,3,52)
Cobalt(II)	40 (48,2,50)	75 (46,2,52)
Chromium(III)	76 (42,3,55)	76 (42,3,55)
Mercury(II)	17 (49,2,49)	19 (47,2,51)

Lithium(I)	1	6 (49,0,51)
Manganese(II)	66 (50,3,47)	70 (50,2,48)
Nickel(II)	17 (51,0,49)	75 (48,2,50)
Zinc(II)	58 (50,1,49)	100 (48,3,49)
Copper(II)§	97 (44,3,53)	97 (44,3,53)

Table 1. Conversion of nitrate (%) and regioselectivities (ortho, meta, para %) for nitration of toluene (50 mL) under Menke conditions (acetic anhydride 6 mL) by 5 g of heterogeneous reagent (15 mmol NO_3^-) made by depositing the metallic nitrate from an acetone suspension[4] onto the K10 montmorillonite. § "claycop"

We chose the above series of metallic nitrates on the basis of the determination by a Japanese group of the reactivity sequence of 10 metallic nitrates toward aromatic nitration, using thermographic methods[5].

2. Reaction Temperature (Figs.1-4)

On the basis of this first series of results (Table 1) we have selected the nitrates of aluminum, bismuth, zinc, and copper as the most promising. The resulting regioselectivities are depicted as a function of the reaction temperature in Figs.1-4, the conversion percentages being determined by VPC.

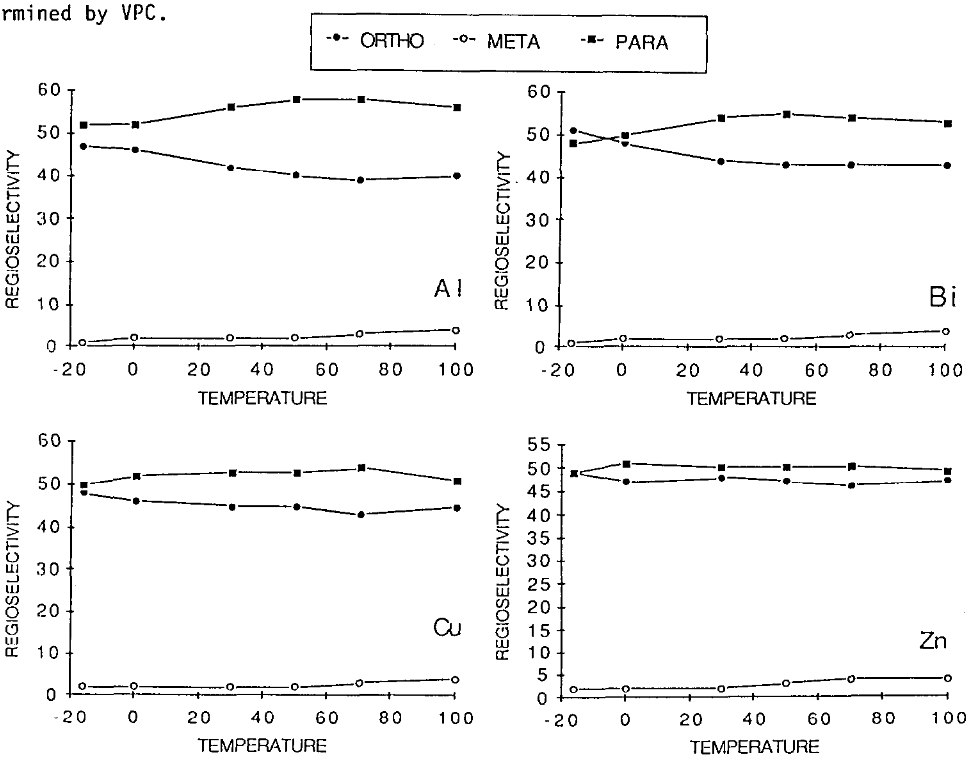

Fig. 1-4- Regioselectivities of ring nitration of toluene as a function of temperature (°C), using nitrates of Aluminum, Bismuth, Copper and Zinc respectively (other conditions as in Table 1). The expectation, based on earlier work on the nitration of halobenzenes[6], was of a considerable dependence of the product distribution on temperature.

The effect of temperature on the observed regioselectivities was unexpectedly small and we chose therefore to carry on the work at room temperature. We do not understand yet why temperature has such a minimal effect.

3. Effect of the Solvent.

In order to determine the best reaction medium, we thus ran reactions at room temperature, in 43 mL of solvent, in the presence of acetic anhydride (6 mL), for reaction times of 15-20 h. Since cupric nitrate was among the best performers in Table 1, the reagent for this series of experiments consisted of "claycop" : 11 g of cupric nitrate (trihydrate) co-suspended in acetone with 10 g of dry K10 clay, and then treated in the usual way[2,4]. The yields given below and henceforth are those for isolated products, determined by weighing. No products of polynitration nor of oxidation could be found.

Solvents can be put in four classes : those (the FC72 Freon (JANSSEN Chimica), acetonitrile) in which no reaction occurs. A second class consists of solvents in which the product distribution does not have the para as the main isomer (< 50 % para) : cyclohexane, acetone, bromochloromethane, 1,1,2,2-tetrachloroethane, and 1,2-dichloroethane. The third class includes solvents giving rise to product distributions having between 50 and 55 % of the para isomer : n-hexane, toluene, 2-chloropropane, o-dichlorobenzene, and methylene chloride.

Finally, the fourth (and best) class consists only of chlorine-containing solvents; these give para preferences better than 55 % of the total products : chloroform, carbon tetrachloride, trichloroethylene, tetrachloroethylene, 1,1-dichloroethane, and 1,2-dichloropropane. If one's goal is to maximize the relative amount of para-nitrotoluene, then carbon tetrachloride is the best choice : the para preference increases by small but significant amounts in the series methylene chloride (50.2), chloroform (55.4), and carbon tetrachloride (56.1), as the number of polarizable chlorines goes up. No other solvent parameter besides polarizability (dielectric constant, dipole moment, internal pressure, etc.) correlates with these results.

4. Effect of Dilution

We interject here a note or rationality in what is otherwise an altogether empirical account. The reader will recall from our earlier work with halobenzenes[6] that one of the contributing factors to the observed products distribution is the electrostatic interaction of the electrophile with the polarizable electronic distribution of the substituent. Qualitatively, this factor "pulls" the electrophile next to the substituent, in the ortho position. If the solvent molecules bear themselves polarizable groups, they will compete with the substrate for stabilizing the electrophile in this manner, thus favoring conversely para substitution. This is exactly what is observed with the solvent effects in the previous section.

To further explore the validity of this working hypothesis, we determine the influence of dilution. The prediction is that increasing the dilution in the highly polarizable carbon tetrachloride will further upgrade the para preference (Table 2) :

Volume of the CCl_4 solvent	Toluene introduction	Reaction time, h	ortho-meta-para
2 L	perfusion:0.6 mL.h^{-1} of 1 mL toluene in 50 mL carbon tetrachloride	120	20 - 1 - 79
2 L	1 mL, one shot	41	23 - 1 - 76
50 mL	perfusion, as in the first run above	144	35 - 2 - 63

Table 2 : Improvement of the para preference by dilution, in the presence of 6 mL acetic anhydride (Menke conditions), with "claycop" (5 g). All these are quantitative runs (100 % isolated yields).

To sum-up, we have shown that it is possible to nitrate toluene quantitatively with a para preference of 80 % (Table 2). It is important to note that all these experiments display an induction period, manifested by a color change and by marked improvement in the regioselectivity, and attributable to drying by Ac_2O of the reaction centers at the solvent-clay interface. This induction period lasts 0.5 h in CCl_4, 1.25 h in CH_2Cl_2, and 1 h in $CHCl_3$ (at 22° C). The aromatic hydrocarbon to be nitrated is best added after the end of this induction phase.

A final point should be mentioned : can the process be made catalytic, with a view to possible industrial extension ? The answer is yes[7].

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