Tetrahedron Letters,Vol.26,No.12,pp 1509-1512,1985
Printed in Great Britain

0040-4039/85 $3.00 + .00

ELECTROSYNTHESIS OF CARBOXYLIC ACIDS FROM ORGANIC HALIDES AND CARBON DIOXIDE

By : Oumar SOCK, Michel TROUPEL and Jacques PERICHON

Laboratoire d'Electrochimie Organique, U.A. C.N.R.S. 329, Université Paris-Val de Marne,
94010 CRETEIL CEDEX (France)

ABSTRACT :

The electrocarboxylation of a large variety of organic halides is achieved in simple and mild conditions in diaphragm-less cells.

Former attempts to obtain carboxylic acids by electroreduction of organic halides (RX) in the presence of carbon dioxide have not been very successful. In most cases faradic and chemical yields are low and RH is formed in a large amount (1). Only benzylic and allylic halides give satisfactory results but in these cases the product is largely converted into the corresponding ester by a further reaction with the unreacted halide (2). We have already shown that the electroreductive carboxylation of aryl and benzylic halides may be improved by catalysis via nickel (3) or cobalt (4) complexes. Although the yields are rather good, the process is limited by the use of diaphragms cells and by a moderate turn-over of the catalyst.

We now report a new method for the electrocarboxylation of a large variety of organic halides (X = I, Br or Cl) by an easy and efficient process where electrolysis is performed in diaphragm-less cell at a temperature close to ambiant and under an atmospheric pressure of CO_2. The concentration of the reactant RX may be unusually high (0.5 M) for an electrochemical synthesis and the reaction may be achieved in a short time by the use of high current densities (5).

The cell is a glass vessel (35 ml) equipped with two electrodes. The anode is a cylindrical rod of magnesium. The cathode encircles the anode and may consist in any conductor such as platinum, gold, nickel, stainless steel, or graphite. The solvent is an aprotic one such as N-methylpyrrolidone, acetonitrile, acetone, NN-dimethylformamide (DMF), tetrahydrofuran (THF) or a mixture of tetrahydrofuran and hexamethylphosphoramide (HMPA). A small amount of a supporting electrolyte such as Bu_4NClO_4, Bu_4NBF_4, Et_4NCl, Bu_4NBr or $LiClO_4$ is added. The cell is then immersed in a cold water bath to dissipate the heat evolved by the electrolysis and to keep the temperature near 5°C. Carbon dioxide is supplied either by a slow bubbling at atmospheric pressure or by a low over-pressure in the cell. A constant current intensity is maintained between the two electrodes until the quantity of electricity reaches

2.1 electrons per mole of initial RX, i.e. 105 % of the theoretical amount.

Unreacted RX and side products as RH or RR are determined by gas chromatography. The carboxylic acid is extracted after an aqueous acid hydrolysis and identified by NMR and melting point. Table 1 presents a list of results that clearly demonstrates the wide scope of synthetic applications of the process and describes the influence of several experimental parameters (nature of the solvent, current density, concentration of RX,...).

The results presented in Table 1 show that this electrocarboxylation can be successfully applied to various classes of organic halides (aliphatic, aromatic, vinylic,...) which can be substituted by various functional groups (F, OR, CO, CO_2R, CN) provided that these groups are not electroreducible in the experimental conditions (e.g. nitro-aromatics are readily reduced to the azoxy).

The process appeared to be particularly convenient to prepare some products of industrial interest, such as those described in the last three examples, which are pharmaceuticals having antiinflammatory activity. For these products experiments have been performed on a larger scale by pumping the solution (1 to 5 liters) through a cell made of a stainless steel tube surrounding a magnesium rod. This process gave results very similar to those obtained in the preceding examples and allowed us to prepare larger amounts of these acids.

In some experiments, the temperature appeared to be a crucial factor since its increase induces a lowering of the carboxylation yield, especially when the current intensity is high (RH or RR are then obtained in larger amounts). We assume that it is linked with the change of solubility of carbon dioxide.

Electrocarboxylation of dichloroderivatives (e.g. methylene chloride, benzalchloride, 1,3-dichloroacetone, o-dichlorobenzene) usually yields monochlorocarboxylic acids with fair selectivity. On resuming electrolysis, dicarboxylic acids are obtained with much lower yields.

In this connection a very recent article (6) reports a similar method for the electrocarboxylation of benzalchloride by electrolysis of solution in DMF between a graphite cathode and aluminium sacrificial anode. We have also tested different metal anodes such as Al, Zn, Fe, Li, for various electrocarboxylations. In some cases the results are very close to those reported with a magnesium anode, but in other cases, we have obtained only a partial carboxylation or no carboxylation at all, so we have prefered the use of a magnesium anode.

The electrochemical reactions can be written as follows :

$Mg \rightarrow Mg^{++} + 2e$ for the anodic process (which has been proven by weighing of the magnesium anode), and :

$RX + CO_2 + 2e \rightarrow RCO_2^- + X^-$ for the cathodic process.

It can then be considered that the present electrosynthesis, according to the total balance :

$$Mg + RX + CO_2 \rightarrow RCO_2^- + Mg^{++} + X^-$$

consists of an electroassisted thermodynamically possible chemical reaction which is quite similar to the conventional carboxylation of GRIGNARD reagents, i.e. :

TABLE 1

RX (0.4 M unless otherwise indicated)	Solvent	Current density(a) (ma/cm²)	R_1 %	R_2 %	R_3 %
$PhCH_2Cl$	DMF	40	> 99	> 99	90
$PhCH_2Cl$	DMF	125	90	80	90
$PhCH_2Cl$	THF	40	> 99	> 99	90
(b) $PhCH_2Cl$	Acetone	30	> 99	80	90
(b) $PhCH_2Cl$	Acetonitrile	30	99	95	90
(c) $PhCH_2Cl$ (0.8 M)	DMF	50	70	97	90
(d) $PhCH_2Cl$ (2 M)	DMF	50	40	95	90
PhBr	DMF	40	> 99	90	85
p-FC_6H_4Br	NMP (40°C)	25	98	70	80
p-FC_6H_4Br	DMF	30	> 99	91	80
PhCl (0.5 M)	DMF	12	78	66	85
2-chlorothiophene	THF-HMPA	10	> 99	85	80
3-bromofuran	THF-HMPA	10	> 99	95	78
$PhCHClCH_3$	DMF	10	> 99	> 99	80
1-bromodecane	DMF	10	> 99	> 99	75
1-bromooctadecane (0.2 M)	THF-HMPA	10	> 99	50	-(e)
p-$BrC_6H_4COCH_3$	DMF	10	> 99	> 99	82
PhCH=CHBr	DMF	10	> 99	> 99	80
$PhCH=CHCH_2Cl$	THF-HMPA	10	> 99	> 99	80
$ClCH_2COOC_2H_5$	THF	10	> 99	90	-(e)
CH_3COCH_2Cl	DMF	30	> 99	> 99	-(e)
(6-methoxy, 2-naphtyl) 1-chloroéthane	DMF	25	95	90	80
m-$PhOC_6H_4CHClCH_3$	DMF	50	75	90	80
m-(iso)C_4H_9-$C_6H_4CHClCH_3$	DMF	50	90	90	85

(a) The current density is expressed versus the area of the anode.

(b, c, d) due to a severe increase of the viscosity, electrolysis were stopped respectively at 1 (b), 1.4 (c) and 0.8 (d) electron mol.$^{-1}$ of RX.

(e) The acid has not been isolated but the yield was determined by acidimetry or chromatography.

R_1 indicates the percentage of consumption of RX.

R_2 indicates the faradic yield of the production of carboxylic acid. This has been calculated by acidimetric titration.

R_3 indicates the yield of isolated acid versus the amount of consumed RX.

$$RX + Mg \rightarrow RMgX \xrightarrow{CO_2} RCO_2MgX$$

However, we have checked that this reaction cannot occur spontaneously under the experimental conditions of our electrolysis. The carboxylation will stop as soon as the electricity is turned off.

In comparison with the chemical synthesis, this electrochemical process obviously allows the carboxylation, in one stage, of a large variety of organic halides including those GRIGNARD derivatives of which are difficult to prepare (e.g. vinylic halides) or unstable (e.g. benzylic or CO, CO_2R,... substituted halides).

Up to now, nothing allows us to say with certainty that electrogenerated GRIGNARD intermediates are involved in the present electrosynthesis. Work is in progress to elucidate the mechanism of the reaction.

REFERENCES

1) T. Matsue, S. Kitahara and T. Osa, Denki Kagaku, 50, 732, (1982).

2) M. Baizer, J. Org. Chem., 37, 1951 (1972).

3) a/ M. Troupel, Y. Rollin, J. Perichon and J.F. Fauvarque, Nouv. J. Chimie, 5, 621 (1981).

   b/ J.F. Fauvarque, A. Jutand, C. Chevrot and M. Troupel, French Pat. Appl. n° 2530266 (1982).

   c/ J.F. Fauvarque, C. Chevrot, A. Jutand, M. François and J. Perichon, J. Organomet. Chem., 264, 273, (1984).

4) J.C. Folest, J.M. Duprilot, J. Devynck and J. Perichon, submitted to Tetrahedron Letters.

5) O. Sock, M. Troupel, J. Perichon, S.N.P.E., French Pat. Appl. n° 8409787 (June 1984).

6) G. Silvestri, S. Gambino, G. Filardo, G. Greco and A. Gulotta. Tetrahedron Letters, 25, 4307, (1984).

ACKNOWLEDGMENT

We thank the "Société Nationale des Poudres et Explosifs" and the C.N.R.S. for financial support of the work. We also thank J. Chaussard (S.N.P.E.) for fruitful discussions and help for larger scale electrosynthesis of arylpropionic acids.

(Received in France 8 January 1985)