Aerobic Oxidation of *N*-Alkylamides Catalyzed by *N*-Hydroxyphthalimide under Mild Conditions. Polar and Enthalpic Effects

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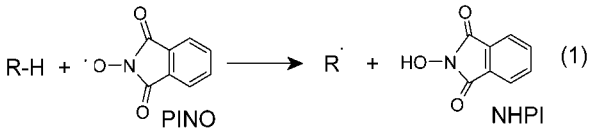
The oxidation of *N*-alkylamides by O_2, catalyzed by *N*-hydroxyphthalimide (NHPI) and Co(II) salt, leads under mild conditions to carbonyl derivatives (aldehydes, ketones, carboxylic acids, imides) whose distribution depends on the nature of the alkyl group and on the reaction conditions. Primary *N*-benzylamides lead to imides and aromatic aldehydes at room temperature without any appreciable amount of carboxylic acids, while under the same conditions nonbenzylic derivatives give carboxylic acids and imides with no trace of aldehydes, even at very low conversion. These results are explained through hydrogen abstraction by the phthalimide-*N*-oxyl (PINO) radical, whose reactivity with benzyl derivatives is governed by polar effects, so that benzylamides are much more reactive than the corresponding aldehydes. The enthalpic effect is, however, dominant with nonbenzylic amides, making the corresponding aldehydes much more reactive than the starting amides. The importance of the bond dissociation energy (BDE) of the O−H bond in NHPI is emphasized.

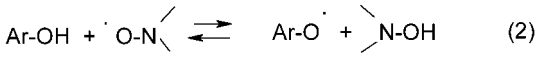
Introduction

N-Hydroxyphthalimide (NHPI) combined with cobalt salts has been recently shown, particularly by Ishii and co-workers,[1] to be an effective catalyst for the oxidation of organic compounds by molecular oxygen under mild conditions. All the evidence[1] would indicate that hydrogen abstraction by the phthalimide-*N*-oxyl radical (PINO), generated in situ, from C−H bonds (eq 1) plays a key role in free-radical chains.



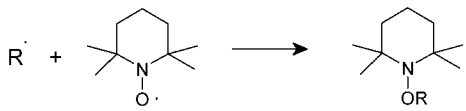
(1)

For example, primary alcohols are oxidized to carboxylic acids[2] or aldehydes[3] at room temperature and atmospheric pressure of oxygen. On the other hand, we have recently reported[4] that the aerobic oxidation of primary alcohols, catalyzed by TEMPO (tetramethylpiperidine-*N*-oxyl) in combination with transition metal salts, leads selectively to the corresponding aldehydes under very mild conditions. We ascribed[3] the different behavior of PINO and TEMPO (both *N*-oxyl radicals) to the difference in bond dissociation energies (BDEs) of the O−H bonds in the corresponding *N*-hydroxy derivatives. The BDE of the O−H bond in *N*-hydroxytetramethylpiperidine is relatively low (70 kcal mol^{-1}), while we have shown[3] that the BDE of the O−H bond in NHPI is at least 16 kcal mol^{-1} stronger, as measured by EPR spectroscopy of the equilibrium shown in eq 2, where Ar−OH is a reference phenol (2,4,6-trimethylphenol, whose BDE in benzene is 82.7 kcal mol^{-1})[3,5] and >N−O−H is NHPI.



(2)

The higher BDE for the O−H bond in NHPI would explain the possibility of hydrogen abstraction following eq 1. A similar reaction by TEMPO instead of PINO would be too endothermic to occur, while on the other hand, TEMPO is an inhibitor of free-radical chains, since it rapidly traps intermediate free radicals (eq 3).



(3)

The effectiveness of the catalytic activity of TEMPO in selectively oxidizing alcohols to aldehydes by O_2 is due to the intermediate formation of the oxoammonium salt (>N^+=O), which is the actual oxidant, but also to the

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(1) Recent review: Ishii, Y.; Sakaguchi, S.; Iwahama, T. *Adv. Synth. Catal.* **2001**, *343*, 393.
(2) Iwahama, T.; Yoshino, Y.; Keitoku, T.; Sakaguchi, S.; Ishii, Y. *J. Org. Chem.* **2000**, *65*, 6502.
(3) Minisci, F.; Punta, C.; Recupero, F.; Fontana, F.; Pedulli, G. F. *Chem. Commun.* In press.
(4) Cecchetto, A.; Fontana, F.; Minisci, F.; Recupero, F. *Tetrahedron Lett.* **2001**, *42*, 6651.
(5) Lucarini, M.; Pedulli, G. F.; Cipollone, M. *J. Org. Chem.* **1994**, *59*, 5063; Lucarini, M.; Pedrielli, P.; Pedulli, G. F.; Cabiddu, S.; Fattuoni, C. *J. Org. Chem.* **1996**, *61*, 9259; Lucarini, M.; Pedulli, G. F.; Valgimigli, L.; Amorati, R.; Minisci, F. *J. Org. Chem.* **2001**, *66*, 5456.

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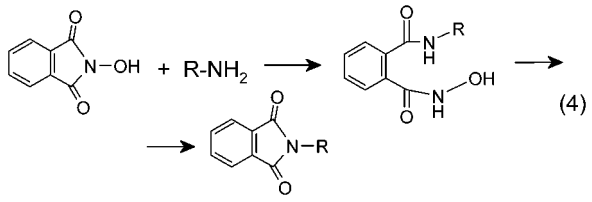
inhibition of the further free-radical oxidation of aldehydes by O_2, which occurs in the absence of TEMPO.[4]

We have also observed[3] that reaction 1 is strongly affected by polar and enthalpic effects, so that, for example, the oxidation of primary benzylic alcohols leads selectively to aldehydes. This happens because benzylic alcohols are much more reactive than the corresponding aldehydes for polar reasons, the enthalpic effect being substantially identical for alcohols and aldehydes. In contrast, nonbenzylic alcohols selectively give carboxylic acids, even at low conversion, because in this case aldehydes are much more reactive than the corresponding alcohols on enthalpic grounds.[3]

The amino group is a more effective electron-releasing substituent than the hydroxy group (the values of the σ_p Hammett constants are -0.57 and -0.35 for $-NH_2$ and $-OH$ groups, respectively) and therefore we would expect a higher reactivity and a stronger polar effect in the oxidation of alkylamines by O_2 and NHPI catalysis compared to the corresponding alcohols.

However, we observed that under conditions in which the alcohols are easily oxidized, the corresponding amines are substantially inert. We soon realized that this inertness was due to the degradation of the catalyst (NHPI) by the amine, according to eq 4.



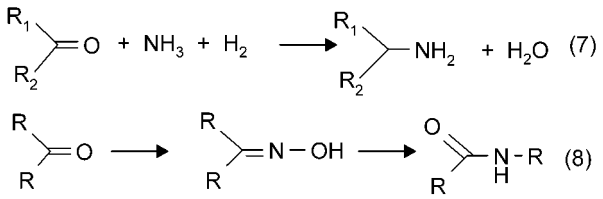
To avoid the deactivation of the catalyst (eq 4), we considered the possibility of protecting the amino group by acylation. Obviously, the acetamido group has a lower electron-releasing character than the amino group, but the enthalpic and polar effects should be still marked enough for the selective oxidation of *N*-alkylamides to occur by O_2 with NHPI catalysis. Actually, the oxidation of *N*-alkylamides by O_2, catalyzed by NHPI and Co salts, occurs under mild conditions, leading to carbonyl products (imides, carboxylic acids, ketones, aldehydes). The exact product distribution depends on the structure of the alkyl group and the reaction conditions.

Classical organic chemical reactions allow the transformation of carbonyl derivatives into amines; the carboxylic acids can be converted to amines through well-known reactions, such as the Hofmann[6,7] (eq 5) and Curtius[8,9] (eq 6) rearrangements.

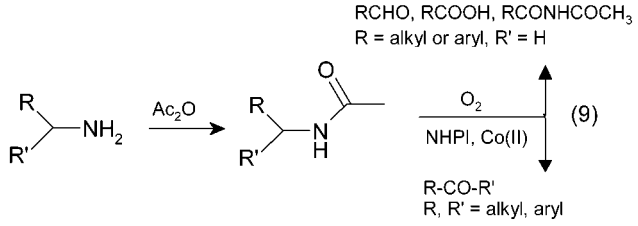
$$\text{R-COOH} \rightarrow \text{R-CO-NH}_2 \rightarrow \text{R-NH}_2 \qquad (5)$$

$$\text{R-COOH} \rightarrow \text{R-CO-N}_3 \rightarrow \text{R-NH}_2 \qquad (6)$$

Moreover, carbonyl derivatives can be transformed into amino derivatives by reductive ammonolysis[10] (eq 7) or through the Beckmann rearrangement[11,12] of the corresponding oximes (eq 8).



In this paper we report, as mentioned above, a new simple oxidation by O_2, catalyzed by NHPI, which allows the reverse transformation of alkylamines to carbonyl compounds through the intermediate amides (eq 9).

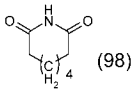
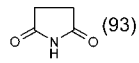
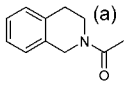
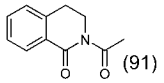
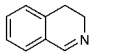
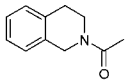
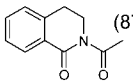
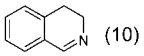


Results and discussion

Results and Discussion

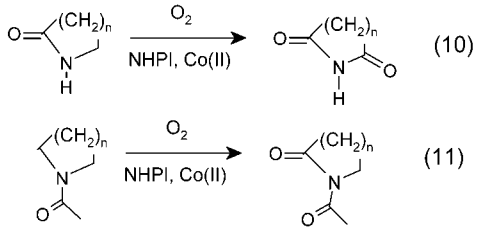
Cyclic Amides. The oxidation of lactams or acetamides of cyclic amines does not lead to the cleavage of the ring but to the formation of cyclic imides (eq 10) or *N*-acetyl lactams (eq 11) (Table 1).

Table 1. Oxidation of Lactams or Acetamides of Cyclic Amines by O_2 in CH_3CN

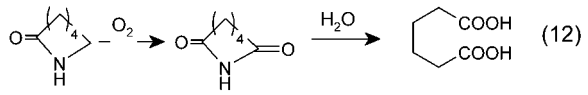
Amide	T (°C)	t (h)	Conv. (%)	Products Selectivity (%)
	80	3	96	 (98)
	80	5	97	 (93)
 (a)	20	1	100	 (91)  (7)
	80	4	100	 (87)  (10)
	80	4	45	 (94)

[a] 0.25 mmol of *m*-chlorobenzoic acid was utilized for 5 mmol of amide.

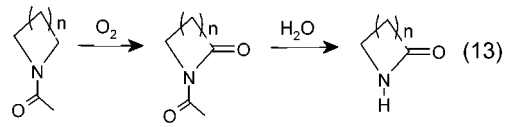
(6) Malpass, J. R. In *Comprehensive Organic Chemistry;* Sutherland, I. O., Ed.; Pergamon Press: Oxford, 1979; Vol.2, p 17.
(7) Banthorpe, D. V. *The chemistry of the amino group*; Patai, S., Ed.; Wiley: New York, 1968; p 630.
(8) Reference 6, p 18.
(9) Reference 7, p 623.
(10) Reference 6, p 10.
(11) Challis, B. C.; Challis, J. A. In *Comprehensive Organic Chemistry*, Sutherland, I. O., Ed.; Pergamon Press: Oxford, 1979; Vol.2, p 966.
(12) Reference 7, p 624.



The hydrolysis of the cyclic imides leads to dicarboxylic acids; for example, caprolactam gives the cyclic imide in high yields and, by hydrolysis, it turns into adipic acid (eq 12).



The hydrolysis of *N*-acetyllactams leads to lactams (eq 13).

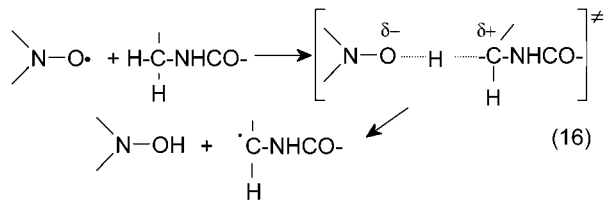


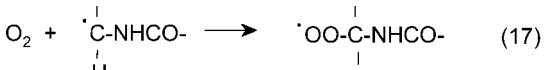
Equation 13 represents a simple procedure for the transformation of cyclic amines to lactams by acetylation, O_2 oxidation, and hydrolysis. The mechanism of the transformation of the methylene into the carbonyl group must explain the combined catalytic activity of NHPI and Co(II) salts (both are necessary for the oxidation under mild conditions). Co(II) salts appear to have a 2-fold function: they can initiate (eqs 14, 15) chain processes, as suggested by Ishii.[1]

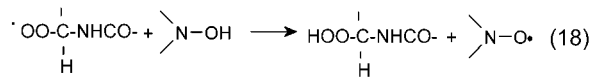
$$\text{Co(II)} + O_2 \rightarrow \text{Co(III)OO}^{\bullet} \quad (14)$$

$$\text{Co(III)OO}^{\bullet} + \text{H-O-N<} \rightarrow \text{Co(III)OOH} + {}^{\bullet}\text{O-N<} \text{ (PINO)} \quad (15)$$

PINO then initiates a free-radical chain, leading to the hydroperoxide under mild conditions (eqs 16−18).

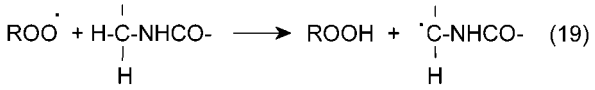






The C−H bonds adjacent to either NH or CO groups are both activated from an enthalpic standpoint, but reaction 16, involving the electrophilic PINO radical, occurs selectively to the CH_2 next to the NH for polar reasons.

The free-radical chain of eqs 16−18, suggested by Ishii in general for the oxidations by O_2 catalyzed by NHPI, would appear, however, quite intriguing. The question is, why does the peroxyl radical abstract a hydrogen atom from NHPI generating the PINO radical (eq 18) and not directly from the amide (eq 19), while the PINO radical abstracts a hydrogen atom from the amide (eq 16) and not from the hydroperoxide under mild conditions (room temperature)?

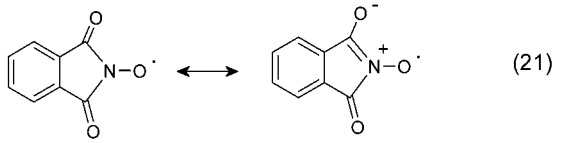


The question arises from the fact that both nitroxyl and peroxyl radicals have a clear-cut electrophilic character, so both reactions 16 and 19 should be favored by polar effects, while reaction 18 should be negatively affected by the polar effect and substantially governed by the enthalpic effect.

We know the BDE for the O−H bond in the hydroperoxide (88 kcal mol^{-1}) but only the lower limit for the BDE of the O−H bond in NHPI (>86 kcal mol^{-1}),[3] and we can reasonably assume that reaction 18 is either almost thermoneutral or slightly endothermic, so the general eq 20 can be considered an equilibrium process.

Moreover, we know the absolute rate constants for hydrogen abstraction from C−H bonds by peroxyl radicals (eq 19) ($\sim 10^{-2}$−10^{-1} M^{-1} s^{-1}at room temperature), but we have not yet determined[13] the order of magnitude for hydrogen abstraction by PINO radical.

The intriguing aspects of eqs 16 and 18 could be explained by a more marked polar effect for hydrogen abstraction by PINO than by the peroxyl radical, which would make eq 16 faster than eq 19 and thus shift the equilibrium of eq 20 to the right. This polar effect should be due to the carbonyl groups bonded to nitrogen (eq 21).



The effect is, in our opinion, similar to that observed for acylperoxyl radicals, R−C(═O)OO•, compared to alkylperoxyl radicals, R−OO•; the former is more electrophilic than the latter.[14] The phenomenon would be more marked with PINO than with acylperoxyl radicals, because nitrogen can settle a positive charge, as in eq 21, better than oxygen.

For the same reason we believe the BDE for the O−H bond to be higher in NHPI than in alkyl-*N*-hydroxy derivatives: for NHPI, a conjugation similar to eq 21 increases the polarization of the O−H bond and therefore the electrostatic attraction between H and O and hence the BDE of the O−H bond.

Again the situation is similar to that of peracids and hydroperoxides (the BDE values for the O−H bonds in ROO−H and R−C(═O)OO−H are respectively 88 and 93

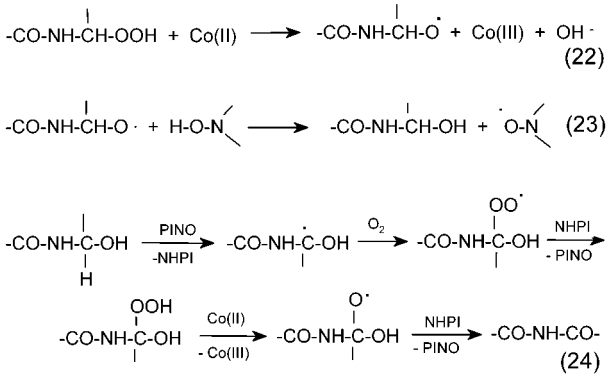
(13) The determination by ESR spectroscopy of the absolute rate constants for hydrogen abstraction from NHPI by alkoxyl and peroxyl radicals and from C−H bonds by PINO is in progress (G. F. Pedulli, et al.)

(14) Bravo, A.; Bjørsvik, H.-R.; Fontana, F.; Minisci, F.; Serri, A. *J. Org. Chem.* **1996**, *61*, 9409.

kcal mol^{-1}) and it is reflected also in alcohols and carboxylic acids (the BDE values for the O−H bonds in RO−H and R−C(=O)O−H are respectively 103 and 110 kcal mol^{-1}).

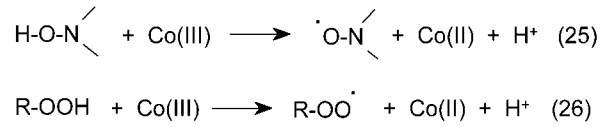
However, a more plausible explanation, in our opinion, can be due to a more complex mechanism, characterized by a superimposition of a redox chain (which represents the other function of the Co salt beside eqs 14 and 15) to the free-radical chain of eqs 16−18.

The imide can be, in fact, obtained from the hydroperoxide by loss of water,[15] but more probably by a redox chain according to eqs 22−24.

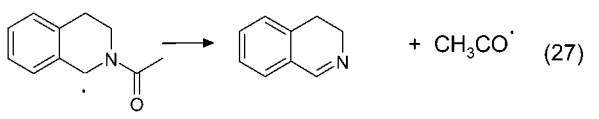


Co(III), formed in eqs 22 and 24, can be reduced to Co(II) either by NHPI (eq 25) or by the hydroperoxide (eq 26) formed in eqs 18 and 24, generating a redox chain.

Reaction 22 shifts the equilibrium of eq 20 to the right by decomposing the hydroperoxide; the alkoxyl radical reacts with NHPI (eq 23) much faster than the peroxyl radical (eq 18) for enthalpic reasons (eq 23 is more exothermic than eq 18 by about 15 kcal mol^{-1}), generating an effective chain process by the combination of eqs 16−18 and 22−26.



In any case, for this mechanism to be effective, hydrogen abstraction from C−H bonds always has to be faster by PINO than by the peroxyl radical, as above-discussed, and hydrogen abstraction by the alkoxyl radical must be much faster from NHPI than from C−H bonds.[13] The only byproduct, formed in small amounts in the oxidation of *N*-acetyltetrahydroisoquinoline, is the dihydroisoquinoline, very likely arising from the competitive β-scission of the benzylic radical (eq 27) at low oxygen concentration.



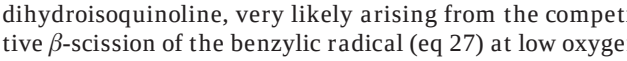
***N*-Benzylacetamides.** The oxidation of *N*-benzylacetamides leads either to imides and minor amounts of aromatic aldehydes at room temperature or to carboxylic acids and variable amounts of imides, depending on the reaction solvent, at higher temperature (60−100 °C) (Table 2).

Table 2. Oxidation of *N*-Benzylacetamides, $ArCH_2NHCOCH_3$, by O_2 in CH_3CN or AcOH

run	Ar	solvent	*T* (°C)	*t* (h)	conv (%)	products selectivity (%)
1	Ph[a]	CH_3CN	20	4	89	ArCHO (21) $ArCONHCOCH_3$ (77)
2	Ph	CH_3CN	60	5	43	ArCOOH (42) $ArCONHCOCH_3$ (56)
3	Ph	AcOH	100	2.5	75	ArCOOH (96) $ArCONHCOCH_3$ (3)
4	*p*-$CH_3C_6H_4$[a]	CH_3CN	20	4	92	ArCHO (24) $ArCONHCOCH_3$ (73)
5	*p*-$CH_3C_6H_4$	CH_3CN	80	5	65	ArCOOH (38) $ArCONHCOCH_3$ (60)
6	*p*-$CH_3C_6H_4$	AcOH	100	3	91	ArCOOH (93) $ArCONHCOCH_3$ (4)
7	*m*-$CH_3C_6H_4$[a]	CH_3CN	20	4	88	ArCHO (22) $ArCONHCOCH_3$ (76)
8	*m*-$CH_3C_6H_4$	CH_3CN	80	5	71	ArCOOH (35) $ArCONHCOCH_3$ (62)
9	*m*-$CH_3C_6H_4$	ACOH	100	3	93	ArCOOH (89) $ArCONHCOCH_3$ (8)
10	*p*-$CH_3OC_6H_4$[a]	CH_3CN	20	2	97	ArCHO (16) $ArCONHCOCH_3$ (82)
11	*p*-$CH_3OC_6H_4$	CH_3CN	80	2	96	ArCHO (11) ArCOOH (35) $ArCONHCOCH_3$ (49)
12	*p*-$CH_3OC_6H_4$	AcOH	100	1	97	ArCHO (13) ArCOOH (82) $ArCONHCOCH_3$ (3)
13	*p*-ClC_6H_4[a]	CH_3CN	20	4	87	ArCHO (19) $ArCONHCOCH_3$ (78)
14	*p*-ClC_6H_4	CH_3CN	80	5	86	ArCOOH (30) $ArCONHCOCH_3$ (64)
15	*p*-ClC_6H_4	AcOH	100	2	92	ArCOOH (66) $ArCONHCOCH_3$ (32)

[a] 0.25 mmol of *m*-chlorobenzoic acid was utilized for 5 mmol of *N*-benzyl derivative. The oxidation of $PhCH(CH_3)NHCOCH_3$ under all the conditions reported in this table always gives $PhCOCH_3$ with selectivity >90%.

The oxidation, catalyzed by NHPI and $Co(OAc)_2$, takes place at room temperature in CH_3CN only in the presence of a catalytic amount of *m*-chlorobenzoic acid, which avoids the precipitation of the cobalt salt, necessary for the oxidation to occur, as already observed for the oxidation of alcohols.[2,3] Moreover, Co benzoates appear to be more efficient in the redox decomposition of the hydroperoxides.[1] The formation of imides can be explained by the same mechanism above-discussed for cyclic amides; the formation of the aldehyde is clearly due to the hydrolysis of the hydroxyamide (eq 28), formed in eq 23, in competition with its further oxidation according to eq 24.



Acetamide is, in fact, a byproduct of the oxidation; its formation together with that of the aldehyde supports the oxidation mechanism leading to imides (eqs 16−18 and 22−26). No appreciable amount of carboxylic acid is formed under these conditions, meaning that the *N*-benzylamide is more reactive than the corresponding aromatic aldehyde. We[16] have recently observed a similar behavior in the oxidation of *N*-benzylamides by H_2O_2 catalyzed by Br_2; the aldehyde is the main reaction product because the strong acidic medium, due to the

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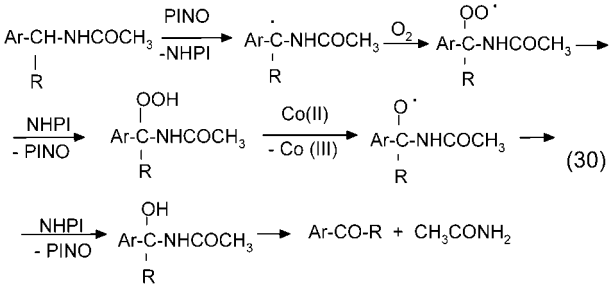
formation of HBr, catalyzes the hydrolysis according to eq 28. Bromine atom is the hydrogen-abstracting species that determines the selectivity of the oxidation, suggesting that also in this case the *N*-benzylamide is more reactive than the corresponding aromatic aldehyde.

The enthalpic effect is quite similar for hydrogen abstraction from *N*-benzylamide and aromatic aldehyde (BDE is about 87 kcal mol^{-1} for both ArCH(NH-$COCH_3$)−H and ArCO−H) and the polar effect, due to the electrophilic character of the bromine atom and the PINO radical (eq 16), determines the selectivity by making the benzylamide more reactive than the aldehyde.

The oxidation takes place at higher temperatures (60−100 °C) also in the absence of *m*-chlorobenzoic acid in CH_3CN or in AcOH solution. Under these more drastic conditions, aldehydes are oxidized to carboxylic acids and the reaction products are mixtures of carboxylic acids and imides; the former prevail in AcOH solution at 100 °C, the latter in CH_3CN solution at 60−80 °C. The higher temperature and the acidic medium favor the hydrolysis according to eq 28, thus increasing the amount of carboxylic acid. Since the imide can be easily converted into the carboxylic acid by hydrolysis catalyzed by a strong acid (eq 29), high yields in carboxylic acids can be obtained from benzylamines by this oxidation method.

$$\text{Ar-CONH-COCH}_3 + \text{H}_2\text{O} + \text{H}^+ \rightarrow \text{Ar-COOH} + \text{CH}_3\text{COOH} + \text{NH}_4^+ \quad (29)$$

Secondary *N*-benzylamides give selectively the corresponding ketones and acetamide (eq 30).



This result is good evidence supporting the mechanism for the imide formation (eqs 16−18 and 22−26).

***N*-Alkylacetamides.** Two aspects of the oxidation of *N*-alkylacetamides are different from that of *N*-benzylacetamides (Table 3): (a) No traces of aldehyde are formed in CH_3CN at room temperature, even at low conversion, but the imide and the carboxylic acid are the reaction products when a primary alkyl group is involved. Also in this case, the hydrolysis of the imide according to eq 29 gives high yields in carboxylic acid, and the overall process represents a simple and cheap way to transform an alkylamine into a carboxylic acid.

The absence of the aldehyde, even at low conversion, suggests that the aldehyde is much more reactive than the starting amide. This is due to the fact that the selectivity in hydrogen abstraction by PINO (eq 16), contrary to the behavior of the benzyl derivatives, is governed in this case by the enthalpic effect (BDE for the CONHC−H bond is 6−8 kcal mol^{-1} higher than for RCO−H), which makes the aldehyde much more reactive than the amide.

Table 3. Oxidation of *N*-Alkylacetamides, $RNHCOCH_3$, by O_2 in CH_3CN

run	R	*T* (°C)	t (h)	conv (%)	products selectivity (%)
1	*n*-hexyl[a]	20	5	70	*n*-C_4H_9COOH (4) *n*-$C_5H_{11}COOH$ (15) *n*-$C_5H_{11}CONHCOCH_3$ (67)
2	*n*-hexyl	80	4	98	*n*-C_4H_9COOH (14) *n*-$C_5H_{11}COOH$ (13) *n*-$C_5H_{11}CONHCOCH_3$ (68)
3	*n*-dodecyl[a]	20	5	74	*n*-$C_{10}H_{21}COOH$ (2) *n*-$C_{11}H_{23}COOH$ (8) *n*-$C_{11}H_{23}CONHCOCH_3$ (81)
4	*n*-dodecyl	80	6	97	*n*-$C_{10}H_{21}COOH$ (6) *n*-$C_{11}H_{23}COOH$ (11) *n*-$C_{11}H_{23}CONHCOCH_3$ (81)
5	cyclohexyl	80	4	60	cyclohexanone (98)

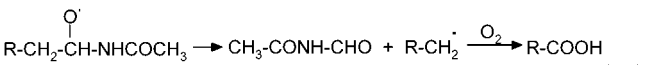
[a] 0.25 mmol of *m*-chlorobenzoic acid was utilized for 5 mmol of amide.

The same behavior was observed in the oxidation of primary alcohols by O_2 with NHPI catalysis; the benzyl alcohol selectively gives the aldehyde while nonbenzylic alcohols give carboxylic acids. The oxidation selectivity of the former is governed by the polar effect, while the enthalpic effect is dominant for the latter.[3]

This behavior appears to be general when hydrogen abstraction by an electrophilic radical is involved in the oxidation. The same selectivity was, in fact, observed in the oxidation of alcohols, ethers, and amides by H_2O_2 with Br_2 catalysis, where the bromine atom is the hydrogen-abstracting species: benzyl derivatives selectively give aldehydes, while carboxylic acids and esters are formed with nonbenzylic derivatives.[16−18]

When a secondary alkyl group is involved in the oxidation of alkylamides, the corresponding ketones are obtained according to eq 30 for both benzylic and nonbenzylic amides.

(b) At higher temperatures (80−100 °C) in CH_3CN or AcOH, the oxidation always leads to a mixture of imides and carboxylic acids, as in point (a), but the amount of carboxylic acids significantly increases and above all, in addition to carboxylic acids corresponding to the alkyl groups ($RCH_2CH_{2-} \rightarrow RCH_2COOH$), also the carboxylic acid showing loss of a carbon atom is formed ($RCH_2CH_2- \rightarrow RCOOH$). The plausible explanation for the formation of the latter is related, in our opinion, to the β-scission of the alkoxy radical (eq 31) formed in eq 22 in competition with hydrogen abstraction from NHPI (eq 23).



This β-scission is more favored by an increase in temperature and by a protic solvent[19] than hydrogen abstraction, and the result represents a further significant support for the oxidation mechanism (eqs 16−18 and 22−26).

Experimental Section

All the starting materials and the catalysts (*N*-hydroxyphthalimide and $Co(OAc)_2$) were obtained from commercial sources and used as such.

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General Procedures. Method A. A solution of the amide (5 mmol), *N*-hydroxyphthalimide (0.5 mmol), and $Co(OAc)_2$ (0.025 mmol) in 10 mL of the solvent (CH_3CN or AcOH) was placed in a three-necked flask under an atmosphere of O_2. The solution was stirred at the temperatures and for the times reported in Tables 1−3. The catalyst was removed through silica gel and the solution was analyzed by gas chromatography by using the internal standard technique. All the reaction products were known and were identified by GC−MS spectra and comparison with authentic samples. The results are reported in Tables 1−3.

Method B. The procedure is identical to method A with the difference that 0.25 mmol of *m*-chlorobenzoic acid was also added and the temperature was kept in all cases at 20 °C for the reaction times reported in Tables 1−3.

Most of the reaction products (aromatic aldehydes, aromatic and aliphatic carboxylic acids, cyclohexanone, succinimide) are well-known, common commercial products. The acetylbenzoylamines (MeCONH−CO−Ar, Table 2) were prepared according to the procedure reported by Tanaka et al.[20] The aliphatic imides (RCONH−COMe) were prepared according to a known procedure.[21] Cyclic imides obtained in runs 1, 3, and 5 of Table 1 were prepared respectively according to the known procedures.[22−24]

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