Reaction of 1, 2, and 3 with Amines. To a stirred solution containing 200 mL of the appropriate amine under nitrogen was added somamide (0.05 mol), and the mixture was stirred for 15 min. Haloarene **1**, **2**, or **3** (0.025 mol) was added, and the mixture was stirred at room temperature, in the case of modest sized amines, or at refluxing temperatures, in the case of bulky amines. The progress of the reaction was monitored by analyzing small aliquots (ca. 0.5 mL), taken periodically from the reaction mixture, by GLC analysis. After the reaction was complete (0.5-1 h), 2 mL of methanol and 75 mL of methylene chloride were added succesively, and the resulting mixture was stirred vigorously for 10 min and then filtered through a medium-sized fritted glass funnel. The mother liquor was concentrated (rotary evaporator) to yield an oil from which the amine products were obtained by flash chromatography (19:1 hexane/methylene chloride).

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Supplementary Material Available: Elemental analyses and IR, ^{1}H NMR, ^{13}C NMR, and MS spectral data for amines **7**–**13**, **15**, and **17** (20 pages). Ordering information is given on any current masthead page.

Enol Form of 2,3-Butadione (Biacetyl)[1]

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Information concerning keto–enol equilibria in aqueous solutions of 1,2-diketones[3] is much more limited than for 1,3-diketones. Existing data show an unusual relationship between the structure of the diketone and the extent of the enolization. Spectrophotometry[3c,d,4] and NMR spectra[4,5] indicate that biacetyl exists in aqueous solutions predominantly (more than 99%) in the diketo form, with one keto group about 77% hydrated,[3f] while 1,2-cyclohexanedione is present 60% in the enol form, 39% in the monohydrate form and less than 1% in the free diketo form.[3e] For 1,2-cyclopentanedione the content of the enol form is somewhat smaller;[3a] 1,2-cycloheptadione[3b] on the other hand is present in more than 98% in the diketo form and resembles straight-chain diones. No quantitative information was available for the pK value corresponding to the formation of a carbanion–enolate. In the course of investigation of the reaction of biacetyl with arginine,[6] which is useful both for determination of guanidine groups in biological materials and for the synthetic use of biacetyl for protecting such groups, the understanding of the nature of the species predominating in individual pH ranges became important.

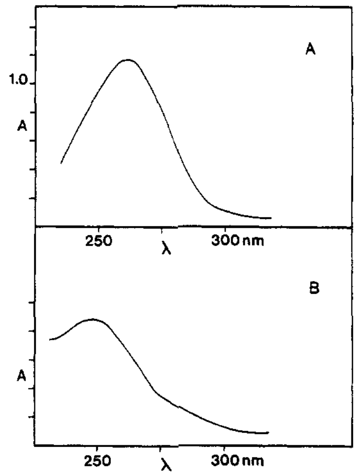
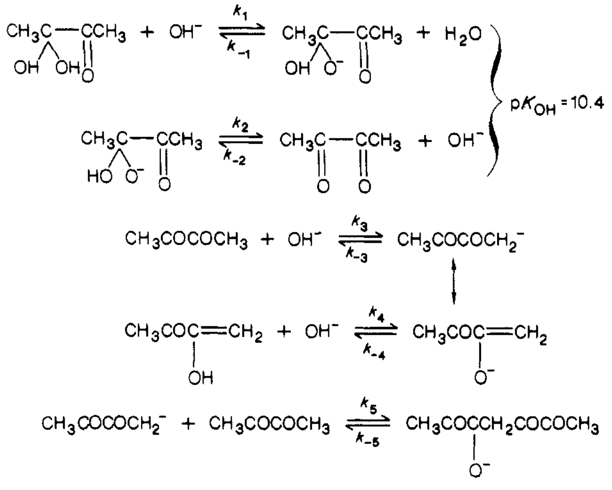


Figure 1. Electronic spectra of (A) 0.5 mM 2-hydroxy-1-cyclohexen-3-one in 0.01 M HCl and (B) 1.96 mM biacetyl in 0.1 M NaOH neutralized after 120 s to pH 3.2 by addition of phosphoric acid.

Decrease of absorption spectra of biacetyl or polarographic limiting currents with increasing pH indicated formation of a carbanion–enolate with pK_a = 13.8. This reaction (eq 3 and 4) is preceded by base-catalyzed dehydration (eq 1 and 2). Carbanion–enolate present undergoes subsequently aldolization (eq 5). Rates of all reactions studied increased with pH. Polarographic data[4] indicate that base catalyzed dehydration (eq 1 and 2) has a half-life of less than 1 s and occurs rapidly when compared with subsequent reactions. Formation of the carbanion in reaction 3 has in 1 M NaOH a half-life about 10 s, consecutive aldolization in the same solution containing 2 × 10^{-4} M biacetyl has a half-life of about 20 min.



$$CH_3C(OH)_2-\overset{O}{\overset{\|}{C}}CH_3 + OH^- \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} CH_3C(OH)(O^-)-\overset{O}{\overset{\|}{C}}CH_3 + H_2O \quad (1)$$

$$CH_3C(OH)(O^-)-\overset{O}{\overset{\|}{C}}CH_3 \underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} CH_3\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}CH_3 + OH^- \quad (2)$$

$$pK_{OH} = 10.4 \quad (1),(2)$$

$$CH_3COCOCH_3 + OH^- \underset{k_{-3}}{\overset{k_3}{\rightleftharpoons}} CH_3COCOCH_2^- \quad (3)$$

$$CH_3CO\underset{OH}{C}{=}CH_2 + OH^- \underset{k_{-4}}{\overset{k_4}{\rightleftharpoons}} CH_3CO\underset{O^-}{C}{=}CH_2 \quad (4)$$

$$CH_3COCOCH_2^- + CH_3COCOCH_3 \underset{k_{-5}}{\overset{k_5}{\rightleftharpoons}} CH_3CO\underset{O^-}{C}CH_2COCOCH_3 \quad (5)$$

Formation of the carbanion–enolate in eq 3, which can produce the desired enol after acidification, was measured from the increase of the carbanion–enolate absorption band at 250 nm, from the decrease of polarographic limiting current of biacetyl and from the increase in concentration of the monoenol species determined by bromometric titration after acidification of biacetyl solution in 0.01 M NaOH after chosen time intervals. Reaction was proved to be first order in biacetyl and first in hydroxide ions with second-order rate constant (k_3 + k_{-3}) of about 3 × 10^{-3} L mol^{-1} s^{-1}.

Understanding of the details of the processes involved made it possible to prepare solutions containing the biacetyl partly in the monoenol–monoketo form. The enol form was produced and identified after acidification. Alkaline conversion to carbanion–enolate was most effective at low concentrations of biacetyl (less than 10^{-3} M) and low sodium hydroxide concentration (0.01–0.1 M), as under such conditions the second order reaction 5 was least

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[1] Partly based on M.Sc. Thesis of N.S., Clarkson College of Technology, Potsdam, NY, 1978.

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[3] (a) Schwarzenbach, G.; Wittwer, Ch. *Helv. Chim. Acta* **1974**, *30*, 663, 669. (b) Hesse, G. *Ann. Chem.* **1955**, *593*, 35, 42. (c) Bakule, R.; Long, F. A. *J. Am. Chem. Soc.* **1963**, *85*, 2309. (d) Long, F. A.; Bakule, R. *Ibid.* **1963**, *85*, 2313. (e) Segretario, J. P.; Sleszynski, N.; Zuman, P. *J. Electroanal. Chem. Interfacial Electrochem.* **1986**, *214*, 259. (f) Segretario, J. P.; Sleszynski, N.; Partch, R. E.; Zuman, P.; Horak, V. *J. Org. Chem.* **1986**, *51*, 5393.

[4] Segretario, J. P. Ph.D. Thesis, Clarkson College of Technology, Potsdam, NY, 1982.

[5] (a) Greenzaid, P.; Rapport, Z.; Samuel, D. *Trans. Faraday Soc.* **1967**, *63*, 2131. (b) Hooper, D. L. *J. Chem. Soc. B.* **1967**, 169.

[6] Veivia, D., M.S. Thesis, Clarkson University, Potsdam, NY, 1985.

0022-3263/87/1952-2622$01.50/0

competing. Detection was carried out spectrophotometrically from the enol band at 250 nm, which resembles strongly that of 2-hydroxy-1-cyclohexen-3-one (Figure 1) and by bromometric titration. Assuming similarity of molar absorptivity of the band at 250 nm and that of 2-hydroxy-1-cyclohexen-3-one both methods gave similar results for the enol content, varying from 10% to 30% depending on the sodium hydroxide concentration and time of quenching. At pH 3 the conversion of the monoenol to diketo form takes place during tens of hours, similarly as was observed[3a] for the cyclic monoenols.

Clearly, the combination of polarography and spectrophotometry is a powerful tool in the study of these complex equilibria. We are currently trying to utilize our understanding of these equilibria in attemps to isolate the enol form of biacetyl proved in acidic solutions and to study other 1,2-diketones in this manner.

Experimental Section

Biacetyl (Eastman Organic Chemicals) was used as received. Sodium hydroxide and chemicals used for buffer preparation were reagent grade. Acetonitrile, Me_2SO, and DMF were "Baker Analyzed" reagent grade solvents.

Spectra were recorded at 25 °C on a Unicam SP800A UV-vis spectrophotometer. Polarograms were recorded on a Sargent-Welch Model XVI polarograph in a two-electrode configuration with liquid junction (Kalousek cell), with SCE and a DME with $m = 3.02$ mg s^{-1} and $t_1 = 4.62$ s at $h = 60$ cm. Potentiometric bromometric titrations were carried out with a Pt-electrode.

Stock solutions (0.025 M) of biacetyl in acetonitrile were added to deaerated solutions of a buffer or sodium hydroxide so that the final concentration for spectroscopy or polarography was 5×10^{-4} M and that of acetonitrile 2%. For obtaining the values of pK_{OH} and pK_a measured absorbance or limiting current were extrapolated to $t = 0$. For kinetic studies of carbanion formation, absorbance at 250 nm or polarographic limiting current were measured continuously as a function of time by using cells as reactors. The first measurement was carried out about 30 s after mixing.

To produce the enol form of biacetyl a stock solution of the compound was transferred into 0.01–0.1 M NaOH so that final biacetyl concentration was lower than 1×10^{-3} M. After a time period chosen from kinetic experiments known, an amount of phosphoric acid was added so that the resulting pH was 3.2. An absorption band at 250 nm was used as a measure of enol content of the reaction mixture. Alternatively, an aliquot of this solution was titrated potentiometrically by bromine at 0 °C. As the establishment of the enol–keto equilibrium at pH 3.2 takes several hours, the results of the bromometric titrations were well reproducible even at 25 °C and independent of sampling time within 30 min after acidification. The enol form was not extracted into hexane, carbon tetrachloride, chloroform, or diethyl ether.

Registry No. Biacetyl, 431-03-8; 2-hydroxy-1-cyclohexen-3-one, 10316-66-2.

Cobalt-Catalyzed Normal Pressure Carbonylation of Aryl Halides. Notable Solvent Effects on the Ratio of Mono- to Double-Carbonylation

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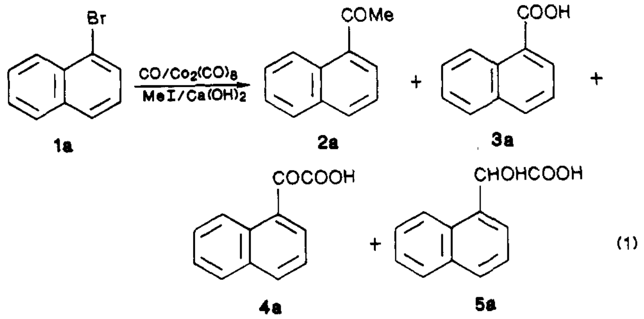
Transition-metal-catalyzed carbonylation of alkyl and aryl halides often gives a mixture of mono- and double-carbonylated products, the composition being influenced by many variables.[1,2] Recently, Foa and his co-workers have demonstrated that in the presence of base alkyltetracarbonylcobalt can catalyze carbonylation of aryl halides in aliphatic alcohols under a normal pressure of carbon monoxide to produce either the corresponding ester or the α-keto acid as the predominant product, depending on the identity of the base employed.[3] In direct contrast, we discovered that the carbonylation of 1-bromonaphthalene (**1a**) catalyzed by methyltetracarbonylcobalt generated in situ in aqueous organic solvents in the presence of sodium hydroxide, gives 1-acetylnaphthalene (**2a**) together with 1-naphthoic acid (**3a**).[4] When the carbonylation is performed in the presence of calcium hydroxide in 3:1 dioxane–water, however, 1-naphthylglyoxylic acid (**4a**) is obtained predominantly.[4b]

In this paper we report our findings that in the cobalt-catalyzed carbonylation of aryl halides using calcium hydroxide as the base in aqueous organic solvents, both the identity of the solvent and the content of water are the drastic factors detertmining the product composition.

Results and Discussion

The carbonylation of 1-bromonaphthalene (**1a**) with 0.3 equiv of $Co_2(CO)_8$ in the presence of methyl iodide (10 equiv) and calcium hydroxide (25 equiv) was undertaken at room temperature under a normal pressure of carbon monoxide for 20 h. When the reaction was performed in dioxane–water (1:1, v/v), 1-naphthoic acid (**3a**) was obtained in 37% yield together with 1-acetylnaphthalene (**2a**, 10%), 1-naphthylglyoxylic acid (**4a**, 15%), and 1-naphthylglycolic acid (**5a**, 3%) (eq 1 and Table I). In direct contrast, the reaction in 3:1 dioxane–H_2O gave predominantly **4a** (52%) together with **2a** (1%) and **3a** (8%). In the reaction in 3:1 tetrahydrofuran (THF)–H_2O, **4a** was the major product also. The reaction in 3:1



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[1] (a) Alper, H.; Des Abbeyes, H. *J. Organomet. Chem.* **1977**, *134*, C11. (b) Des Abbayes, H.; Buloup, A. *J. Chem. Soc., Chem. Commun.* **1978**, 1090. (c) Perron, R. U.S. Pat. 4 152 352, 1979. (d) El-Chahawi, M.; Brit. Pat. 2026478A, 1979. (e) Francalanci, F.; Foa, M. *J. Organomet. Chem.* **1982**, *232*, 59. (f) Hirai, H.; Ojima, I. Jpn. Pat. 85-61550, 1985. (g) Kashimura, T.; Kudo, K.; Mori, S.; Sugita, N. *Chem. Lett.* **1986**, 483.

[2] (a) Ozawa, F.; Soyama, H.; Yamamoto, T.; Yamamoto, A.; *Tetrahedron Lett.* **1982**, *23*, 3833. (b) Kobayashi, T.; Tanaka, M. *J. Organomet. Chem.* **1982**, *233*, C64. (c) Ozawa, F.; Soyama, H.; Yanagihara, H.; Aoyama, I.; Takino, H.; Izawa, K.; Yamamoto, T.; Yamamoto, A. *J. Am. Chem. Soc.* **1985**, *107*, 3245. (d) Tanaka, M; Kobayashi, T.; Sakakura, T.; Itatani, H.; Danno, S.; Zushi, K. *J. Mol. Catal.* **1985**, *32*, 115. (e) Ozawa, F.; Kawasaki, N.; Yamamoto, T.; Yamamoto, A. *Chem. Lett.* **1985**, 567. (f) Tanaka, M.; Kobayashi, T.; Sakakura, T. *J. Chem. Soc., Chem. Commun.* **1985**, 837.

[3] (a) Foa, M.; Francalanci, F.; Bencini, E.; Gardano, A. *J. Organomet. Chem.* **1985**, *285*, 293. (b) Francalanci, F.; Bencini, E.; Gardano, A.; Vincenti, M.; Foa, M. *J. Organomet. Chem.* **1986**, *301*, C27.

[4] (a) Miura, M.; Akase, F.; Nomura, M. *J. Chem. Soc., Chem. Commun.* **1986**, 241. (b) Miura, M.; Akase, F.; Shinohara, M.; Nomura, M. *J. Chem. Soc., Perkin Trans. 1*, in press.