and then acetone, and dried under high vacuum (2 g, 11.3 mmol, 67%): λ_{max} (0.1 *N* KOH) 250 mμ (ε 1.72 × 10^4), 354 (7.17 × 10^3). *Anal.* Calcd for $C_7H_7N_5O$: C, 47.5; H, 3.95; N, 39.5. Found: C, 47.3; H, 4.08; N, 39.9.

2-Amino-4-hydroxy-6-phenylpteridine.—2,4,5-Triamino-6-hydroxypyrimidine sulfate (2.0 g, 8.4 mmol) was suspended in 30 ml of H_2O, and $BaCl_2\cdot2H_2O$ (2.0 g, 8.4 mmol) was added. The solution was stirred for 10 min and filtered. The filtrate was adjusted to a pH of 4.0 with sodium acetate. Phenyl glyoxal (1.1 g, 8.2 mmol) was dissolved in 10 ml of methanol and added to the pyrimidine solution. The resulting mixture was heated on the steam bath for 3 hr. The pale yellow precipitate was collected on a sintered-glass filter and washed with water. This material, pure **2a** by pmr analysis, was dissolved in a minimum amount of 1 *M* sodium hydroxide and the sodium salt was precipitated with 10 *M* sodium hydroxide. The sodium salt was dissolved in a minimum amount of hot 1 *M* sodium hydroxide and cooled overnight. This pale yellow material was taken up in water and the solution was brought to neutrality with acetic acid. The pale yellow precipitate was collected by vacuum filtration, washed with water and acetone, and dried at high vacuum (0.85 g, 3.5 mmol, 41%): λ_{max} (0.1 *M* NaOH) 270 mμ (ε 2.38 × 10^4), 377 (1.00 × 10^4). *Anal.* Calcd for $C_{12}H_9N_5O$: C, 60.3; H, 3.8; N, 29.3. Found: C, 60.0; H, 3.9; N, 29.6.

2-Amino-4-hydroxy-7-phenylpteridine.—2,4,5-Triamino-6-hydroxypyrimidine (4 g, 16.8 mmol) was suspended in 60 ml of H_2O, and $BaCl_2\cdot2H_2O$ (4 g, 16.8 mmol) was added. The solution was stirred for 10 min and filtered. The pH of the filtrate was adjusted to 9.0 with 1 *M* sodium hydroxide. Phenyl glyoxal (2.2 g, 16.4 mmol) in 20 ml of methanol was added slowly, and the pH of the solution was kept above 8 with 1 *M* sodium hydroxide. The solution was stirred for 2 hr at room temperature and the pH was adjusted to neutrality with acetic acid. The precipitate was collected by vacuum filtration and washed with water and acetone. This material was pure **2b** by pmr analysis. The filter cake was suspended in 100 ml of hot dimethylformamide and concentrated hydrochloric acid was added until all the material dissolved. The solution was allowed to cool to room temperature and placed in the cold overnight. The crystals were collected by vacuum filtration and taken up in water, the pH was adjusted to neutrality, and the precipitate was collected by vacuum filtration and washed with water and acetone (1.60 g, 6.8 mmol, 41%): λ_{max} (0.1 *M* NaOH) 236 mμ (ε 1.97 × 10^4), 265 (2.00 × 10^1), 374 (1.28 × 10^4). *Anal.* Calcd for $C_{12}H_9N_5O$: C, 60.3; H, 3.8; N, 29.3. Found: C, 59.9; H, 3.9; N, 29.5.

Registry No.—**2a**, 25846-86-0; **2b**, 32136-35-9; **2c**, 13165-98-5; **2d**, 13040-58-9.

Novel Imidazole Ring Formation from α Olefins, Carbon Monoxide, and Ammonia

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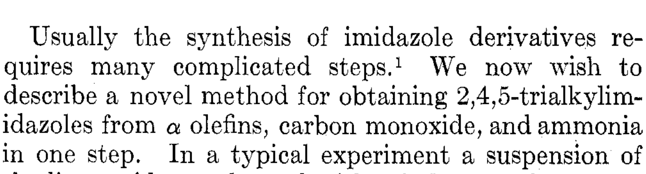
Rhodium-catalyzed reactions of α olefins with carbon monoxide and concentrated aqueous ammonia give 2,4,5-trialkylimidazoles in one step and in 50–60% yields. When dilute aqueous ammonia was used, an *N*-acyl α-amino ketone intermediate was isolated.

Usually the synthesis of imidazole derivatives requires many complicated steps.[1] We now wish to describe a novel method for obtaining 2,4,5-trialkylimidazoles from α olefins, carbon monoxide, and ammonia in one step. In a typical experiment a suspension of rhodium oxide was heated with ethylene, carbon monoxide, and ammonia at 150° for several hours. From the reaction mixture, 2,4,5-triethylimidazole and propionamide were obtained in 52 and 15% yields, respectively.

When a dilute ammonia solution is used in the reaction of ethylene with carbon monoxide, *N*-propionyl-3-amino-4-hexanone was obtained in 40% yield in addition to a small amount of triethylimidazole. The formation of the amino ketone was confirmed by ir, mass spectra, nmr (three ethyl groups and a methine proton, δ 4.5, of the asymmetric carbon), and elemental analysis of the 2,4-dinitrophenylhydrazone derivatives. The analysis of gas remaining in the reactor after completion of the reaction showed the presence of carbon dioxide and a little ethylene. From these results, the reaction may be described as follows.



In these reactions, the ring carbons of the imidazole ring and the asymmetric carbon of the ketoamide group apparently arise from carbon monoxide. These carbons are probably introduced as carbonyl groups first and then reduced with the aid of the rhodium catalyst.

It is well known that cobalt and rhodium carbonyls are the active catalysts in the carbonylation reaction,[2] and Heck has suggested that $HM(CO)_3$ (M = Co, Rh) is the active species in the catalytic carbonylation.[3]

However, cobalt carbonyl has not shown any catalytic activity for the formation of imidazole rings.

Furthermore, one of the present authors has shown recently that carbon monoxide is easily oxidized to carbon dioxide by a rhodium complex.[4] On the basis of these results, the formation of $HRh(CO)_3$ is assumed to occur as shown below. A similar mechanism of

$$\tfrac{1}{2}Rh_4(CO)_{12} + H_2O + CO \longrightarrow 2HRh(CO)_3 + CO_2$$

hydrorhodium carbonyl formation is found in the reaction of ethylene with carbon monoxide.[5]

Thus, $HRh(CO)_3$ adds to olefin to give an σ-alkyl rhodium carbonyl, which rearranges to an acyl rhodium complex and dimerized to yield an α diketone as reported by Tsutsumi.[6]

(1) K. Hofmann, "The Chemistry of Heterocyclic Compounds," Interscience, New York, N. Y., 1953.

(2) C. W. Bird, "Transition Metal Intermediates in Organic Synthesis," Logos Press, London, 1967.

(3) R. F. Heck, "Mechanism of Inorganic Reactions," American Chemical Society, Washington, D. C., 1965.

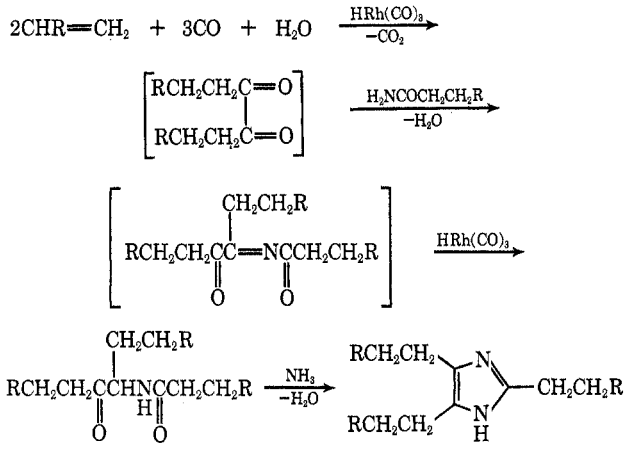
(4) Y. Iwashita and A. Hayata, *J. Amer. Chem. Soc.*, **91**, 2525 (1969).

(5) Y. Iwashita and M. Sakuraba, *Tetrahedron Lett.*, 2409 (1971).

(6) M. Ryang, S. Kwang-Myeong, Y. Sawa, and S. Tsutsumi, *J. Organometal. Chem.*, **5**, 305 (1966).

From these discussions Scheme I is suggested. This reaction course was supported by the formation of 2,4-diethyl-5-methylimidazole from pentane-2,3-dione and propionamide under a similar reaction condition.

SCHEME I



The multifunctional activity of rhodium, as a carbonylation catalyst in the first stage of the reaction and subsequently as a reduction catalyst, make the one-step imidazole ring formation possible from olefins, carbon monoxide, and ammonia.

Application of this reaction to propylene and 1-butene gives 2,4,5-tripropylimidazole in 59% and 2,4,5-tributylimidazole in 40% yields, respectively.

However, cyclohexene gives cyclohexanecarbonamide, *N*,*N*-di(cyclohexylmethyl)formamide, *N*,*N*-di(cyclohexylmethyl)methylamine, and tri(cyclohexylmethyl)-amine, as shown in Scheme II. The reaction products are similar to those obtained by reaction of cyclohexene with carbon monoxide and ammonia in the presence of cobalt carbonyl.[7] This fact is considered to be due to the difference of reactivity between terminal and internal olefins.

Experimental Section

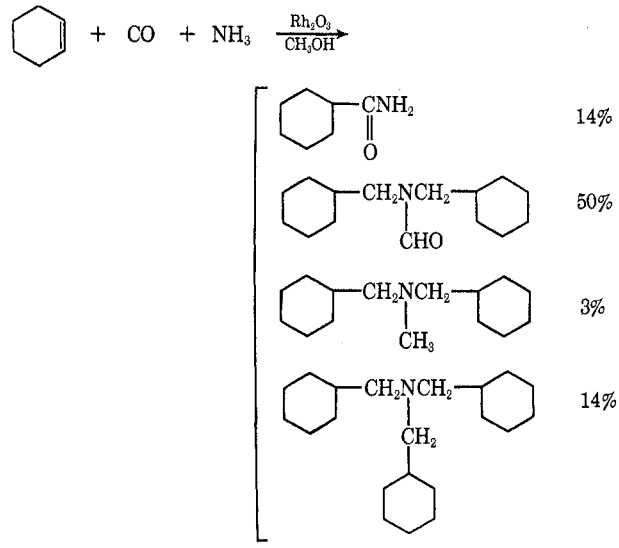
2,4,5-Trialkylimidazole Derivatives.—Rhodium oxide (50 mg) was suspended in aqueous methanol and placed in a 300-ml stainless steel autoclave. Propylene (32 g), ammonia (17 g), and carbon monoxide (250 kg/cm²) were introduced and the reaction was carried out at 150° for 5 hr. From the reaction mixture, 2,4,5-tripropylimidazole (29.3 g) was obtained by distillation, bp 125° (1 mm), in 59% yield.

Identification was made from its mass (*m/e* 194, 179, 165), uv [(C_2H_5OH) λ_{max} 220 and 278 nm], ir, and nmr spectra.

Anal. Calcd for $C_{12}H_{22}N_2$: C, 74.17; H, 11.41; N, 14.42. Found: C, 74.20; H, 11.64; N, 14.32.

(7) V. A. Striegler and J. Weber, *J. Prakt. Chem.*, **4**, 281 (1965).

SCHEME II



The same procedure was applied for ethylene and 1-butene, and 2,4,5-triethylimidazole, bp 119–123° (1 mm), and 2,4,5-tributylimidazole, bp 142–148° (0.6 mm), were obtained, in 59 and 52% yield, respectively.

Identification of 2,4,5-triethylimidazole was made from the mass (*m/e* 152, 137, and 123), uv, nmr (three different ethyl groups), and ir spectra.

Anal. Calcd for $C_9H_{16}N_2$: C, 70.99; H, 10.61; N, 18.40. Found: C, 70.91; H, 10.92; N, 18.30.

***N*-Propionyl-3-amino-4-hexanone.**—Methanol (40 ml) and 28% ammonia aqueous solution (15 ml), in which rhodium oxide (50 mg) was suspended, were placed in a 100-ml stainless steel autoclave. In the reactor ethylene (0.33 mol) and carbon monoxide (260 kg/cm²) were introduced and this vessel was heated for 4 hr at 130° (pressure drop about 200 kg). By distillation [117–125° (1 mm)], *N*-propionyl-3-amino-4-hexanone (7.6 g) was obtained in 40% yield. Identification was done by ir (ester C=O 1720, amide C=O 1650 cm^{-1}) and nmr (described before) spectra, and elemental analysis as the 2,4-dinitrophenylhydrazone.

Anal. Calcd for $C_{15}H_{20}N_4O_9$: C 51.27; H, 6.02; N, 19.93. Found: C, 51.34; H, 6.17; N, 19.72.

Reaction of Pentane-2,3-dione with Propionamide.—Pentane-2,3-dione (30 g) and propionamide (20 g) were added to a methanolic ammonia solution, in which rhodium oxide (50 mg) was suspended, and were allowed to react at 150° for 10 hr under a pressure of 150 kg/cm² of carbon monoxide. 2,4-Diethyl-5-methylimidazole was obtained and identified by nmr and mass spectra (*m/e* 152, 137, 123) and elemental analysis.

Registry No.—Carbon monoxide, 630-08-0; ammonia, 7664-41-7; 2,4,5-tripropylimidazole, 32044-26-1; 2,4,5-triethylimidazole, 32044-27-2; 2,4,5-tributylimidazole, 32044-28-3; *N*-propionyl-3-amino-4-hexanone, 32044-29-4.

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