3. R. H. Saunders, USA Patent 2,996,537 (1961); Chem. Abstr., 55, 26448d (1961).
4. G. A. Shvekhgeimer and G. A. Mikheichev, Zh. Org. Khim., 30, No. 1, 30 (1971).
5. J. C. Hoffsommer, M. J. Kamlet, and J. C. Dacons, J. Org. Chem., 26, No. 12, 4881 (1961).
6. O. A. Luk'yanov and G. V. Pokhvisneva, Izv. Akad. Nauk SSSR, Ser. Khim., No. 11, 2540 (1991).

REACTIONS OF ARYL AND HETERYL IODIDES WITH TERMINAL ACETYLENES IN THE PRESENCE OF CO, CATALYZED BY PALLADIUM COMPLEXES

A. B. Ponomarev, M. V. Shostakovskii,
and V. N. Kalinin

UDC 542.97:547.538.241:547.539.4

The influence of the nature of the solvent, of the base, the catalyst, the temperature, and the pressure of CO on reactions of aryl and heteryl iodides RI with terminal acetylenes $R'C{\equiv}CH$ in the presence of CO, catalyzed by palladium complexes is studied.

Ethynyl ketones are important intermediate products in the synthesis of some heterocyclic compounds, for instance of pyrazoles. 1,3-Disubstituted 1-propyn-3-ones are obtained by the reaction of acid chlorides with the corresponding acetylenides of copper [1] and zinc [2], or with terminal acetylenes in the presence of copper iodide [3] and palladium complexes [4, 5], or by some other methods [6]. It has been shown in [7] that terminal acetylenes react with aryl, vinyl, and heteryl halides under a CO pressure in the presence of palladium complexes, giving the corresponding ethynyl ketones with good yields.

$$ArI + CO + RC{\equiv}CH \xrightarrow[Et_3N]{Pd\,(cat.)} ArCOC{\equiv}CR \qquad (1)$$

With the objective of determining the optimum conditions for these reactions we have studied the influence of various factors on the selectivity and yield of ethynyl ketones. The reaction of p-nitroiodobenzene (I) with phenylacetylene (II) was chosen as the model reaction. Table 1 shows that the yield of the carbonylation product depends strongly on the nature of the solvent used. In the reaction of (I) with (II) and CO (2 MPa) in the presence of 4 moles triethylamine (III) and 1 mole % $PdCl_2(CH_3CN)_2$ (IV) at 60°C the maximum yield of $p\text{-}NO_2C_6H_4COC{\equiv}CPh$ (V) was obtained when using benzene (69%) and chloroform (80%) as the solvent; the lowest yield of (V) was obtained in (III), HMPA, and DMF. It must be pointed out for comparison that the authors of [7] obtained (V) with a yield of 58% by carrying out the reaction of (I) with (II) and CO (2 MPa) in (III) at 100°C for 1.5 h.

A decrease in the temperature of the reaction of (I) with (II) to ~20°C (test 7) leads to a sharp decrease in the reaction rate: after 3 h the conversion of (I) was only 5%. No product (V) was obtained from (I) when the temperature was increased to 90°C (test 6); this can be attributed to its instability at the reaction conditions.

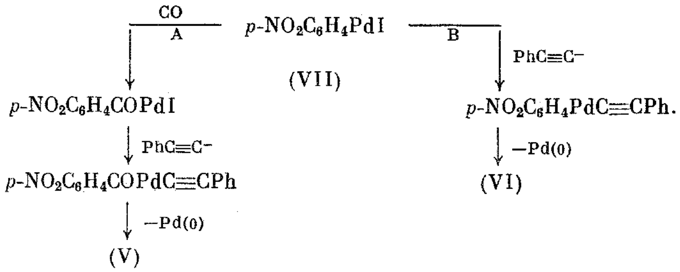
A decrease of the CO pressure from 2 to 0.1 MPa reduces the yield of (V) (tests 5, 8, 9); however, the cross-combination product $p\text{-}NO_2C_6H_4C{\equiv}CPh$ (VI) appears, related to the competition between the carbonylation of the intermediate complex (VII) [reaction (2), path A] and the substitution of iodine by an organic group (path B) (see scheme on following page).

A decrease in the CO concentration (due to a decrease in pressure) leads to an increase in the fraction of path B: at 0.1 MPa CO the yield of (VI) was 10% (Table 1). The use of

---

A. N. Nesmeyanov Institute of Heteroorganic Compounds, Academy of Sciences of the USSR, Moscow. Translated from Izvestiya Akademii Nauk SSSR, Seriya Khimicheskaya, No. 11, pp. 2548-2551, November, 1991. Original article submitted December 14, 1990.

0568-5230/91/4011-2224$12.50

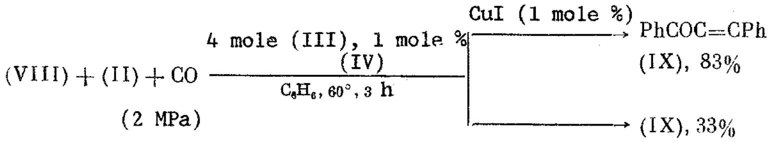


(2)

other amines (piperidine, pyridine) as the base in the reaction of (I) with (II) did not lead to the formation of (V) (tests 10, 11).

The influence of the nature of the catalyst was studied on the carbonylation of p-iodoanisole and (II). Table 2 shows that good results were obtained with all phosphine complexes except with $PdCl_2$(dppe) [where dppe is 1,2-bis(diphenylphosphino)ethane] and with the acetonitrile complex of palladium.

Reactions of different aryl and heteryl iodides with phenylacetylene and CO were carried out at the established conditions (Table 3). It is known that the addition of copper (I) accelerates the cross-combination of the terminal acetylenes with organic halides in the presence of palladium complexes [8]. It was found that in some instances the addition of copper(I) iodide in reaction (1) increased the yield of the carbonylation product (Table 3). For instance, in the reaction of PhI (VIII) with (II) in the presence of 1 mole % CuI the yield of (IX) was 83%, while in the absence of CuI it was only 33%.



(3)

It must be pointed out that the addition of CuI combined with the use of other solvents and catalysts leads to a significant shortening of the reaction time. For instance, in the carbonylation of (VIII) and (II) at 0.1 MPa CO and 80°C in (III) in the presence of $PdCl_2$(dppf) [where dppf is 1,1'-bis(diphenylphosphino)ferrocene] (IX) was obtained in [7] with a yield of 93% after 26 h; performance of this reaction in HMPA in the presence of (IV) and 1 mole % CuI gave (IX) with a quantitative yield already after 2 h.

It has been demonstrated in [9] that the carbonylation of o-iodophenols and terminal acetylenes in the presence of palladium complexes at 2 MPa CO and 120°C leads to the formation of flavones or 2-substituted chromones. In this instance the addition of 1 mole % CuI increases somewhat the yield of flavone in the reaction of o-iodophenol with (II) (Table 3).

TABLE 1. Reaction of $p\text{-}NO_2C_6H_4I$ with PhC≡CH and CO in the Presence of an Amine (4 moles) and $PdCl_2(CH_3CN)_2$ (1 mole %), 3 h

Test No.	Solvent	Amine	p_{CO}, MPa	T, °C	Yield* of $p\text{-}NO_2C_6H_4COC{\equiv}CPh$, %
1	Et_3N	Et_3N	2	60	14
2	HMPA	»	2	60	10
3	DMF	»	2	60	Traces
4	C_6H_6	»	2	60	69
5	$CHCl_3$	»	2	60	80
6	C_6H_6	»	2	90 †	0
7	»	»	2	20	Traces
8	$CHCl_3$	»	0,5	60	74
9	»	»	0,1	60	68 ‡
10	C_6H_6	Piperidine	2	60	Traces
11	»	Pyridine	2	60	0

*In tests 1-6 and 8-10 the conversion of $p\text{-}NO_2C_6H_4I$ was 100%; in test 7, 5%; and in test 11, 24%.

†Reaction time 2 h.

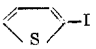
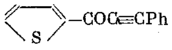
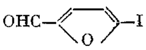
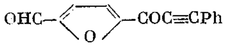
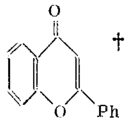
‡Yield of $p\text{-}NO_2C_6H_4C{\equiv}CPh$ 10%.

TABLE 2. Reaction of p-$CH_3OC_6H_4I$ with PhC≡CH and CO (2 MPa) in the Presence of Et_3N (4 moles) and a Palladium Catalyst (1 mole %) in HMPA, 80°C, 2 h

Catalyst	Yield of p-$CH_3OC_6H_4COC{\equiv}CPh$, %*
$PdCl_2(PPh_3)_2$	79
$PdCl_2(CH_3CN)_2$	67
$PdCl_2$(dppf)	80
$PdCl_2$(dppe)	25
p-$NO_2C_6H_4PdI(PPh_3)_2$	82

*Conversion of p-$CH_3OC_6H_4I$ 100%.

TABLE 3. Reaction of Aryl and Heteryl Iodides with PhC≡CH and CO (2 MPa) in the Presence of Et_3N and $PdCl_2(CH_3CN)_2$ (1 mole %)

Iodide	Reaction conditions			Products	Yield, %*	
	Solvent	*T*, °C	*t*, h		with CuI	without CuI
p-$NO_2C_6H_4I$	C_6H_6	60	3	*p*-$NO_2C_6H_4COC{\equiv}CPh$	75	69
p-$CH_3OC_6H_4I$	HMPA	80	2	*p*-$CH_3NC_6H_4COC{\equiv}CPh$	69	67
C_6H_5I	HMPA	70	3	$PhCOC{\equiv}CPh$	83	33
	C_6H_6	70	2		79	84
	HMPA	50	2		–	51
o-HOC_6H_4I	Et_2NH	60	5	 †	75	63

*Conversion 100%.
†Catalyst $PdCl_2$(dppf).

EXPERIMENTAL

The mass spectra were obtained on a Finnigan INCOS-50 spectrometer (70 eV), the UV spectra on a Specord M40 spectrophotometer in methanol, and the IR spectra on a Specord M80 spectrophotometer in chloroform. The PMR spectra were taken on a Bruker WP-200 SY spectrometer (200.13 MHz) in $CDCl_3$. Silufol UV-254 plates were used for TLC. The product yields are quoted for reactions without the addition of CuI.

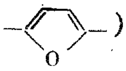
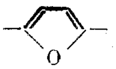
Reaction of p-$NO_2C_6H_4I$ with Phenylacetylene in the Presence of CO, Et_3N and $PdCl_2(CH_3CN)_2$. A 100-ml autoclave was charged with 2.56 ml benzene, 0.200 g ($8.032 \cdot 10^{-4}$ mole) p-$NO_2C_6H_4I$, 0.160 g (0.180 ml, $1.606 \cdot 10^{-3}$ mole) phenylacetylene, 0.320 g (0.440 ml, $3.213 \cdot 10^{-3}$ mole) triethylamine, and $2.00 \cdot 10^{-3}$ g ($8.032 \cdot 10^{-6}$ mole) $PdCl_2(CH_3CN)_2$. The reaction was conducted at 2 MPa CO and 60°C, with stirring by a magnetic stirrer for 3 h. The yield of p-$NO_2C_6H_4COC{\equiv}CPh$ (69%) was determined by TLC and UV spectroscopy. The product was isolated on Silpearl silica gel (eluent hexane–chloroform 2:1), 0.139 g, as pale-yellow needles (ethanol–benzene 1:1). UV spectrum: λ_{max}, nm (log ε): 271 (4.25), 307 (4.23), mp 161°C (cf. [10]: 161-162°C).

1-Phenyl-3-(4-methoxyphenyl)-1-propyn-3-one, 0.127 g (67%), colorless crystals, from hexane. UV spectrum, λ_{max}, nm (log ε): 316 (4.41), mp 98-99°C (cf. [11]: 99°C).

1,3-Diphenyl-1-propyn-3-one (IX), colorless crystals, from hexane, 0.055 g (33%), λ_{max}, nm (log ε): 289 (4.28), mp 64.5-65.5°C (cf. [12]: 65-66°C).

1-Phenyl-3-(2-thienyl)-1-propyn-3-one, 0.143 g (85%), colorless crystals, from hexane. UV spectrum, λ_{max}, nm (log ε): 317 (4.34), mp 56-57°C (cf. [13]: 57°C).

Flavone, 0.112 g (63%), colorless crystals, from hexane. UV spectrum, λ_{max}, nm (log ε): 251 (4.33), 294 (4.40), mp 96-98°C (cf. [14]: 97-98°C).

1-Phenyl-3-(5-furfuryl)-1-propyn-3-one, 0.091 g (51%), pale-cream platelets, from hexane, mp 130-131°C. UV spectrum, λ_{max}, nm (log ε): 319 (4.35). IR spectrum (ν, cm^{-1}): 2200 (C≡C), 1692 (C=O, CHO), 1642 (C=O, COC≡C). PMR spectrum (δ, ppm): 7.40 d (1H, J = 4 Hz, ), 7.45-7.75 m (5H, Ph), 7.70 d (1H, J = 4 Hz, ), 9.89 s (1H, CHO). Mass spectrum, m/z (I_{rel}, %): 224 (59) [M^+], 196 (32) [M^+ – CO], 168 (14) [M^+ – 2CO], 139 (53) [M^+ – 3CO – H], 129 (100) [PhC≡CCO$^+$], 101 (17) [PhC≡C$^+$].

LITERATURE CITED

1. C. E. Castro, R. Havlin, V. K. Hanwad, et al., J. Am. Chem. Soc., 91, No. 23, 6464 (1969).
2. E. Negishi, V. Bagheri, S. Chatterjee, et al., Tetrahedron Lett., 24, No. 47, 5181 (1983).
3. A. S. Zanina, S. I. Shergina, I. E. Sokolov, and I. L. Kotlyarevskii, Izv. Akad. Nauk SSSR, Ser. Khim., No. 5, 1158 (1981).
4. Y. Tohda, K. Sonogashira, and N. Hagihara, Synthesis, No. 11, 777 (1977).
5. I. E. Sokolov, A. S. Zanina, S. I. Shergina, et al., Izv. Akad. Nauk SSSR, Ser. Khim., No. 8, 1898 (1983).
6. M. Iman, P. Bouysson, and J. Chenault, Synthesis, No. 7, 631 (1990).
7. T. Kobayashi and M. Tanaka, J. Chem. Soc. Chem. Commun., No. 7, 333 (1981).
8. K. Sonogashira, Y. Tohda, and N. Hagihara, Tetrahedron Lett., No. 50, 4467 (1975).
9. V. N. Kalinin, M. V. Shostakovskii (Shostakovsky), and A. B. Ponomarev (Ponomaryov), Tetrahedron Lett., 31, No. 28, 4073 (1990).
10. C. Barat, J. Indian Chem. Soc., No. 7, 851 (1930).
11. C. L. Bickel, J. Am. Chem. Soc., 69, No. 9, 2134 (1947).
12. C. D. Hurd and F. L. Cohen, J. Am. Chem. Soc., 53, No. 3, 1068 (1931).
13. G. Duguay and H. Quiniou, Bull. Soc. Chim. Fr., No. 5, 1918 (1970).
14. S. P. Korshunov, N. V. Korzhova, V. M. Kazantseva, et al., Zh. Org. Khim., 22, No. 9, 1847 (1986).