

Nickel(0) Catalysed Additions of Hydrogen Cyanide to Alkynes: Stereochemistry, Mechanism, and Preparative Application

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The addition of hydrogen cyanide to both terminal and disubstituted acetylenes occurs with *cis*-stereospecificity in moderate to excellent yields when catalysed by a nickel(0) complex.

The addition of hydrogen cyanide to acetylene has been carried out on a large commercial scale using acid catalysis.¹ Copper based catalyst systems have also been used to promote this reaction.²

We report that the addition of hydrogen cyanide to substituted acetylenes is catalysed by zerovalent nickel and palladium compounds and that α,β -unsaturated nitriles can be obtained stereospecifically in moderate to quantitative yields. Very high conversions were obtained for diaryl- (**1**, R¹ = R² = Ph) and dialkyl-acetylenes (**1**, R¹ = Bu^t; R² = Me) when a solution of hydrogen cyanide (34 mmol) in toluene was slowly added over 10 h to a solution of the acetylene (32 mmol) in toluene containing tetrakis(triphenylphosphite)nickel(0) (0.5 mmol), triphenylphosphite (2.5 mmol), and zinc chloride (1 mmol) or when the acetylene, nickel catalyst, and excess of phosphite were allowed to react in the absence of zinc chloride in a small autoclave. The results are summarised in Table 1. Diphenylacetylene gave excellent yields of *E*- α -(phenylmethylene)benzeneacetonitrile (**2**, R¹ = R² = Ph) under either set of conditions (Reactions 1 and 3) and a moderate yield (57%) of the nitrile was obtained when hydrogen cyanide was replaced by acetone cyanohydrin in the reaction carried out in the autoclave (Reaction 2).

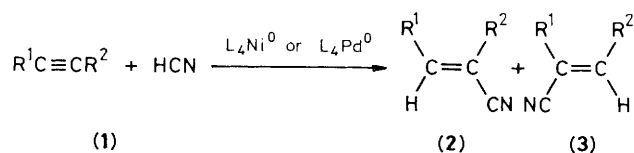
The terminal acetylenes, phenylacetylene (**1**, R¹ = Ph; R² = H) and 3,3-dimethylbut-1-yne (**1**, R¹ = Bu^t; R² = H), when

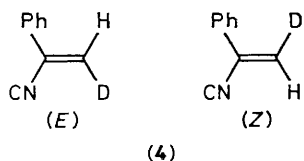
allowed to react under conditions similar to those for diphenylacetylene gave α,β -unsaturated nitriles in yields which were approximately half those obtained for diphenylacetylene

Table 1. Hydrocyanation of acetylenes.

| Reaction number | Reactant (1) R ¹ | R ² | Reaction temperatures/°C Autoclave ^a Slow addition ^b | Yield of nitrile(%) ^c |
|-----------------|--------------------------------|--------------------|---|----------------------------------|
| 1 | Ph | Ph | 120 | 93 |
| 2 | Ph | Ph | 120 ^d | 57 |
| 3 | Ph | Ph | | 60 |
| 4 | Ph | Ph | 120 ^e | 82 |
| 5 | Bu ^t | Me | | 8 |
| 6 | CO ₂ Me | CO ₂ Me | 100 | 60 |
| 7 | CO ₂ Me | CO ₂ Me | | 78 ^f |
| 8 | Ph | H | 75 | 27 |
| 9 | Ph | H | 120 | 60 ^g |
| 10 | Ph | H | 120 ^d | 5 |
| 11 | Ph | H | | 51 ^h |
| 12 | Bu ^t | H | 120 | 48 ⁱ |
| 13 | Bu ^t | H | | 20 ^j |
| 14 | Ph | H | 80 ^h | 60 |
| 15 | Ph | H | 80 ⁱ | 35 ^k |
| 16 | Pr | H | 120 | 15 ^l |
| | | | | 45 ^m |
| | | | | 8 |
| | | | | 5 |
| | | | | 60 |

^a The reaction was performed in benzene in a stainless steel autoclave with Ni[P(OPh)₃]₄ (0.18 mmol), P(OPh)₃ (2.5 mmol), HCN (32 mmol), and the acetylene (40 mmol) for 20 h. ^b Slow addition of a slight excess of HCN to a toluene solution of Ni[P(OPh)₃]₄ (0.5 mmol), P(OPh)₃ (2.5 mmol), ZnCl₂ (1 mmol), and the acetylene (32 mmol) over 10 h. ^c All compounds gave satisfactory physical, spectral, and analytical data. ^d HCN replaced by acetone cyanohydrin. ^e Pd(diop)₂-diop catalyst, diop = (-)-2,3-*O*-isopropylidene-2,3-dihydroxy-1,4-bis(diphenylphosphino)butane. ^f Ratio of (**2**):(**3**) ca. 9:1. ^g Slow addition of both HCN and the acetylene to catalyst solution. ^h Pd(PPh₃)₄-PPh₃ catalyst system. ⁱ Pd[P(OPh)₃]₄-P(OPh)₃ catalyst system.





(Reactions 8—13). Nitriles were still obtained in *ca.* 50% yield after distillation. Unchanged alkyne together with a small amount of polymeric material were also recovered. The regioselectivity in all cases was between 10 and 20 to 1 in favour of the terminal nitrile (**2**, $R^1 = \text{Ph}$ or Bu^t ; $R^2 = \text{H}$). This regioselectivity was shown to be due mainly to steric factors by the reaction of 4,4-dimethylpent-2-yne (**1**, $R^1 = \text{Bu}^t$; $R^2 = \text{Me}$) which gave a mixture of (**2**) and (**3**), ($R^1 = \text{Bu}^t$; $R^2 = \text{Me}$) in *ca.* 80% yield in which the ratio of (**2**):(**3**) was *ca.* 9:1. Where steric interactions are minimised, as in the reaction of pent-1-yne (**1**, $R^1 = \text{Pr}$, $R^2 = \text{H}$) the major product isolated was the internal nitrile (**3**, $R^1 = \text{Pr}$; $R^2 = \text{H}$), again in moderate yield (Reaction 16).

Addition of hydrogen cyanide proceeded even when two electron withdrawing substituents were attached to the alkyne as in the case of dimethyl acetylenedicarboxylate (**1**, $R^1 = R^2 = \text{CO}_2\text{Me}$). (Reactions 6 and 7). A competing reaction in these cases was the well known transition metal catalysed trimerisation.³ However, a useful yield of a dimethyl 2-cyanobut-2-enedioate was obtained which was found to be identical with a sample prepared previously by another route to which the *E*-stereochemistry had tentatively been assigned.⁴ Our route represents a convenient, stereospecific synthesis of this compound and an unambiguous assignment of stereochemistry by *X*-ray crystallographic analysis will be required. †

The stereochemistry of all of the major products involved *cis*-addition of hydrogen cyanide. The only exception was the minor product (**4**) obtained from the addition of deuterium cyanide to phenylacetylene where ²H n.m.r. spectroscopy of the product suggested that this minor reaction may be non-stereospecific and that both the *E*- and *Z*-isomers had been formed in the ratio *ca.* 2*Z*:1*E*.

The regioselectivity and predominant stereospecificity of the reaction are similar to those of the metal catalysed addition of hydrogen cyanide to alkenes⁵ and this suggests

that a very similar mechanism may be operating. However, in contrast to the alkene reactions it was found that zerovalent palladium compounds were less effective as catalysts than zerovalent nickel compounds (Reactions 4, 14, and 15). Also terminal straight chain alkynes give internal unsaturated nitriles in contrast to terminal alkenes which give predominantly terminal nitriles. It is possible that electronic factors favour the formation of internal nitriles, but that steric factors favouring the formation of terminal nitriles predominate except in the case of reactions of terminal alkynes, $\text{RC}\equiv\text{CH}$ where the group *R* has low steric demands.

The reactions described above complement the catalytic hydrocyanation of acetylenes with concurrent reductions which can be achieved by using an excess of cyanide ion with sodium borohydride or zinc metal as reducing agents in the presence of tetracyanonickelate, $[\text{Ni}(\text{CN})_4]^{2-}$.⁶ In addition the stereospecific formation of *E*-alk-2-ene nitriles from terminal acetylenes complements the recently published synthesis of the *Z*-isomers from aldehydes.⁷ The stereospecific *cis*-addition to disubstituted alkynes can lead to useful preparations of stereochemically pure alkenyl nitriles.

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References

- 1 Kirk-Othmer, 'Encyclopedia of Chemical Technology,' Vol. 1, Wiley, New York, 3rd edn., 1978, p. 419.
- 2 L. V. Melnikova, L. N. Reshetova, O. N. Temkin, and R. M. Flid, *Kim. Atsetilena Tekhnol Karbida Kaltsiya*, 1972, 361, *Chem. Abs.*, 1974, **80**, 36680.
- 3 D. St. C. Black, W. R. Jackson, and J. M. Swan in 'Comprehensive Organic Chemistry,' ed. D. H. R. Barton and W. D. Ollis, Pergamon Press, Oxford, 1979, p. 1215.
- 4 H. K. Hall and P. Ykman, *J. Am. Chem. Soc.*, 1975, **97**, 800; H. K. Hall and R. C. Daly, *Macromolecules*, 1975, **8**, 22.
- 5 W. R. Jackson and C. G. Lovel, *Tetrahedron Lett.*, 1982, 1621; J. E. Backvall and O. S. Andell, *J. Chem. Soc., Chem. Commun.*, 1981, 1098.
- 6 T. Funabiki and Y. Yamazaki, *J. Chem. Soc., Chem. Commun.*, 1979, 1110.
- 7 Y. Sato and Y. Niinomi, *J. Chem. Soc., Chem. Commun.*, 1982, 56.

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