Tetrahedron Letters Vol. 21, pp 1343 - 1346
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0040-4039/80/0401-1343$02.00/0

THE $[Fe_4S_4(SR)_4]^{2-}$ CATALYTIC REDUCTION OF DIPHENYLACETYLENE TO CIS-STILBENE IN THE PRESENCE OF $NaBH_4$

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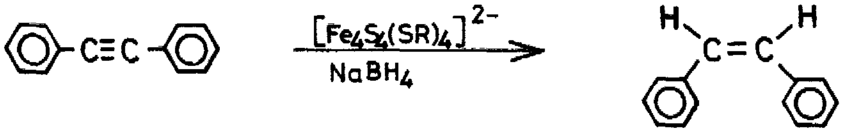
Abstract: The cluster $[Fe_4S_4(SR)_4]^{2-}$ catalyzed the reduction of diphenylacetylene to cis-stilbene in the presence of $NaBH_4$. The ligand effects for the reduction are investigated.

Iron-sulfur proteins exist widely in biological systems[1)] and have many important functions including electron transfer systems for N_2 fixation[2)], CO_2 fixation and steroid hydroxylation[3)]. In order to understand the properties of iron-sulfur proteins, it is necessary to know the characteristics of their active sites. The clusters $[Fe_4S_4(SR)_4]^{2-}$, first synthesized by R. H. Holm et. al.,[4)] are synthetic analogues of and have active sites similar to iron-sulfur proteins such as oxidized Fe ferredoxin from Peptococcus aerogenes or reduced Fe protein from Chromatium. The electronic properties of the clusters have been



(1)

Table 1. The reduction yields of diphenylacetylene by $NaBH_4$ in the presence of various "catalysts"

entry	catalyst		yield (%)*	
			cis	trans
1.	$[Fe_4S_4(SC_6H_5)_4]^{2-}$	(0.1mmol)	70	2
2.	$FeCl_2$	(0.1mmol)	1	0
3.	$FeCl_3$	(0.1mmol)	6	1
4.	Na_2S	(0.1mmol)	4	2
5.	C_6H_5SH	(0.1mmol)	0	0
6.	$FeS_4C_4(C_6H_5)_4$ (Schrauzer complex)	(0.1mmol)	5	2

Reaction conditions: $C_6H_5C{\equiv}CC_6H_5$ (1.0mmol), $NaBH_4$ (10.0mmol),
React. Temp. 20°C, Solvent, CH_3CN (10ml)/ CH_3OH (10ml)
React. Time 1.0 hr(entry 1), 24 hr(entry 2-6),
*In all cases (entry 2-6) diphenylacetylene (>90%) was recovered.

investigated thoroughly by R. H. Holm and were found to be very similar to those of iron-sulfur proteins[5]. The chemical reactivities of the cluster, however, have hardly been investigated. Recently we reported the catalytic function of these clusters in the thiol oxidation[6].

In this paper we wish to report that the clusters catalyze the reduction of diphenylacetylene with $NaBH_4$ to stilbene and that this reduction is stereoselective, that is, the product is the cis-isomer.[7] (Scheme 1)

A typical experimental procedure is as follows: A CH_3CN/CH_3OH (10ml/10ml) solution containing $NaBH_4$(10.0mmol), diphenylacetylene(1.0mmol) and the cluster $[Fe_4S_4(SC_6H_5)_4]^{2-}$(0.10mmol) (Fig.1) was stirred under an Ar atmosphere. The reaction was initiated by the addition of the cluster. The reaction system was homogeneous. Cis-stilbene was formed with about a 70% yield, while the yield of the trans-isomer was only 2%. Other products were not detected. The recovery of the starting material was 28%. Identification of the product was performed in comparing I.R. and N.M.R. spectra with those of cis-stilbene and yields were determined by G.L.C.. Control experiments were also performed in using $FeCl_2$, $FeCl_3$, RSH or Na_2S instead of the cluster (Table 1). It was found that these compounds hardly assisted the reduction and a similar result occurred for the Schrauzer complex.[8] The reaction was almost complete after 1.0 hr. (Table 2, entries 3, 4) Also with increasing concentration of the cluster (up to 0.10 mmol) an increase in product yield occurred. (Table 2, entries 1,2,3,4) When the cluster concentration was greater than 0.10mmol, the yields decreased. (Table 2, entries 5,6) The reason for these results has yet to be found.

Table 2: The reduction yields of diphenylacetylene by the cluster $[Fe_4S_4(SC_6H_5)_4]^{2-}$ in the presence of $NaBH_4$ in CH_3CN/CH_3OH

entry	$[Fe_4S_4(SC_6H_5)_4]^{2-}$ (mmol)	reaction time (hr)	yields (%) cis	trans
1.	0.05	0.25	50	0
2.	0.05	0.50	61	1
3.	0.10	0.25	67	2
4.	0.10	1.00	70	2
5.	0.20	1.00	45	2
6.	1.00	1.00	10	trace

Reaction conditions: $C_6H_5C{\equiv}CC_6H_5$(1.0mmol), $NaBH_4$(10.0mmol)
solvent; CH_3CN(10ml)/CH_3OH(10ml)

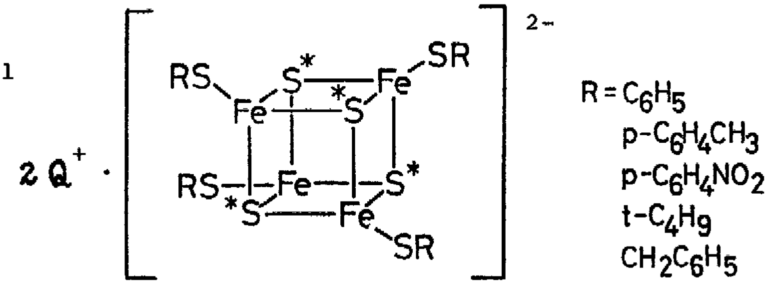
Next, the ligand effects of the clusters for the catalytic reduction are considered. Five clusters were synthesized according to the methods of R. H. Holm et.al..[9] Consequently it has become apparent that the catalytic effects decrease in the case of R=alkyl groups. (Table 3, entries 4,5) Also the cluster (R=p-$C_6H_4NO_2$) is not very good for promoting the reaction (entry 3), suggesting a deactivating influence of the NO_2 group.[10]

Next, solvent effects are examined. If CH_3OH is not added to the reaction mixture, the yields become poor.[11—a)] (24hr, cis-stilbene yield: CH_3CN 7%, DMF 5%, $C_2H_5OC_2H_5$ 3%) Moreover when C_2H_5OH(10ml)/CH_3CN(10ml) is used instead of CH_3OH(10ml)/CH_3CN(10ml), the yields increase to 95%(cis) and 4%(trans) though longer reaction times are required (5hr). Using iso-PrOH(10ml)/CH_3CN(10ml), the yields fell to 27%.[11—b)] CH_3CN solvent(10ml) is added in order to dissolve the cluster.

When the reaction was carried out in CH_3OD/CH_3CN, only cis-$C_6H_5CD{=}CHC_6H_5$ was formed. This was confirmed by N.M.R. spectra (δ($CDCl_3$/TMS): 6.59(1H, s), 7.20 (10H, m)) and Mass spectra(m/e: 181(M^+)). Namely it was revealed that one hydrogen atom of cis-stilbene originated from the solvent(CH_3OD) and the other from $NaBH_4$.

These above results show that the $[Fe_4S_4(SR)_4]^{2-}$ cluster compounds are excellent catalysts for the acetylene reduction to stilbene. Also it is

Fig. 1



Q= $(n\text{-}Bu)_4N$

S^*= labile inorganic sulfur

Table 3: The reduction yields of Diphenylacetylene by the various clusters in the presence of $NaBH_4$ in CH_3CN/CH_3OH

entry	$[Fe_4S_4(SR)_4]^{2-}$ (R)	reaction time (hr)	yields(%) cis	trans
1.	C_6H_5	1.0	70	2
2.	p-$C_6H_4CH_3$	1.0	74	4
3.	p-$C_6H_4NO_2$	4.0	45	8
4.	t-C_4H_9	20.0	7	0
5.	$CH_2C_6H_5$	20.0	11	1

Reaction conditions: $C_6H_5C{\equiv}CC_6H_5$ (1.0mmol), $NaBH_4$ (10.0mmol) $[Fe_4S_4(SR)_4]^{2-}$(0.1mmol), solvent; CH_3CN(10ml)/CH_3OH(10ml) particularly interesting that the reduction is stereoselective. A slight amount of trans-stilbene seems to be produced by isomerization of cis-isomer. The study on the reaction mechanism is significant for knowing the characteristics of iron-sulfur proteins. Studies on the mechanism are in progress.

Acknowledgement: This study supported by the Grant in Aid for Scientific Research from the Ministry of Education, the Japanese Government.

REFERENCES

1) a) J.R.Herriott and L.H.Jensen, Acta Crystallogr., Sect.B, 29, 943 (1973).
   b) L.H.Jensen, Iron-Sulfur Proteins, 2, 163 (1973).
   c) E.T.Adman, L.C.Sieker and L.H.Jensen, J. Biol. Chem., 248, 3987 (1973); 251, 3801 (1976).
   d) E.Adman, K.D.Watenpaugh and L.H.Jensen, Proc. Natl. Acad. Sci. U.S.A., 72, 4854 (1975).
   e) C.W.Carter, Jr., Iron-Sulfur Proteins, 3, 157 (1977).
2) H.Dalton, L.E.Mortenson, Bacteriol. Rev., 36, 231 (1972).
3) K.Suzuki, T.Kimura, Biochem. Biophys. Res. Commun., 19, 340 (1965).
4) a) B.A.Averill, T.Herskovitz, R.H.Holm and James A.Ibers, J. Am. Chem. Soc., 95, 3523 (1973).
   b) R.H.Holm, W.D.Philips, B.A.Averill, J.J.Mayerle and T.Herskovitz, J. Am. Chem. Soc., 96, 2109 (1974).
5) As summaries of this research;
   a) R.H.Holm, Endeavour, 34, 38, (1975).
   b) R.H.Holm and J.A.Ibers, Iron Sulfur Proteins, 3, 205 (1977).
   c) R.H.Holm, Acc. Chem. Rev., 10, 427 (1977).
6) T.Nagano, K.Yoshikawa and M.Hirobe, Tetrahedron Letters 1980 in press.
7) Presented at the 99th Annual Meeting of the Pharmaceutical Society of Japan, Sapporo, August, 1979.
8) G.N.Schrauzer, V.P.Mayweg, H.W.Finck and W.Heinrich, J. Am. Chem. Soc., 88, 4604 (1966).
9) B.V.Depamphilis, B.A.Averill, T.Herskovitz, L.Que, Jr. and R.H.Holm, J. Am. Chem. Soc., 96, 4159 (1974).
10) Unpublished data. The clusters reduce several nitro groups to amine in CH_3CN solution under Ar atmosphere.
11) a) In all cases diphenylacetylene (>90%) was recovered.
    b) Any other products were not detected.

(Received in Japan 4 January 1980)