μ-Alkyne dicobalt hexacarbonyl complexes of conjugated enynes as substrates in the arylthio-mediated stepwise Ad_E reactions

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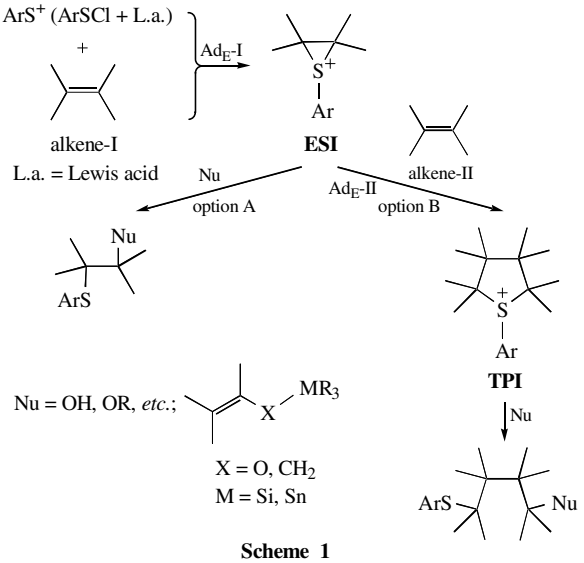
10.1070/MC2001v011n06ABEH001527

The title compounds were shown to be useful as alkene substrates in the arylthio-mediated one-pot multicomponent coupling leading to the formation of functionalised alkyne derivatives.

Multi-step sequential transformations are widely used in organic synthesis.[1(a)–(c)] Among organic reactions employed as basic steps in these sequences, very few belong to the category of Ad_E processes and those are nearly exclusively intramolecular.[1(a),(b),2] Previously, we suggested a novel protocol for the one-pot multicomponent coupling based upon the arylthio-mediated controlled sequence of the intermolecular Ad_E reactions, which proceed *via* the formation of bridged sulfonium ion species as stable intermediates.[3,4] This approach was successfully applied to a number of three- and four-component couplings outlined in Scheme 1 as options A and B, respectively.[3–5] The formation of episulfonium ion (ESI) and thiophanium ion (TPI) intermediates in these couplings was well-substantiated by the observed pattern of their reactivity and in several cases was also unequivocally proven by the results of NMR and X-ray studies of the isolated salts.[6,7]

Option A was shown to be applicable to a wide set of structurally diverse non-functionalised alkenes, as well as to 1-alkoxyalkenes.[3] Untill recently, only the latter have been employed as both alkene-I and alkene-II substrates in option B.[4,5] In the search of other functionalised unsaturated substrates for the above couplings, we turned our attention to μ-alkyne dicobalt hexacarbonyl (DCHC) complexes of conjugated enynes since according to the published data these compounds interact easily with a number of cationoid carbon electrophiles such as *tert*-alkyl, acyl[3] or benzhydryl cations[8] to give the respective propargyl cation intermediates, which turned out to be sufficiently reactive to alkylate allylsilanes or silyl enol ethers.[9] Below are presented data showing that DCHC complexes of conjugated enynes can also be utilised as the alkene substrates in the sequences represented by the options A and B in Scheme 1.

Initially we investigated an opportunity to use DCHC complexes of conjugated enynes as alkene-I substrates in the three



Scheme 1

components coupling (option A, Scheme 1). It was found that DCHC complex of isopropenyl acetylene **1** reacted readily with *p*-tolyl sulfenyl chloride to give corresponding 1,2-adduct **2**. The *in situ* treatment of the latter with $TiCl_4$ resulted in the formation of stable cationoid intermediate **3a** presumably assigned to the structure of the episulfonium ion (ESI). The same intermediate can also be generated directly upon the treatment of **1** with the $ArSCl–AgSbF_6$ system, an equivalent of the ArS^+ electrophile (Scheme 2).

No attempts were made to isolate this intermediate but its identity was substantiated by the results of its quenching with a set of π-donors used as carbon nucleophiles (Nu_C). Thus, the reaction of **3a** with tri-*n*-butylallylstannane **4a** proceeded smoothly at –45 °C and led to the formation of the DCHC complex of adduct **5** in 78% yield.† Oxidative decomplexation of the latter proceeded with a nearly quantitative yield to give adduct **6**.

Similarly, the treatment of cationoid intermediate **3a** with other π-donors such as 1-phenyl-1-(trimethylsiloxy)ethylene **7**, methyl trimethylsilyl dimethylketene acetal **8**, 2-trimethylsiloxyfuran **9**, 1-(trimethylsiloxy)cyclopentene **10** and 1-cyclopropyl-1-(trimethylsiloxy)ethylene **11** followed by the decomplexation furnished adducts **12**–**16** (Scheme 2).†,‡,§

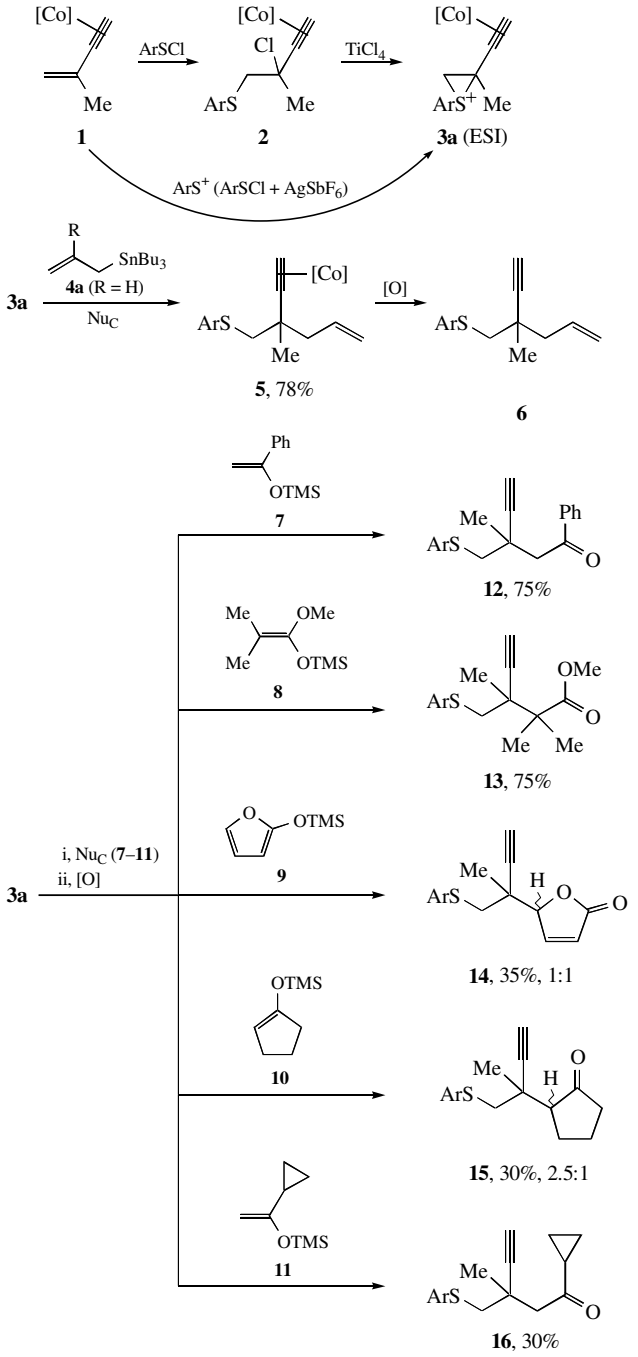
The sequence of reactions shown in Scheme 2 was found to work equally well with DCHC complexes of other conjugated enynes such as **17**–**19** and resulted in the formation of expected products **20**–**23** in satisfactory to good yields (Scheme 3).†

The above data clearly indicated that the presence of the β-arylthio group as an additional cation-stabilising moiety in DCHC complexed propargyl cation intermediates **3a**–**d** did not affect noticeably the ability of the latter species to serve as efficient electrophiles in the reactions with π-donors[9] and hence

† Yields (not optimised) refer to the isolated and purified products. The structures were unambiguously established by ^1H and ^{13}C NMR spectra and HRMS and/or satisfactory elemental analysis.

‡ Adducts **14** and **15** were formed as a mixture of diastereomers in ratios of 1:1 and 2.5:1, respectively.

§ *Typical experimental procedure.* To a stirred solution of DCHC complex of isopropenyl acetylene **1** (0.352 g, 1 mmol) in CH_2Cl_2 (20 ml) at –70 °C a solution of *p*-TolSCl (0.159 g, 1 mmol) in CH_2Cl_2 (1 ml) was added, followed by $TiCl_4$ (0.11 ml, 1 mmol). After 30 min, the TLC data revealed the complete disappearance of starting compound **1**. Then, the temperature was raised up to –45 °C and methyl trimethylsilyl dimethylketene acetal (0.328 g, 2 mmol) was added. The mixture was kept at this temperature for 30 min and quenched with $NaHCO_3–H_2O$–diethyl ether. An usual workup followed by column chromatography gave DCHC complex of 2,2,3-trimethyl-3-*p*-tolylsulfonylmethylpent-4-ynoic acid methyl ester as a deep-red oil, which was dissolved in acetone (15 ml) and treated with cerium(IV) ammonium nitrate (3 mmol) at 0 °C for 15 min (TLC control). The solvent was removed on a rotary evaporator, the residue was dissolved in chloroform and washed with brine. After preparative TLC, adduct **13** was isolated as an individual compound in 75% yield. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.41, 1.42 and 1.45 (3s, 9H), 2.28 (s, 1H), 2.35 (s, 3H), 3.1 and 3.47 (dd, 2H), 3.75 (s, 3H), 7.13 and 7.36 (dd, 4H). ^{13}C NMR, δ: 20.9, 22.2, 22.3, 25.6, 43.0, 48.7, 51.8, 72.0, 86.3, 129.5, 130.0, 133.9, 136.0, 175.7. HRMS (Finnigan Mat 95), *m/z*: 291.1420 $(M + H)^+$.



Throughout this paper [Co] refers to $Co_2(CO)_6$ and Ar refers to *p*-Tolyl.

Scheme 2

the DCHC complexes of conjugated enynes could be used as alkene-I components in the sequences shown in Scheme 1.

In a related series of experiments, we have investigated the reactivity pattern of the DCHC complexed conjugated enynes as alkene-II substrates in the Ad_E reactions with ESI electrophiles generated *in situ* upon the interaction of β-arylthio-α-chloroalkyl methyl ethers with Lewis acids (option B, Scheme 1).[4,5] In a typical experiment, vinyl methyl ether **24** was first treated in a CH_2Cl_2 solution at –70 °C with 1 equivalent of *p*-TolSCl followed by 1 equivalent of $SnCl_4$. The ESI-like intermediate **25** thus generated reacted readily with DCHC complex **1** at –60 °C (TLC control) to give the next stabilised cationoid intermedate tentatively identified as cyclic thiophanium ion (TPI) **26**. Here again no attempts were made to isolate intermediate **26** as a stable salt, but the results of its quenching with standard nucleophiles fully corroborated with the expected reactivity pattern of the TPI-like intermediates (Scheme 4) (*cf.* refs. 3–7).

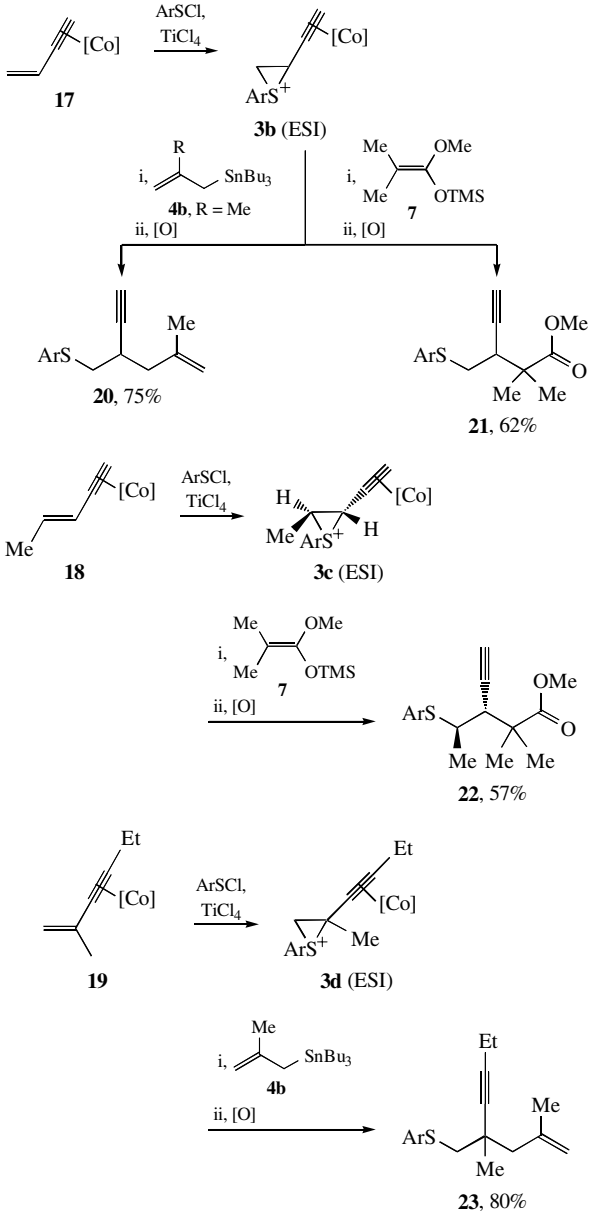
Thus, the treatment of intermediate **26** with a MeOH–K_2CO_3 mixture produced (after oxidative decomplexation) methoxy adduct **27**,† while hydroxy adduct **28**† was formed upon the quenching of **26** with Bu_4NOH. Hydride reduction of **26** with Bu_4NBH_4 resulted in the formation of adduct **29**† contaminated by proton elimination adduct **30**. The latter was formed as the sole product in the reaction of **26** with Et_3N.

Under similar conditions, the interaction of ESI **25** with the DCHC complex of 1-ethynylcyclohexene **31** resulted in the generation of intermediate **32** as is evidenced by the formation of the corresponding products of proton elimination **33a**,**b**† or hydride reduction **34**† upon the treatment with H_2O–$NaHCO_3$ or Bu_4NBH_4, respectively (Scheme 5). It is noteworthy that in the latter case only one of the four possible diastereomers was isolated (NMR data, stereochemistry undetermined).

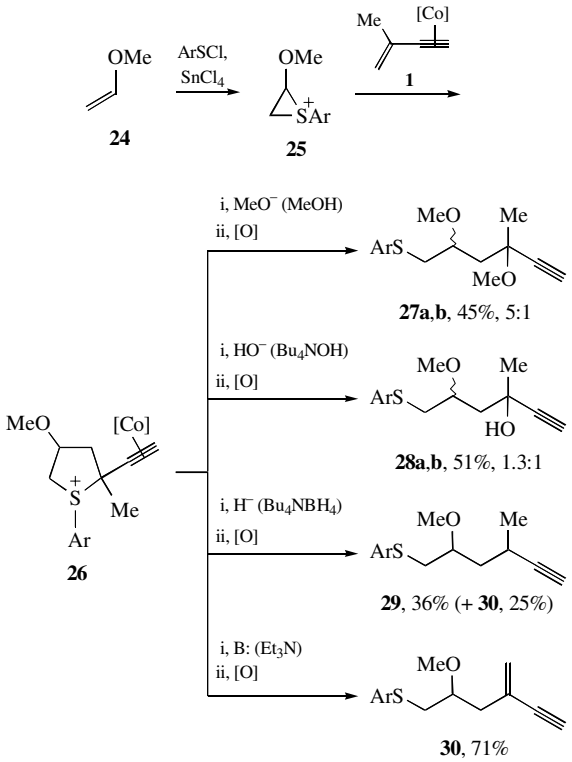
To summarise, the above data clearly indicated that the protocol elaborated earlier to carry out the tandem sequence corresponding to the general equation:

ArS + vinyl ether-I + vinyl ether-II + nucleophile → adduct[3–7]

is also applicable to the transformations which involve the usage of the DCHC complexes of conjugated enynes instead of vinyl ethers as either one of the alkene components. Both options of the one-pot coupling described in this paper seem to be promising for the elaboration of a new route for a ready assembly of the polyfunctional adducts bearing a triple bond moiety from simple precursors.



Scheme 3



Scheme 4

This work was supported by the Russian Foundation for Basic Research (grant no. 00-03-3790), the US CRDF agency (award no. RC2-2207) and the Donors of the Petroleum Research Fund Administered by the American Chemical Society (grant ACP-PRF no. 35453-B1).

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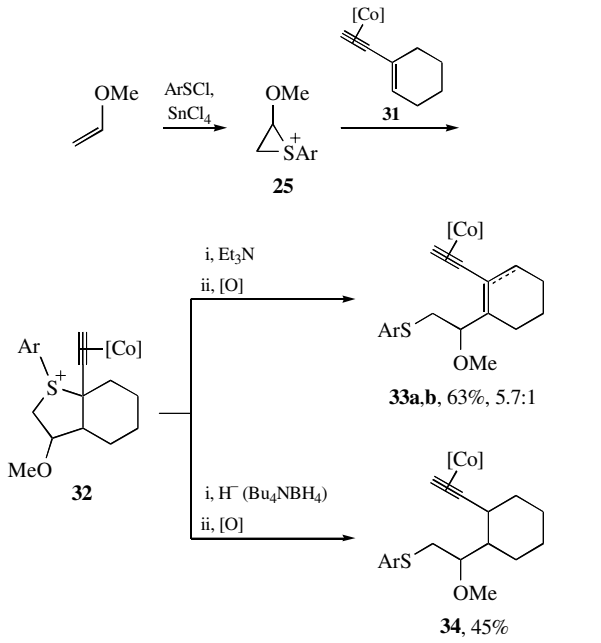

Scheme 5

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Received: 22nd October 2001; Com. 01/1853