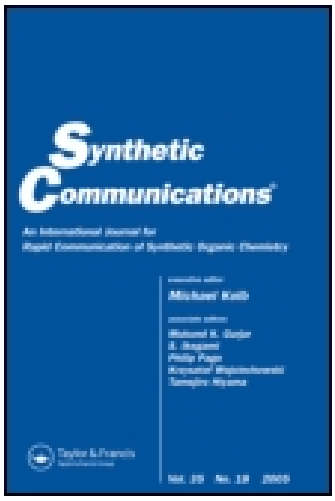

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SILICA-SUPPORTED HETEROPOLYACIDS READILY INDUCE CYCLODIMERIZATION OF STYRENES AND STILBENES

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SILICA-SUPPORTED HETEROPOLYACIDS READILY INDUCE CYCLODIMERIZATION OF STYRENES AND STILBENES

Elba Alesso,[1,*] Rosario Torviso,[1] Magali Erlich,[1] Liliana Finkielsztein,[1] Beatriz Lantaño,[1] Graciela Moltrasio,[1] José Aguirre,[2] Patricia Vázquez,[3] Luis Pizzio,[3] Carmen Cáceres,[3] Mirta Blanco,[3] and Horacio Thomas[3]

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ABSTRACT

Heteropolyacids such as molybdophosphoric and tungstophosphoric acids, supported over silica, readily induce cyclodimerisation reactions of styrenes and stilbenes affording a mixture of indane and/or tetraline derivatives with remarkably high efficiency and in reduced reaction time.

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Key Words: Heteropolyacid; Cyclodimerisation; Styrenes; Stilbenes; Indanes; Tetralines; Molybdophosphoric acid; Tungstophosphoric acid; Supported

INTRODUCTION

Use of supported reagents and catalysts for organic syntheses is of current research interest, since reactions under solid-solution biphasic conditions provide many practical advantages unavailable by conventional solution-phase counterparts.

Among frequently employed support materials, heteropolyacids supported over silica have enjoyed extensive use as solid acid catalysts. This is primarily due to the advantages associated with the use of solid acids such as easy work-up, eco-friendly nature, regeneration and reversibility, and on occasion, their shape-selective nature.

Recently, we have reported the preparation of silica-supported molybdophosphoric acid and tungstophosphoric acid catalysts (MPA/S and TPA/S, respectively)[1] and shown that they behaved as useful reagents for the dehydration of some secondary as well as tertiary alcohols.[2] In some cases, it has been found that not only olefin products, but also their dimerization derivatives were obtained.

Acid-catalysed dimerization of styrenes and stilbenes involves organic reactions of commercial significance and academic interest, as a rule carried out using mineral or Lewis acids.

Pursuing our interest in reactions catalysed by MPA/S and TPA/S, we investigated their use in the formation of cyclodimerization products of stilbene and styrene derivatives and compared the results with those obtained employing mineral or Lewis acids.

RESULTS AND DISCUSSION

Acid-catalysed dimerization of α-methyl styrene (**1**) (AMS) with acidic ion exchange resins, clays and aqueous sulphuric acid affords a number of products (**2–4**) (Fig. 1).[3] Treated with ethyl-alumininum dichloride under several conditions in a benzene solution, AMS rendered the indane-type dimer **4** and trimer **5**.[4] (Fig. 1).

When AMS was treated with TPA/S or MPA/S in chloroform, it afforded the dimer **4**[4] with a quantitative yield in barely 15 min.

The results obtained by the reaction of AMS with several acid catalysts including MPA/S and TPA/S in different conditions are shown in Table 1.

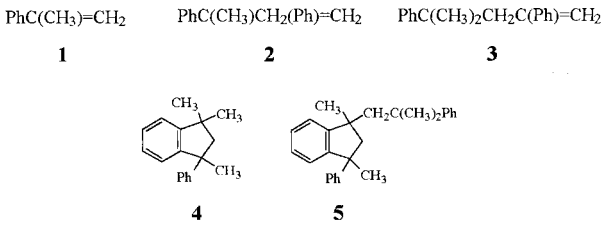
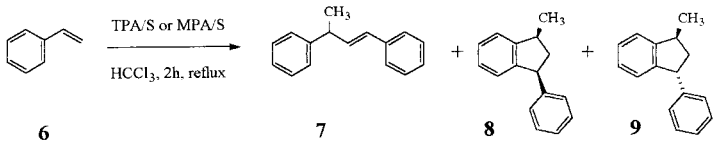


Figure 1.

Table 1. Reaction Products of AMS Using Different Catalysts

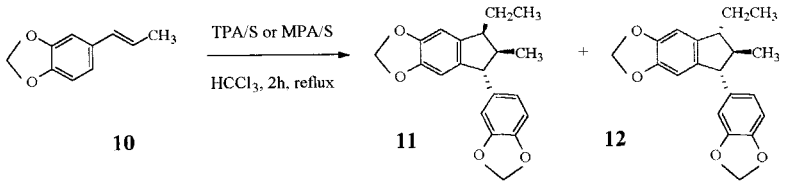
Reagents	Temp. (°C)	Reaction Time	AMS Yield (%)	2	3	4	5	Other
H_2SO_4/H_2O/ MeOH	80	7 h	45	37.4	3.0	0.05		4.55
$EtAlCl_2$	4	5 min	92			37	55	
$EtAlCl_2$	25	5 min	80			52	28	
$EtAlCl_2$	80	80 min	86			73	13	
TPA/S	60	90 min	Quant.			>99		
MPA/S	r.t.	30 h	Quant.			>99		
MPA/S	60	2 h	Quant.			>99		



Scheme 1.

The above findings prompted us to repeat the experiment using styrene (**6**) as starting material. In chloroform at reflux, after 2 h the open dimer (**7**)[5] was isolated together with the *cis* and *trans* 1-methyl-3-phenylindanes (**8**)[6] and (**9**),[6] respectively, in a 1 : 4 : 1 ratio (Sch. 1). The reaction products were fully characterised by physical and spectral data.

Tricyclic dimers, obtained from styrenes with acidic reagents, have been known for over ninety years.[7] The phenylindane structure was first established for the anethole dimer and subsequently for the isohomogenol



Scheme 2.

dimer and that of isosafrol (**10**), diisosafrole. Four racemates of these indanes are possible (α, β, γ, and δ) but only two (α and γ) have been obtained from propenylbenzenes with acid reagents.[7]

In the present work, we explored the behavior of isosafrol (**10**) with two acid catalysts (TPA/S, MPA/S) and compared them with the ones obtained using EPP[8] (ethylpolyposphate) and 50% H_2SO_4.[7] Two racemates were obtained with all the acid catalysts. The major (**11**) and minor (**12**) products were respectively, concluded to have the 1,2-*cis*-2,3-*trans*-configuration (α racemate) and 1,2-*trans*-2,3-*trans*-configuration (γ racemate)[7,8] (Sch. 2). The conditions used and the results obtained are listed in Table 2. Once again, TPA/S and MPA/S showed exceptional catalytic activity for the formation of indanes from styrenes and the isolation of products, which were identified by comparison of NMR spectra with those in the literature, was straightforward.

We also examined the cyclodimerization reaction of several stilbenes with TPA/S or MPA/S. When 4-bromo-3′,4′-dimethoxystilbene (**13**) was treated with TPA/S or MPA/S, a mixture of diasteroisomeric indanes was obtained, namely **14** (γ configuration) and **15** (α configuration)[9] (Sch. 3). These results were compared with those obtained with EPP[9] and with 50% H_2SO_4[9] and given in Table 2. Data show a higher efficiency of reactions carried out with TPA/S or MPA/S in comparison to those performed with EPP or 50% H_2SO_4.

Treatment of 3,4,3′,4′-tetramethoxystilbene **16** with EPP[9] or 50% H_2SO_4[9] rendered only the tetraline **17**[9] with all *trans*-configuration, but with TPA/S or MPA/S stilbene **16** afforded a mixture of tetraline **17** with a new compound **18** (Sch. 4). The choice between tetralinic and indanic structure was made on the basis of the following data: (a) in the mass spectra of 1-benzylindanes the base peak was originated from the loss of the benzyl group, whereas in the case of tetralines, it derives from a retro Diels-Alder type clevage[9]; (b) comparing chemical shift data of the carbon atoms of the four racemic diasteroisomers of 1-benzyl-2,3-diphenylindane and also of 1,2,3-triaryltetralines[9]; and (c) based on the values of the general coup-

Table 2. Reaction Products of Styrenes and Stilbenes with Different Catalysts

Comp.	Yield (%)	EPP[a] Isomeric Relation	Yield (%)	H_2SO_4[b] Isomeric Relation	Yield (%)	TPA/S Isomeric Relation	Yield (%)	MPA/S Isomeric Relation
10	20	(**11**:**12**) 1:0	49	(**11**:**12**) 4:0.6	99.3	(**11**:**12**) 3:1	99.4	(**11**:**12**) 3:1
13	65	(**14**:**15**) 2:3	60	(**14**:**15**) 3:1	98.5	(**14**:**15**) 3:2	98	(**14**:**15**) 3:2
16	98	(**17**:**18**) 1:0	60	(**17**:**18**) 1:0	90	(**17**:**18**) 1:1	90	(**17**:**18**) 1:1
19	40	[c]	59	[c]	77	(**20**:**21**) 1.3:1	77	(**20**:**21**) 1.3:1
22		no reaction		no reaction	99	**23**	99	**23**

[a]EPP in ether:chloroform solution, 8 h, 80°C; [b]H_2SO_4 50%, 3 h, 70°C; [c]undetermined mixture of cyclodimers.

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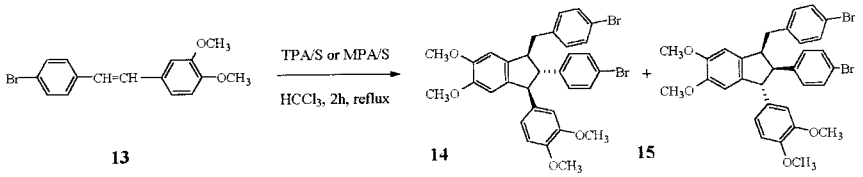
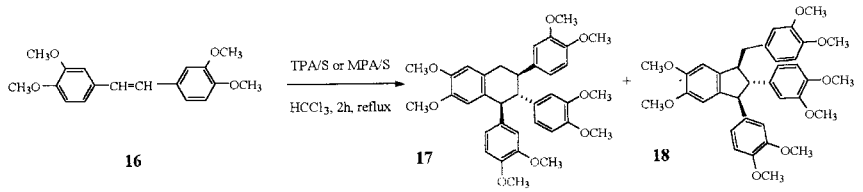


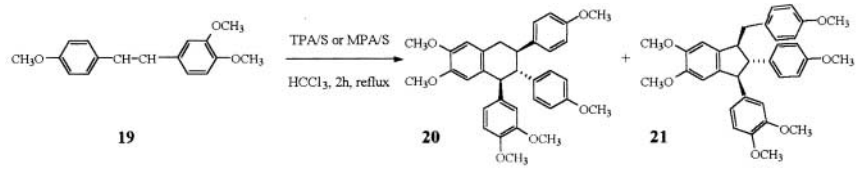
13 14 15

Scheme 3.



16 17 18

Scheme 4.



19 20 21

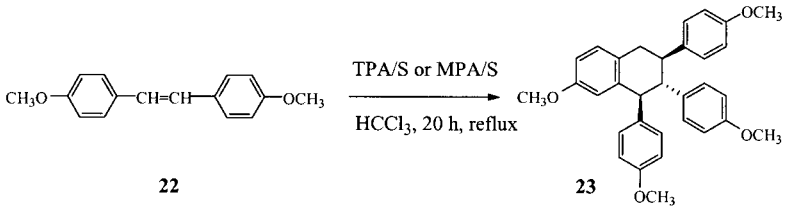
Scheme 5.

ling constants of the benzyl methylene hydrogen atoms. The value is in the order of 13 Hz for the exocyclic benzyl groups and of 16 Hz for the endocyclic benzyl groups.[9] Table 2 summarizes these results.

When 3,4,4′-trimethoxystilbene **19** was treated with TPA/S or MPA/S, a mixture of tetraline **20** and indane **21** was obtained (Sch. 5).

Treatment of **19** with several acids in comparison to results obtained with TPA/S or MPA/S are shown in Table 2. A complex mixture of regio- and stereo-isomers was obtained by treatment of **19** with EPP or 50% H_2SO_4. The separation of this mixture proved impracticable.[9]

Lastly, when 4,4′-dimethoxystilbene **22** was treated with TPA/S or MPA/S, tetraline **23**[10] was obtained with 99% yield (Sch. 6). All efforts to achieve cyclodimerization products by treatment of **22** with EPP or 50% H_2SO_4 rendered only starting material.[9] This tetraline was obtained by other authors in reactions carried out in



22 23

Scheme 6.

1,1,1,3,3,3-hexafluoropropan-2-ol, and in dichloromethane solutions with catalytic amounts of *tris*-(2,4-dibromophenyl)aminium hexachloro antimonate.[10]

In conclusion, the present new method for the preparation of indanes and/or tetralines offers significant improvements over existing procedures and provides a useful contribution to available methods. The main advantages are mild reaction conditions, reduced reaction time, lack of side-products, and excellent yields.

EXPERIMENTAL

^{1}H and ^{13}C NMR spectra were recorded with a Bruker AC-300 spectrometer with $CDCl_3$ as solvent, employing Me_4Si as internal standard (δ: 0.00) J values are given in Hz. Mass spectra were obtained by direct injection of the sample as chloroform solution by using Shimadzu GCQP 1000 mass spectrometer operating at an ionizing electron energy of 70 eV. Elemental analysis was carried out in our laboratories with a Colleman Analyser. Melting point (uncorrected) was obtained with a Thomas Hoover apparatus. Preparative thin layer chromatography (*p*-tlc) was performed on a 20×20 cm glass plate coated with silica gel 60 F_{254} (0.50 mm).

General Procedure

Styrenes or stilbenes were mixed with the catalyst (0.1 meq of catalyst/meq. of reactive) in chloroform. The resulting mixture was heated at reflux temperature and the reaction was followed using thin layer chromatography. After completion of the reaction, the catalyst was removed by filtration, washed with chloroform and dried to be reused in other reactions.[1] The solvent was evaporated under reduced pressure and the residue was purified either by recrystallization or via *p*-tlc.

Dimerization reaction of styrene 1: Oil (lit[11] 52°C). Spectroscopy data were coincident with those which appeared in the literature.[12]

Dimerization reaction of styrene 6: Reaction time: 2 h. The residue was purified by *p*-tlc and developed with hexane. The upper band yielded a mixture of *cis* and *trans* 1-metyl-3-phenylindane (**8** and **9**)[5] (**8** : **9** = 14 : 1). Yield: 47%.

The lower band yielded 1,3-diphenylbutene (**7**). Yield: 33%. ^{1}H NMR spectra of **7** correlated to the one which is shown in literature.[5] ^{13}C NMR δ 21.2 (CH_3), 42.5 (CH), 126.1 (CH=), 126.2 (CH=), 127.0, 127.3, 128.4, 135.2, 137.5, 145.6. *m*/*z*: 208 (29, M^+), 193 (30), 167 (28), 118 (91), 105 (100), 77 (86).

Dimerization reaction of styrene 10: Reaction time: 2 h. The residue afforded a mixture of *r*-1-ethyl-*c*-2-methyl-*t*-3-(3,4-methylenedioxyphenyl)-5,6-methylendioxyindane (**11**) and *r*-1-ethyl-*t*-2-methyl-*c*-3-(3,4-methylenedioxyphenyl)-5,6-methylendioxyindane (**12**). Yield 99.4%. Isomeric relation: **11** : **12** = 3 : 1. The mixture was separated by fractional crystallization from ethanol and the spectroscopy data were coincident with those which appeared in the literature.[7]

Dimerization reaction of stilbene 13: Reaction time: 2 h. The residue afforded a mixture of *r*-1-(4-bromobenzyl)-*t*-2-(4-bromophenyl)-*c*-3-(3,4-dimethoxyphenyl)-5,6-dimethoxyindane (**14**) and *r*-1-(4-bromobenzyl)-*c*-2-(4-bromophenyl)-*t*-3-(3,4-dimethoxyphenyl)-5,6-dimethoxyindane (**15**). Yield: 98%. Isomeric relation: **14** : **15** = 3 : 2. The mixture was separated by fractional crystallization from ethanol and the spectroscopy data were coincident with those which appeared in the literature.[9]

Dimerization of 3,4,3′,4′-tetramethoxystilbene (16): Reaction time: 2 h. The residue was purified by *p*-tlc using hexane : ethyl acetate (5 : 3) as eluent to give *r*-1-(3,4-dimethoxyphenyl)-*t*-2,*c*-3-*bis*-(3,4-dimethoxyphenyl)-6,7-dimethoxytetralin (**17**)[9] (lower band) and *r*-1-(3,4-dimethoxybenzyl)-*t*-2-(3,4-dimethoxyphenyl)-*c*-3-(3,4-dimethoxyphenyl)-5,6-dimethoxyindane (**18**) (upper band). Yield: 90% of cyclodimers.

***r*-1-(3,4-Dimethoxybenzyl)-*t*-2-(3,4-dimethoxyphenyl)-*c*-3-(3,4-dimethoxyphenyl)-5,6-dimethoxyindane (18):** Oil. Yield: 43%. ^{1}H NMR δ 2.86 (dd, *J* 14, *J* 8, 1H, CH_2Ar), 2.96 (br t, 1H, H-2), 3.09 (dd, *J* 5, *J* 14, 1H, CH_2Ar), 3.68, 3.72, 3.74, 3.76, 3.78, 3.83, 3.84, 3.85 (s, 24H, OCH_3), 3.85 (m, 1H, H-1), 4.16 (d, *J* 9, 1H, H-3), 6.40 (d, *J* 1.9, 1H, Ar), 6.45 (s, 1H, Ar), 6.50 (dd, *J* 1.9, *J* 8, 1H, Ar), 6.57 (d, *J* 1.9, 1H, Ar), 6.63 (m, 3H, Ar), 6.72 (m, 4H, Ar). ^{13}C NMR δ 39.4 (CH_2), 51.7 (C-1), 55.6 (OCH_3), 55.7 (OCH_3), 55.8 (OCH_3), 56.0 (OCH_3), 59.1 (C-3), 63.0 (C-2), 107.0, 107.8, 110.7, 110.8, 110.9, 111.0, 112.5, 120.0, 120.5, 121.5, 132.5, 135.2, 136.4, 136.7, 137.2, 147.2, 147.4, 148.3, 148.5. *m*/*z*: 600 (15, M^+), 449 (100, $M^+ - 3,4\text{-di-}CH_3OPhCH2$). Calcd. for $C_{36}H_{40}O_8$: C, 71.98; H, 6.71. Found: C, 71.62; H, 6.80.

Dimerization of 3,4,4′-trimethoxystilbene (19): Reaction time: 2 h. The residue was purified by *p*-tlc using hexane : ethyl acetate (3 : 1) as

eluent to give the *r*-1-(3,4-dimethoxyphenyl)-*t*-2-*c*-3-*bis*-(4-methoxyphenyl)-6,7-dimethoxytetralin (**20**) (upper band) and the *r*-1-(4-methoxybenzyl)-*t*-2-(4-methoxyphenyl)-*c*-3-(3,4-dimethoxyphenyl)-5,6-dimethoxyindane (**21**) (lower band).

***r*-1-(3,4-Dimethoxyphenyl)-*t*-2,*c*-3-*bis*-(4-methoxyphenyl)-6,7-dimethoxytetralin (20):** Oil. Yield: 44%. ^{1}H NMR δ 3.00–3.50 (m, 4H, H-2, H-3, CH_2), 3.62, 3.63, 3.71, 3.74, 3.82, 3.85 (s, 18H, OCH_3), 4.10 (d, *J* 10.1, 1H, H-1), 6.19 (s, 1H, Ar), 6.30 (m, 2H, Ar), 6.50–6.80 (m, 8H, Ar), 6.95 (d, *J* 8.7, 2H, Ar). ^{13}C NMR δ 39.5 (CH_2), 45.3 (C-3), 53.5 (C-1), 54.2 (OCH_3), 54.4 (OCH_3), 54.6 (OCH_3), 55.1 (C-2), 110.5, 110.6, 112.5, 112.6, 113.0, 113.4, 120.3, 128.5, 129.3, 130.5, 131.6, 134.2, 136.7, 138.0, 146.9, 147.2, 148.1, 157.2, 157.4. *m*/*z*: 540 (25, M^+), 419 (13.6), 389 (7.5), 269 (100, $M^+/2$). Calcd. for $C_{34}H_{36}O_6$: C, 75.53; H, 6.71. Found: C, 75.62; H, 6.85.

***r*-1-(4-Methoxybenzyl)-*t*-2-(4-methoxyphenyl)-*c*-3-(3,4-dimethoxyphenyl)-5,6-dimethoxyindane (21):** Oil, Yield: 33%. ^{1}H NMR δ 2.85 (dd, *J* 14, *J* 8 Hz, 1H, CH_2Ar), 2.96 (br t, 1H, H-2), 3.04 (dd, *J* 4.5, *J* 14, CH_2Ar), 3.74, 3.77, 3.79, 3.82, 3.83, 3.86 (s, 18H, OCH_3), 3.85 (m, 1H, H-1), 4.19 (d, *J* 9.3, 1H, H-3), 6.42 (s, 1H, Ar), 6.50 (s, 1H, Ar), 6.54 (s, 1H, Ar), 6.76 (m, 3H, Ar), 6.82 (d, *J* 8.5, 1H, Ar), 6.90 (d, *J* 8.5, 2H, Ar), 6.99 (d, *J* 8.5, 2H, Ar), 7.05 (d, *J* 8.5, 2H, Ar). ^{13}C NMR δ 38.7 (CH_2), 51.2 (C-1), 53.7 (OCH_3), 54.5 (OCH_3), 54.7 (OCH_3), 57.9 (C-3), 62,9 (C-2), 107.1, 107.7, 112.1, 112.5, 112.8, 118.9, 119.3, 127.3, 128.2, 128.3, 128.7, 129.3, 131.1, 134.4, 138.2, 138.9, 139.0, 147.3, 148.1, 148.4, 156.9, 157.0. *m*/*z*: 540 (12.3, M^+), 419 (100, $M^+ - 4CH_3OPhCH_2$). Calcd. for $C_{34}H_{36}O_6$: C, 75.58; H, 6.71. Found: C, 75.82; H, 6.78.

Dimerization fo 4,4′-dimethoxystilbene (22): Reaction time: 12 h. The crude product afforded *r*-1,*t*-2,*c*-3-*tris*(4-methoxyphenyl)-7-methoxytetralin (**23**) as an oil. Yield: 99%. ^{1}H NMR δ 3.10 (dd, *J* 4.1, *J* 16, 1H, H-4), 3.13–3.28 (m, 2H, H-4, H-2), 3.37 (td, *J* 4.1, *J* 10.5, H-3), 3.72, 3.75, 3.81, 3.88 (s, 12H, OCH_3), 4.19 (d, *J* 10.3, 1H, H-1), 6.27 (d, *J* 2.6, 1H, H-8), 6.53 (d, *J* 8.7, 2H, Ar), 6.51–6.77 (m, 9H, Ar), 6.98 (d, *J* 8.7, 2H, Ar), 7.03 (d, *J* 8.7, 1H, Ar). ^{13}C NMR δ 39.0 (CH_2), 45.4 (C-3), 53.4 (OCH_3), 53.6 (OCH_3), 53.7 (OCH_3), 54.4 (C-1), 55.0 (C-2), 111.8, 112.2, 112.4, 112.5, 113.0, 113.3, 126.4, 127.4, 127.9, 128.0, 128.2, 129.2, 134.1, 135.6, 136.6, 140.1, 156.4, 156.6, 156.8, 156.9. *m*/*z*: 480 (17.2, M^+), 359 (18.3, $M^+ - 4CH_3OPhCH_2$), 240 (100, $M^+/2$).

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