

Regio- and stereoselective Diels-Alder reaction of diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide with *N*-(4-substituted-phenyl)maleimides and maleic anhydride

Ivaylo K. Ivanov, Ismail E. Ismailov, and Valerij Ch. Christov*

Department of Organic Chemistry & Technology, Faculty of Natural Sciences, Konstantin Preslavsky University of Shumen, BG-9712 Shumen, 115, Universitetska str., Bulgaria

E-mail: vchristo@shu-bg.net

Dedicated to Professor Marko Kirilov from Sofia University, Bulgaria on the occasion of his 90th anniversary

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Abstract

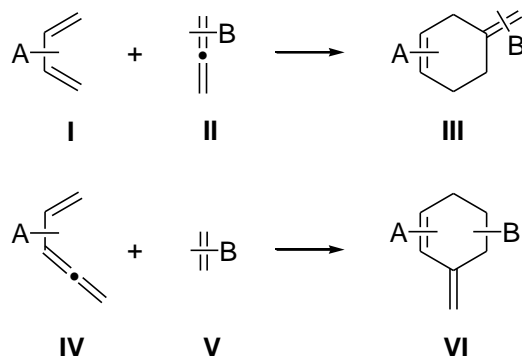
Regio- and stereoselective Diels-Alder reaction of diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide **1** with *N*-(4-substituted-phenyl)maleimides or maleic anhydride and the formation of a series of the 5-(diphenylphosphinoyl)-4-isopropylidene-2-(4-substituted-phenyl)-3a,4,7,7a-tetrahydroisindole-1,3-diones **5a-g** and the 5-(diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisobenzofuran-1,3-dione **3** respectively is described.

Keywords: Diels-Alder reaction, 1-vinylallenyl phosphine oxide, *N*-(4-substituted-phenyl)maleimides, maleic anhydride, tetrahydroisindole-1,3-diones, tetrahydroisobenzofuran-1,3-dione

Introduction

Over the past four decades, the synthesis and use of allene derivatives have been expanded in synthetic organic chemistry. An impressive number of carbo- and heterocyclic systems has been prepared from allenic starting materials.¹⁻⁶ Due to the fact that it allows the selective formation of two carbon-carbon bonds and up to four centers of chirality in a single step, the Diels-Alder reaction is perhaps one of the most important transformations in organic chemistry and is probably the most valuable and most applied reaction in synthetic organic chemistry.⁷⁻¹¹ Among the many different dienes and dienophiles employed in Diels-Alder reaction, allenes have played only a minor role.¹²⁻¹⁵ In most cases, they have been used as dienophiles (**II**) (see Scheme 1) and converted into cycloadducts (**III**) by reactions with dienes (**I**).¹⁶⁻²¹ If the allene bears another conjugated double bond, however, it can be used as the diene component (**IV**), and the Diels-

Alder reaction with dienophiles (V) gives cycloadducts with an exocyclic double bond (VI).²² However, there are only a limited number of examples for the use of vinylallenes as dienes (IV) in inter-²³⁻²⁷ and intramolecular [4+2] cycloadditions.²⁸⁻³⁴



Scheme 1. Role of the allenes as dienophiles and the vinylallenes as diene components in Diels-Alder reaction.

Compared to the application of ordinary conjugated dienes, the use of vinylallenes as diene components in Diels-Alder reaction is advantageous from the viewpoint of both reactivity and stereoselectivity.²³⁻³⁵ Thus, Bond³⁵ showed by *ab initio* calculations that the equilibrium between the *s-trans* and *s-cis* conformers is more on the side of the *s-cis* isomer for vinylallenes than it is for the 1,3-dienes. Consequently, vinylallenes exhibit a higher reactivity in [4+2] cycloadditions. In another paper, Reich et al.²³ demonstrated that Diels-Alder reaction of unfunctionalized vinylallenes takes place with high regio-, *exo-endo*-, and facial selectivity, allowing control of the stereochemistry of the cyclohexene ring and the exocyclic double bond formed.

The synthetic utility of functionalized vinylallenes has been demonstrated by Okamura and coworkers,^{31,36} in a variety of preparations and interesting reactions, including the preparation of vinylallenes which are useful intermediates in organic synthesis in general²² and natural polyenes, such as Vitamins A and D, in particular.³¹

During our previous works concerning electrophilic cyclization reactions of alkatrienyl phosphine oxides, we were able to show that 1-³⁷ and 3-vinylallenyl³⁸ phosphine oxides are readily accessible by [2,3]-sigmatropic rearrangement of the corresponding 1- and 3-vinylpropargylic phosphinites, formed in the reactions of the corresponding α -alkynols with diphenylphosphinous chloride.

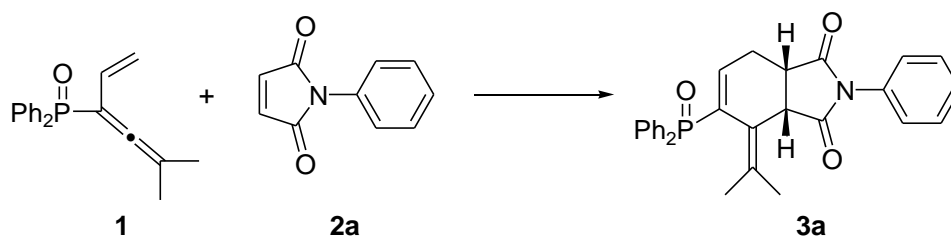
In view of the advantages of vinylallenes as the diene component in [4+2] cycloaddition reactions²³⁻³⁵ and our results on the cycloaddition reactions of vinylallenyl sulfoxides and sulfones³⁹⁻⁴² with dimethyl but-2-ynedioate⁴³ and maleic anhydride⁴⁵ as well as on the cheletropic addition of sulfur dioxide⁴⁴ to them, we therefore continued a study of the use of the diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide³⁷ in the Diels-Alder reaction with *N*-(4-substituted-phenyl)maleimides and maleic anhydride. The results of this work are presented here.

However, to the best of our knowledge, there are few reports on the Diels-Alder reaction of vinylallenes with *N*-arylmaleimides⁴⁷ and maleic anhydride⁴⁸.

Results and Discussion

To test the Diels-Alder reaction, we selected the reaction of diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide **1** with *N*-phenylmaleimide **2a** as a model reaction. The reaction conditions have been optimized in order to obtain better yields (see Table 1).

Table 1. Screening of reaction conditions for the Diels-Alder reaction of vinylalleny phosphine oxide **1** with *N*-phenylmaleimide **2a**



Entry	Solvent	Reaction temp.(°C)	Reaction time (h)	Yield ^a (%)
1	benzene	r.t.	48	42
2	benzene	reflux	14	71
3 ^c	benzene	reflux	14	60
4 ^d	benzene	reflux	14	54
5	THF	reflux	24	25
6	CH ₂ Cl ₂	reflux	24	25
7	CHCl ₃	reflux	24	28
8	ClCH ₂ CH ₂ Cl	reflux	24	32
9	EtOH	reflux	48	38
10	MeCN	reflux	48	48
11	MeNO ₂	reflux	48	53
12	EtOAc	reflux	48	40
13	toluene	reflux	13	78
14	xylene	reflux	13	63

^a Unless otherwise, the reaction was carried out with **1** (1 mmol) and **2a** (1.5 mmol) in the appropriate solvent (5 + 5 ml).

^b Isolated yields by chromatographical purification on silica gel.

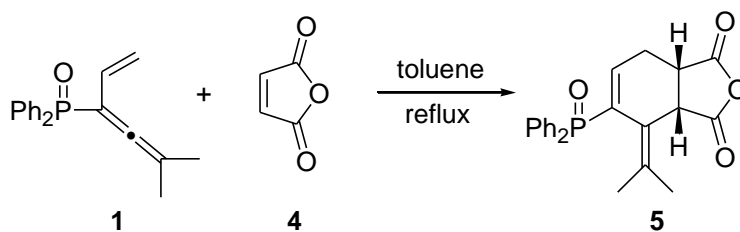
^c The reaction was carried out with **1** (1 mmol) and **2a** (1 mmol).

^d The reaction was carried out with **1** (1.5 mmol) and **2a** (1 mmol).

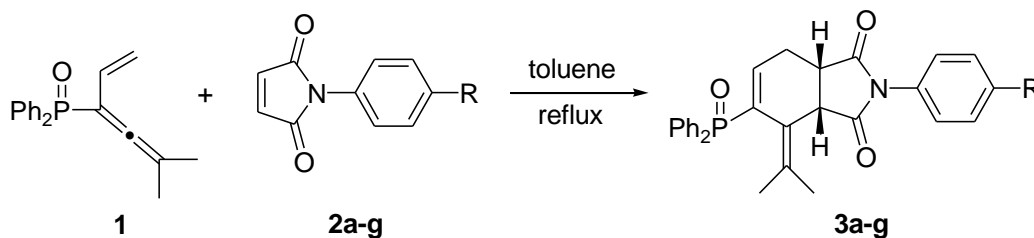
Note that when the reaction mixture was stirred in benzene at room temperature, thin-layer chromatography showed that the two reactants still interacted (much more slowly) and the reaction was complete within 48 hours with the formation of the desired cycloadduct **3a**. It is necessary to carry out this reaction under argon atmosphere since vinylallenyl phosphine oxides are sensitive to the moisture in air.^{37,38} The desired product **3a** was obtained in 42% yield (see Table 1, entry 1). When the reaction was carried out at reflux, it was complete within 14 hours and the yield was considerably higher (71%, entry 2). Lower yield was obtained in THF at reflux for 24 hours (entry 5) and similar yields were obtained in chlorinated hydrocarbons as solvents (entries 6-8). Polar solvents such as ethanol, acetonitrile, nitromethane and ethyl acetate gave low yields, even with longer reaction times (48 hours) and mainly recovered starting materials and/or polymeric residue (entries 9, 10, 11 and 12, respectively). Fortunately, when toluene was used as solvent at reflux for 13 hours, the yield improved to 78% (entry 13). Reaction in xylene at reflux for 13 hours gave lower yield (63%, entry 14). We therefore, conducted the remaining reactions in toluene at reflux using 1.0 equiv. of the 1-vinylallenyl phosphine oxide **1** and 1.5 equiv. of the dienophiles **2**. The cyclic product **3a** was fully characterized by means of NMR (¹H, ¹³C, and ³¹P), and IR spectroscopy.

Having determined the optimized condition, we explored the scope of the Diels-Alder reaction and some of the results that we obtained are listed in Table 2. Generally, when the reaction was carried out with *N*-(4-substituted-phenyl)maleimides **2a-g**, the corresponding cyclic products **3a-g** were obtained with 69-82% yield, irrespective of the electronic nature of the substituents on the benzene ring. Both electron-donating and electron-withdrawing substituents were tolerated and desired products **3a-g** were obtained in high yields.

To establish the generality of this methodology, the Diels-Alder reaction of the 1-vinylallenyl phosphine oxide **1** with classical dienophile - maleic anhydride **4** - was examined under the optimized conditions. Interestingly, this protocol can also be successfully applied to that Diels-Alder reaction and the 5-(diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisobenzofuran-1,3-dione **5** was isolated in 84% yield after heating at reflux for 12 hours (see Scheme 2). Heating at temperatures above these values (for example - in xylene) or reaction time longer than 12 hours decreases the yields due to polymerization of the starting vinylallenlic material or decomposition of the cycloadduct **5**.



Scheme 2. Diels-Alder reaction of the vinylallenyl phosphine oxide **1** with maleic anhydride **4**.

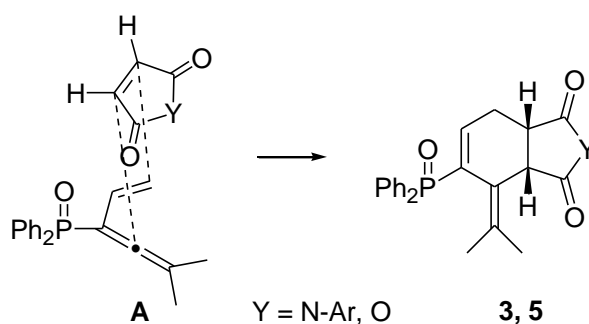
Table 2. Synthesis of a series of 5-(diphenylphosphinoyl)-4-isopropylidene-2-(4-substituted-phenyl)-3a,4,7,7a-tetrahydroisindole-1,3-diones **3a-g**

Entry ^a	R	Product	Reaction time (h)	Mp (°C)	Yield ^b (%)
1	H	3a	13	251-253	78
2	Me	3b	14	232-234	72
3	Cl	3c	12	217-219	80
4	OMe	3d	14	211-213	70
5	NMe ₂	3e	16	174-176	69
6	CO ₂ H	3f	11	290-292	80
7	NO ₂	3g	9	207-209	82

^aThe reaction was carried out with **1** (1 mmol) and **2** (1.5 mmol) in toluene at reflux.

^bIsolated yields by chromatographical purification on silica gel.

Although the exact mechanistic aspects of this transformation have not been rigorously elucidated, the following pathway could be a probable stereochemical route on the basis of experimental results as illustrated in Scheme 3.

**Scheme 3.** Stereoselective Diels-Alder reaction of the vinylallenyl phosphine oxide **1** with *N*-(4-substituted-phenyl)maleimides **2** and maleic anhydride **4**.

Structural assignments of the new cyclic compounds **3a-g** and **5** are based on the ^1H , ^{13}C , and ^{31}P NMR data, IR spectra, as well as elemental analyses. The coupling constants $J_{3a-7a}=7.0-7.2$ Hz and 9.0 Hz in the ^1H NMR spectra of cyclic products **3a-g** and **5** respectively, approve the *syn*-position of the corresponding protons^{25,44}.

Conclusions

We have developed efficient regio- and stereoselective synthesis of the 5-(diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisindole-1,3-diones **3a-g** and the 5-(diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisobenzofuran-1,3-dione **5** via Diels-Alder reaction of the diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide **1** with *N*-(4-substituted-phenyl)maleimides and maleic anhydride as dienophiles.

This study reveals the possibility for synthetic innovations as well as the potential of the Diels-Alder reaction of the vinylallenyl phosphine oxides to selectively construct exocyclic double bond on six-membered rings. Further expansion and applications of this methodology are in progress at our laboratories and will be reported in due course.

Results of an initial investigation of the physiological activity of the compounds prepared were encouraging and the activity of selected compounds is now under investigation. A continuation of these studies towards the synthesis and electrophilic cyclization and cycloaddition reactions of other functionalized vinylallenes is currently in progress in our laboratories.

Experimental Section

General. The melting points were measured in open capillary tubes and are uncorrected. IR spectra were recorded with a SHIMADZU Fourier Transform Infrared spectrophotometer IRAFFINITY-1. ^1H , ^{13}C and ^{31}P NMR spectra were recorded at 250.1, 62.9 and 101.2 MHz respectively on a BRUCKER DRX-250 spectrometer or at 600.1, 150.9 and 242.9 MHz on a Bruker Avance II+600 spectrometer with $\text{DMSO}-d_6$ as solvent. ^1H and ^{13}C NMR chemical shifts (δ) are reported in parts per million (ppm) with respect to internal tetramethylsilane (TMS) and ^{31}P NMR chemical shifts (δ) are reported in ppm relative to 85% H_3PO_4 as external standard. Elemental analyses for C, H and N were obtained using a Vario EL III Element Analyzer. Maleic anhydride **4** and *N*-phenylmaleimide **2a** were purchased from Sigma-Aldrich-Fluka and used without further purification. The remainder dienophiles - 1-(4-methylphenyl)-pyrrole-2,5-dione **2b**, 1-(4-chlorophenyl)-pyrrole-2,5-dione **2c**, 1-(4-methoxyphenyl)-pyrrole-2,5-dione **2d**, 1-(4-dimethylaminophenyl)pyrrole-2,5-dione **2e**, 4-(2,5-dioxo-2,5-dihydro-pyrrol-1-yl)benzoic acid **2f**, and 1-(4-nitrophenyl)-pyrrole-2,5-dione **2g** were synthesized according to the established procedure.⁴⁶ The diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide **1** was synthesized and

described in our earlier paper.³⁷ Column chromatography was performed on Kieselgel F₂₅₄60 (70–230 mesh ASTM, 0.063–0.200 nm, Merck). The solvents for chromatography were purified by standard methods. Dry toluene was distilled from sodium diphenylketyl under argon just prior to use. Reactions were carried out in oven-dried glassware under an argon atmosphere and exclusion of moisture. All compounds were checked for purity on TLC plates Kieselgel F₂₅₄60, Merck.

General synthetic procedure of the regio- and stereoselective Diels-Alder reaction of diphenyl 5-methylhexa-1,3,4-trien-3-yl phosphine oxide 1 with *N*-(4-substituted-phenyl)maleimides 2a-g and maleic anhydride 4. To a solution of vinylallene 1 (0.29 g, 1 mmol) in dry toluene (5 ml) was added a solution of *N*-(4-substituted-phenyl)maleimide 2a-g (1.5 mmol) or maleic anhydride 2 (0.15 g, 1.5 mmol) in the same solvent (5 ml) under an argon atmosphere, and the mixture was stirred for 15 min. Then, the mixture was heated at reflux for several hours (see Table 2, in the case of maleic anhydride 2 – for 12 hours). After the reaction was completed as monitored by TLC (eluent: ethyl acetate-hexane 4:1), the solvents were evaporated under reduced pressure to give a residue, which was purified by silica gel with ethyl acetate/hexane as eluent to afford the cyclic products, which had the following properties:

5-(Diphenylphosphinoyl)-4-isopropylidene-2-phenyl-3a,4,7,7a-tetrahydroisoindole-1,3-dione (3a). White crystals, yield 78%, 0.36 g, mp 251-253 °C; IR (ν_{\max} , cm⁻¹): 1775 and 1711 (C=O), 1579-1605 (C=C-C=C), 1439, 1458 (Ph), 1174 (P=O). ¹H NMR (250.1 MHz, DMSO-*d*₆): δ_{H} 1.48 (s, 3H, CH₃), 1.84 (s, 3H, CH₃), 2.23 (m, 2H, H₇), 3.60 (tt, *J* 7.2 Hz, *J* 5.0 Hz, 1H, H_{7a}), 4.54 (d, *J* 7.2 Hz, 1H, H_{3a}), 6.62 (tt, *J* 4.2 Hz, *J* 17.7 Hz, 1H, H₆), 7.10-7.21 (m, 5H, Ph-N), 7.31-7.68 (m, 10H, 2Ph-P). ¹³C NMR (62.9 MHz, DMSO-*d*₆): δ_{C} 25.1 (2CH₃), 26.7 (*J* 7.9 Hz, C-7), 44.0 (*J* 4.7 Hz, C-7a), 46.2 (*J* 8.0 Hz, C-3a), 126.4-128.3 (Ph-N), 127.2-134.6 (2Ph-P), 134.1 (*J* 6.2 Hz, C-4), 135.0 (*J* 7.9 Hz, C(CH₃)₂), 144.6 (*J* 119.0 Hz, C-5), 148.2 (*J* 6.9 Hz, C-6), 177.0 (C-1), 179.1 (C-3). ³¹P NMR (101.2 MHz, DMSO-*d*₆): δ_{P} = 23.2. Anal. Calcd for C₂₉H₂₆NO₃P (467.50): C, 74.51; H, 5.61; N, 3.00. Found: C, 74.47; H, 5.56; N, 3.04.

5-(Diphenyl-phosphinoyl)-4-isopropylidene-2-(4-methylphenyl)-3a,4,7,7a-tetrahydroisoindole-1,3-dione (3b). Yellow crystals, yield 72%, 0.35 g, mp 232-234 °C; IR (ν_{\max} , cm⁻¹): 1780 and 1709 (C=O), 1570-1587 (C=C-C=C), 1439, 1458 (Ph), 1173 (P=O). ¹H NMR (600.1 MHz, DMSO-*d*₆): δ_{H} 1.48 (s, 3H, CH₃), 1.82 (s, 3H, CH₃), 2.22 (m, 2H, H₇), 2.37 (s, 3H, CH₃), 3.58 (tt, *J* 7.0 Hz, *J* 5.1 Hz, 1H, H_{7a}), 4.51 (d, *J* 7.0 Hz, 1H, H_{3a}), 6.60 (tt, *J* 4.2 Hz, *J* 17.2 Hz, 1H, H₆), 7.04-7.12 (m, 4H, C₆H₄), 7.30-7.70 (m, 10H, 2Ph). ¹³C NMR (150.9 MHz, DMSO-*d*₆): δ_{C} 21.4 (CH₃), 24.8 (2CH₃), 25.9 (*J* 8.0 Hz, C-7), 44.4 (*J* 5.0 Hz, C-7a), 45.8 (*J* 7.9 Hz, C-3a), 125.1-127.1 (C₆H₄), 128.0-134.4 (2Ph), 133.7 (*J* 6.0 Hz, C-4), 135.4 (*J* 7.7 Hz, C(CH₃)₂), 143.9 (*J* 118.4 Hz, C-5), 144.9 (*J* 6.7 Hz, C-6), 177.2 (C-1), 179.1 (C-3). ³¹P NMR (242.9 MHz, DMSO-*d*₆): δ_{P} = 21.8. Anal. Calcd for C₃₀H₂₈NO₃P (481.52): C, 74.83; H, 5.86; N, 2.91. Found: C, 74.90; H, 5.90; N, 2.83.

2-(4-Chlorophenyl)-5-(diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisoindole-1,3-dione (3c). White crystals, yield 80%, 0.40 g, mp 217-219 °C; IR (ν_{\max} , cm⁻¹):

1772 and 1713 (C=O), 1580-1595 (C=C-C=C), 1437, 1456 (Ph), 1179 (P=O). ^1H NMR (600.1 MHz, DMSO- d_6): δ_{H} 1.46 (s, 3H, CH₃), 1.86 (s, 3H, CH₃), 2.21 (m, 2H, H₇), 3.62 (tt, J 7.1 Hz, J 5.0 Hz, 1H, H_{7a}), 4.52 (d, J 7.1 Hz, 1H, H_{3a}), 6.64 (tt, J 4.1 Hz, J 17.2 Hz, 1H, H₆), 7.12-7.21 (m, 4H, C₆H₄), 7.33-7.66 (m, 10H, 2Ph). ^{13}C NMR (150.9 MHz, DMSO- d_6): δ_{C} 23.4 (2CH₃), 25.2 (J 8.1 Hz, C-7), 44.3 (J 4.8 Hz, C-7a), 46.6 (J 7.8 Hz, C-3a), 125.2-127.9 (C₆H₄), 128.2-133.4 (2Ph), 134.4 (J 5.9 Hz, C-4), 136.1 (J 8.0 Hz, C(CH₃)₂), 142.8 (J 120.1 Hz, C-5), 145.3 (J 7.0 Hz, C-6), 176.8 (C-1), 178.8 (C-3). ^{31}P NMR (242.9 MHz, DMSO- d_6): δ_{P} = 23.1. Anal. Calcd for C₂₉H₂₅ClNO₃P (501.94): C, 69.39; H, 5.02; N, 2.79. Found: C, 69.33; H, 4.97; N, 2.85.

5-(Diphenylphosphinoyl)-4-isopropylidene-2-(4-methoxyphenyl)-3a,4,7,7a-tetrahydroisoindole-1,3-dione (3d). White crystals, yield 70%, 0.35 g, mp 211-213 °C; IR (ν_{max} , cm⁻¹): 1777 and 1707 (C=O), 1581-1614 (C=C-C=C), 1437, 1458 (Ph), 1190 (P=O). ^1H NMR (250.1 MHz, DMSO- d_6): δ_{H} 1.49 (s, 3H, CH₃), 1.80 (s, 3H, CH₃), 2.20 (m, 2H, H₇), 3.39 (s, 3H, OCH₃), 3.57 (tt, J 7.1 Hz, J 4.9 Hz, 1H, H_{7a}), 4.52 (d, J 7.1 Hz, 1H, H_{3a}), 6.62 (tt, J 4.3 Hz, J 17.1 Hz, 1H, H₆), 7.04-7.12 (m, 4H, C₆H₄), 7.34-7.68 (m, 10H, 2Ph). ^{13}C NMR (62.9 MHz, DMSO- d_6): δ_{C} 23.0 (2CH₃), 25.5 (J 8.0 Hz, C-7), 43.7 (J 4.7 Hz, C-7a), 45.5 (J 8.0 Hz, C-3a), 55.7 (OCH₃), 122.4-125.3 (C₆H₄), 128.0-134.2 (2Ph), 133.4 (J 5.7 Hz, C-4), 136.2 (J 7.9 Hz, C(CH₃)₂), 141.8 (J 120.2 Hz, C-5), 147.2 (J 6.9 Hz, C-6), 177.4 (C-1), 179.2 (C-3). ^{31}P NMR (101.2 MHz, DMSO- d_6): δ_{P} = 23.8. Anal. Calcd for C₃₀H₂₈NO₄P (497.52): C, 72.42; H, 5.67; N, 2.82. Found: C, 72.49; H, 5.73; N, 2.89.

2-(4-Dimethylaminophenyl)-5-(diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisoindole-1,3-dione (3e). Orange crystals, yield 69%, 0.35 g, mp 174-176 °C; IR (ν_{max} , cm⁻¹): 1777 and 1707 (C=O), 1581-1614 (C=C-C=C), 1437, 1458 (Ph), 1190 (P=O). ^1H NMR (250.1 MHz, DMSO- d_6): δ_{H} 1.48 (s, 3H, CH₃), 1.82 (s, 3H, CH₃), 2.18 (m, 2H, H₇), 2.94 (s, 6H, N(CH₃)₂), 3.55 (tt, J 7.0 Hz, J 5.1 Hz, 1H, H_{7a}), 4.50 (d, J 7.0 Hz, 1H, H_{3a}), 6.58 (tt, J 4.1 Hz, J 17.4 Hz, 1H, H₆), 7.06-7.12 (m, 4H, C₆H₄), 7.32-7.70 (m, 10H, 2Ph). ^{13}C NMR (62.9 MHz, DMSO- d_6): δ_{C} 23.4 (2CH₃), 25.4 (J 7.9 Hz, C-7), 41.7 (N(CH₃)₂), 43.4 (J 5.0 Hz, C-7a), 45.2 (J 7.7 Hz, C-3a), 121.9-124.7 (C₆H₄), 127.6-134.0 (2Ph), 132.9 (J 6.0 Hz, C-4), 136.4 (J 8.0 Hz, C(CH₃)₂), 143.7 (J 118.0 Hz, C-5), 147.5 (J 7.0 Hz, C-6), 177.6 (C-1), 179.4 (C-3). ^{31}P NMR (101.2 MHz, DMSO- d_6): δ_{P} = 23.9. Anal. Calcd for C₃₁H₃₁N₂O₃P (510.56): C, 72.93; H, 6.12; N, 5.49. Found: C, 72.84; H, 6.15; N, 5.44.

4-[5-(Diphenylphosphinoyl)-4-isopropylidene-1,3-dioxo-1,3,3a,4,7,7a-hexahydroisoindol-2-yl]benzoic acid (3f). Pale yellow crystals, yield 80%, 0.41 g, mp 290-292 °C; IR (ν_{max} , cm⁻¹): 1778 and 1709 (C=O), 1589-1605 (C=C-C=C), 1437, 1462 (Ph), 1150 (P=O). ^1H NMR (600.1 MHz, DMSO- d_6): δ_{H} 1.50 (s, 3H, CH₃), 1.85 (s, 3H, CH₃), 2.21 (m, 2H, H₇), 3.62 (tt, J 7.2 Hz, J 4.9 Hz, 1H, H_{7a}), 4.55 (d, J 7.2 Hz, 1H, H_{3a}), 6.62 (tt, J 4.2 Hz, J 17.2 Hz, 1H, H₆), 7.43-7.75 (m, 10H, 2Ph), 8.05-8.20 (m, 4H, C₆H₄), 9.32 (1H, s, CO₂H). ^{13}C NMR (150.9 MHz, DMSO- d_6): δ_{C} 23.6 (2CH₃), 25.3 (J = 8.1 Hz, C-7), 44.0 (J 4.9 Hz, C-7a), 46.7 (J 7.9 Hz, C-3a), 126.0-128.2 (C₆H₄), 128.4-135.2 (2Ph), 134.0 (J 6.1 Hz, C-4), 136.3 (J 7.8 Hz, C(CH₃)₂), 146.3 (J = 119.4 Hz, C-5), 149.0 (J 6.7 Hz, C-6), 169.9 (CO₂H), 176.7 (C-1), 178.8 (C-3). ^{31}P NMR (242.9 MHz,

DMSO- d_6): $\delta_p = 23.3$. Anal. Calcd for $C_{30}H_{26}NO_5P$ (511.50): C, 70.44; H, 5.12; N, 2.74. Found: C, 70.48; H, 5.05; N, 2.70.

5-(Diphenylphosphinoyl)-4-isopropylidene-2-(4-nitrophenyl)-3a,4,7,7a-tetrahydroisindole-1,3-dione (3g). Yellow crystals, yield 82%, 0.42 g, mp 207-209 °C; IR (ν_{max} , cm^{-1}): 1775 and 1680 (C=O), 1597-1618 (C=C-C=C), 1464, 1493 (Ph), 1179 (P=O). 1H NMR (250.1 MHz, DMSO- d_6): δ_H 1.52, (s, 3H, CH_3), 1.88 (s, 3H, CH_3), 2.22 (m, 2H, H_7), 3.64 (tt, J 7.1 Hz, J 5.1 Hz, 1H, H_{7a}), 4.58 (d, J 7.1 Hz, 1H, H_{3a}), 6.64 (tt, J 4.1 Hz, J 17.0 Hz, 1H, H_6), 7.46-7.78 (m, 10H, 2Ph), 8.20-8.40 (m, 4H, C_6H_4). ^{13}C NMR (62.9 MHz, DMSO- d_6): δ_C 23.4 (2 CH_3), 25.1 (J 7.8 Hz, C-7), 43.9 (J 5.0 Hz, C-7a), 46.3 (J 8.0 Hz, C-3a), 125.3-127.9 (C_6H_4), 127.4-133.8 (2Ph), 134.2 (J 6.0 Hz, C-4), 136.6 (J 8.1 Hz, $C(CH_3)_2$), 145.3 (J 120.1 Hz, C-5), 150.1 (J 7.1 Hz, C-6), 177.0 (C-1), 178.4 (C-3) ^{31}P NMR (101.2 MHz, DMSO- d_6): $\delta_p = 28.5$. Anal. Calcd for $C_{29}H_{25}N_2O_5P$ (512.49): C, 67.96; H, 4.92; N, 5.47. Found: C, 68.04; H, 4.88; N, 5.54.

5-(Diphenylphosphinoyl)-4-isopropylidene-3a,4,7,7a-tetrahydroisobenzofuran-1,3-dione (5). White crystals, yield 84%, 0.33 g, mp 116-118 °C; IR (ν_{max} , cm^{-1}): 1842 and 1778 (C=O), 1578-1615 (C=C-C=C), 1434, 1474 (Ph), 1169 (P=O). 1H NMR (250.1 MHz, DMSO- d_6): δ_H 1.54 (s, 3H, CH_3) 1.68 (s, 3H, CH_3), 2.21 (m, 2H, H_7), 2.80 (tt, J 9.0 Hz, J 5.1 Hz, 1H, H_{7a}), 4.70 (d, J 9.0 Hz, 1H, H_{3a}), 6.31 (tt, J 4.1 Hz, J 17.4 Hz, 1H, H_6), 7.34-7.76 (m, 10H, 2Ph). ^{13}C NMR (62.9 MHz, DMSO- d_6): δ_C 24.4 (2 CH_3), 27.2 (J 8.1 Hz, C-7), 43.8 (J 4.7 Hz, C-7a), 45.9 (J 7.8 Hz, C-3a), 128.3-135.2 (2Ph), 133.8 (J 6.1 Hz, C-4), 134.6 (J 7.6 Hz, $C(CH_3)_2$), 144.1 (J 117.0 Hz, C-5), 149.4 (J 6.7 Hz, C-6), 173.2 (C-1), 173.9 (C-3). ^{31}P NMR (101.2 MHz, DMSO- d_6): $\delta_p = 27.9$. Anal. Calcd for $C_{23}H_{21}O_4P$ (392.38): C, 70.40; H, 5.39. Found: C, 70.47; H, 5.35.

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