JOC The Journal of Organic Chemistry

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J. Org. Chem., **Just Accepted Manuscript** • DOI: 10.1021/acs.joc.7b01527 • Publication Date (Web): 23 Aug 2017

Just Accepted

ACS Publications

The Journal of Organic Chemistry is published by the American Chemical Society.
1155 Sixteenth Street N.W., Washington, DC 20036

Copper-catalyzed Oxidative Alkylation (Methylation) of Phosphonamides and Phosphinamides by Using Dicumyl Perxide

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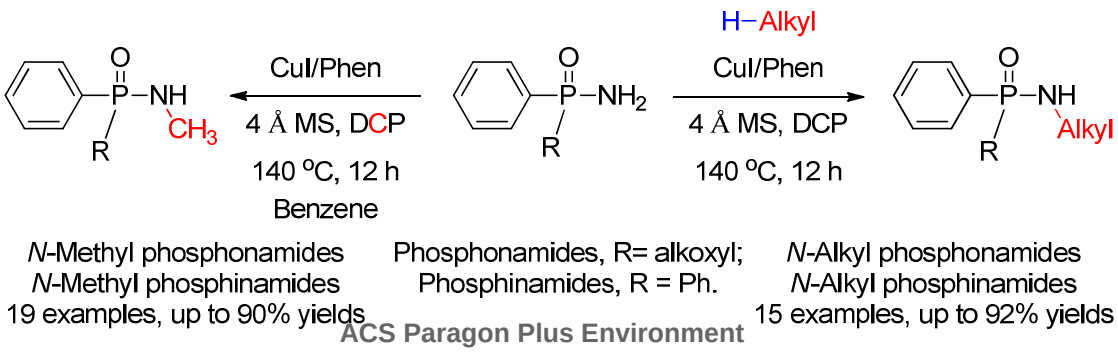
ABSTRACT

An effective and practical CuI-catalyzed methodology towards *N*-alkyl or *N*-methyl phosphonamides and phosphinamides was herein demonstrated. The transformation took place readily under the oxidative conditions, and plenty of *N*-alkylated (methylated) amides (30 examples) were successfully furnished in high efficiency (up to 92% yields). Dicumyl peroxide was considered to act either as the oxidant for the alkylation reaction, or methyl donator for the methylation protocol.



INTRODUCTION

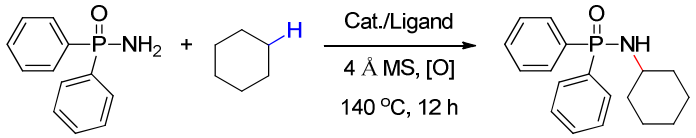
Phosphonamides and phosphinamides, which represents typical amino-fused organophosphorus compounds,[1] have gained increasing interests due to not only the unique structures, but also the distinguished properties in pharmaceutical applications and material science.[2] As well, the chiral *P*-centered modules have been successfully designed for enantioselective sysnthesis.[3] Apart from this, they have been considered as pivotal intermediates for formations of heterocycles such as benzazaphosphole-1-oxides and phosphaisoquinolin-1-oxides[4] which were biologically active molecules. Thus, considerable attention has been paid for the derivations of the versatile compounds. And, rapid growth has been gained on the motifs ever since the first example of direct arylation of phosphinamides by aryl iodides with assistance of Cu(I)-catalysis.[5] Howbeit, methodologies for alkylation (methylation) by using inactive alkanes, have never been reported due to the instabilities of the P-N bonds.[6] Therefore, it is still highly required for alkylation (methylation) of phosphonamides and phosphinamide because of the magic methyl effect[7] and subsequent medicinal explorations. Typically, reactions between phosphoryl chlorides and alkyl amines were invovled for the synthesis of *N*-alkyl products, releasing halo wastes.[8] Beware of that, protocols employing peroxides, which could act as multiple roles as either the oxidant[9] for the coupling of nucleophiles, or methyl donators,[10-12] which have been well-established for the formations of C-C,[10] C-O[11] and C-N[12] bonds. Herein we also wished to disclose an effective and practical method towards *N*-alkyl (methyl) phosphonamides or phosphinamides in a Cu-catalysis. The novel method featured for (1) effective flexible mono alkylation/methylation in a step/atomic-economic fasion in the presence of DCP (dicumyl peroxide) and (2) P-N bonds' maintainabilities under the oxidative conditions.

RESULTS AND DISCUSSION

Firstly, diphenyl phosphinamide (**1a**) and cyclohexane (**2a**) were chosen as the model substrates for the optimization of the conditions as summarized in Table 1. To our delight, 1,10-phenanthroline-liganded CuI made the coupling reaction take place in the presence of DTBP (di-*tert* butyl peroxide), and the

desired *N*-alkylated phosphinamide **3aa** was successfully isolated in 74% yield (entry 1). However, other oxidants, such as TBHP (*tert*-butyl hydroperoxide, 70% in water, entry 2), $K_2S_2O_8$ (entry 3), Ag_2CO_3 (entry 4) and DDQ (2,3-dicyano-5,6-dichlorobenzoquinone for entry 5) failed to make the alkylation reaction occur except DCP (dicumyl peroxide for entry 6), which enabled the occurance of the reaction in high efficiency, up to 90% yield after isolation. Screening on the ligands proved that 1,10-phenanthroline was crucial to the useful transformation because only trace product was observed in the presence of TMEDA (tetramethyl ethylenediamine for entry 7) and DMEDA (dimethyl ethanediamine for entry 8) or even no reaction was detected in the absence of any ligands (entry 9). Other copper or copprus catalysts, for example, CuBr, $CuCl_2$ and $Cu(OAc)_2$ offered inferior performance to CuI did, for **3aa** was isolated in yields ranging from 58% to 78% (entries 10 – 12). Ferric-catalysts, exemplfied by $FeCl_3$ and other organo-catalyts such as TBAI (tetra-*tert*-butyl ammonium iodide) and elemental iodine were found totally useless to the transformation (entries 13 to 15).

Table 1. Conditions Optimization[a]



1a **2a** **3aa**

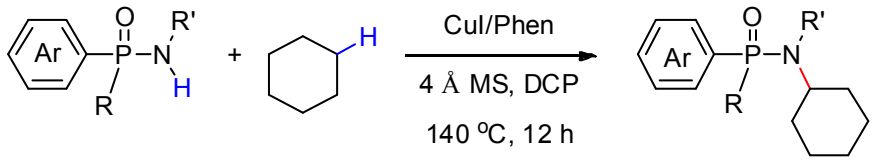
Entry	Cat.	Ligand	[O]	Yield[c]
1	CuI	Phen[b]	DTBP	74%
2	CuI	Phen[b]	TBHP	n.d.[d]
3	CuI	Phen[b]	$K_2S_2O_8$	n.d.
4	CuI	Phen[b]	Ag_2CO_3	n.d.
5	CuI	Phen[b]	DDQ	n.d.
6	**CuI**	Phen[b]	**DCP**	**90%**
7	CuI	TMEDA	DCP	trace
8	CuI	DMEDA	DCP	trace
9	CuI	--	DCP	n.d.
10	CuBr	Phen[b]	DCP	78%
11	$CuCl_2$	Phen[b]	DCP	72%
12	$Cu(OAc)_2$	Phen[b]	DCP	58%
13	$FeCl_3$	Phen[b]	DCP	n.d.

14	TBAI	--	DCP	n.d.
15	I_2	--	DCP	n.d.

[a]**1a** (0.2 mmol), **2a** (2.0 mL, ca. 20 mmol), Cat. (10 mol%), Ligand (10 mol%), 4 Å MS (powdered, 200 wt%), [O] (2.0 equiv.) at 140 °C in sealed tube for 12 h. [b]stands for 1,10-phenanthroline. [b]Isolated yields.[d]stands for not detected.

With the optimized reaction conditions successfully established, substrate scope and limitations of phosphonamides and phosphinamides were evaluated as summarized in Table 2. It was found that *P*-alkoxyl phosphonamides were compatible in the CuI-mediated system. For example, *P*-methoxy-, *P*-ethoxy-, *P*-isopropoxy- and *P*-*n*-butoxy-*P*-phenyl phosphonamides (**1b** – **1e**) coupled freely with **2a**, furnishing the desired *N*-cyclohexyl phosphonamides **3ba** – **3ea** in yields ranging from 78% to 82% (entries 1 – 4). In the similar pattern, *P*-methoxyethoxy-*P*-phenyl phosphonamide **1f** and *P*-chloropropoxy-*P*-phosphonamide **1g** reacted with **2a** under oxidative conditions, providing the corresponding *N*-alkylated phosphonamides **3fa** and **3ga** in 76% and 88% yields, respectively (entries 5 and 6). Subsequently, the tolerance of (un)substituted benzyloxy groups were also checked in the protocol. Luckily, *P*-benzyloxy- (entry 7), *P*-(3-fluorobenzyloxy)- (entry 8), *P*-(4-chlorobenzyloxy)- (entry 9) amd *P*-(2-bromobenzyloxy)- (entry 10) *P*-phenyl phosphonamides **1h** – **1k** underwent the alkylation reaction smoothly under the Cu(I)-catalysis, giving the *N*-cyclohexylated products **3ha** – **3ka** in yields from 75% to 90%. Also, *P,P*-di-(*p*-tolyl) phosphinamide (**1l**) and *P,P*-di-(2-thiophenyl) phosphinamide (**1m**) coupled with **2a** readily, offering the desired *N*-alkyl phosphinamides **3la** and **3ma** in 85% and 78% yields, respectively (entries 11 and 12). Moreover, the activities of *N*-monosubstituted phosphinamides were also examined in the system. And *N*-methyl-*P,P*-diphenyl phosphinamide (**1n**) furnished the desired *N*-dialkyl phosphinamide **3na** in 48% yield, while *N,P,P*-triphenyl phosphinamide (**1o**) offered the corresponding *N*-cyclohexyl product **3oa** in 79% yield (entries 13 and 14).

Table 2. Scope of Phosphonamides and Phosphinamides[a]



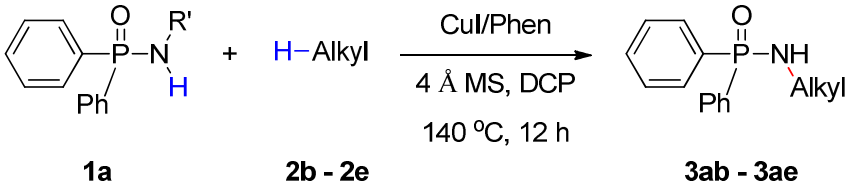
1b - 1o **2a** **3ba - 3oa**

Entry	Ar	R	R'	3	Yield[b]
1	C_6H_5	CH_3O	H	**3ba**	85%
2	C_6H_5	C_2H_5O	H	**3ca**	80%
3	C_6H_5	*i*PrO	H	**3da**	78%
4	C_6H_5	C_4H_9O	H	**3ea**	82%
5	C_6H_5	$CH_3O(CH_2)_2O$	H	**3fa**	76%
6	C_6H_5	$Cl(CH_2)_3O$	H	**3ga**	88%
7	C_6H_5	$C_6H_5CH_2O$	H	**3ha**	81%
8	C_6H_5	3-$FC_6H_4CH_2O$	H	**3ia**	76%
9	C_6H_5	4-$ClC_6H_4CH_2O$	H	**3ja**	90%
10	C_6H_5	2-$BrC_6H_4CH_2O$	H	**3ka**	75%
11	4-$CH_3C_6H_4$	4-$CH_3C_6H_4$	H	**3la**	85%
12	2-Thiophenyl	2-Thiophenyl	H	**3ma**	78%
13	Ph	Ph	CH_3	**3na**	48%
14	Ph	Ph	C_6H_5	**3oa**	79%

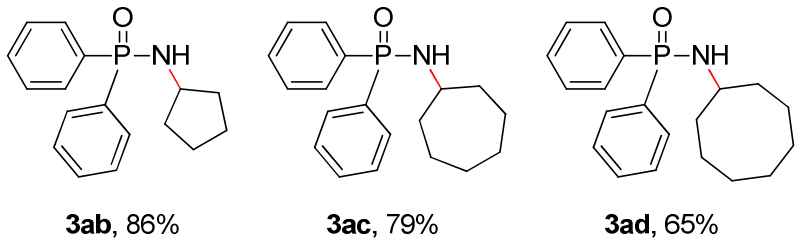
[a]**1a** (0.5 mmol), **2a** (5.0 mL, ca. 50 mmol), CuI (10 mol%), Phen (10 mol%), 4 Å MS (powdered, 200 wt%), DCP (2.0 equiv.) at 140 °C in sealed tube for 12 h. [b]Isolated yields.

The activities of various alkanes for the coupling reaction were also tested in the copper-catalysis as shown in Scheme 1. Except cyclohaxane, cyclopentane (**2b**), cycloheptane (**2c**) and cyclooctane (**2d**) coupled with *P*,*P*-diphenyl phosphinamide (**1a**) freely, and different *N*-cycloalkyl-*P*,*P*-diphenyl phosphinamides **3ab** – **3ad** in 65% - 86% yields. Chained hexane (**2e**) underwent the alkylation reaction with *P,P*-diphenyl phosphinamide (**1a**), offering *N*-2-hexyl phosphinamide (**3ae**) and *N*-3-hexyl phosphinamide (**3ae'**) in a combined 75% yield with a 1:1 ratio (by ^{1}H-NMR calculation).

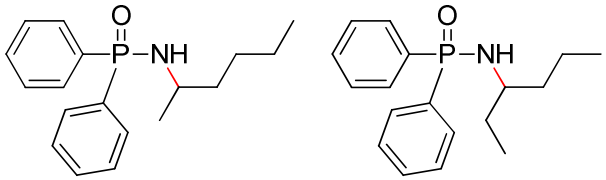
Scheme 1. Scope of alkanes[a]



1a **2b - 2e** **3ab - 3ae**



3ab, 86% **3ac**, 79% **3ad**, 65%

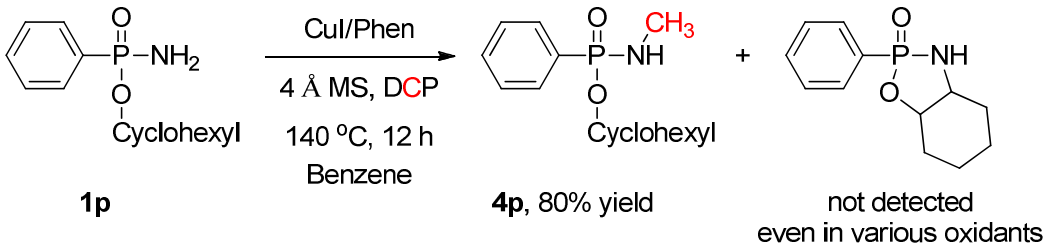


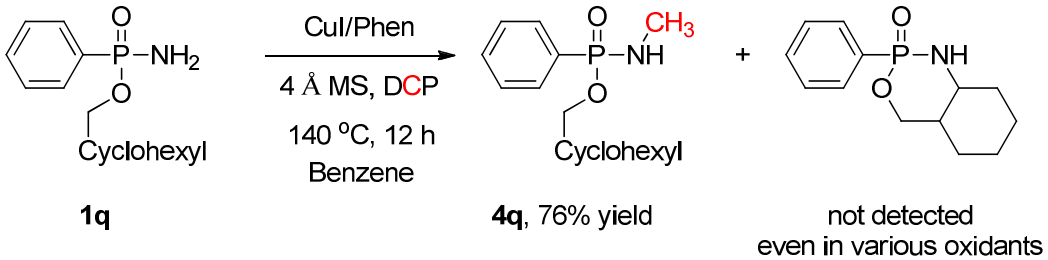
3ae+3ae', 75% (1:1 by NMR)

[a]**1a** (0.5 mmol), **2a** (5.0 mL, ca. 50 mmol), CuI (10 mol%), Phen (10 mol%), 4 Å MS (powdered, 200 wt%), DCP (2.0 equiv.) at 140 °C in sealed tube for 12 h. [b]Isolated yields.

Inspired by the good results of the intermolecular alkylation reactions, intramolecular alkylation was designed on the substrates of *P*-cyclohexyloxy-*P*-phenyl phosphonamides (**1p**) and *P*-cyclohexylmethoxy-*P*-phenyl phosphonamides (**1q**) for the construction of five or six-membered O-P-N-backboned heterocyclic compounds (Scheme 2).

Scheme 2. Unexpected Methylation Reactions

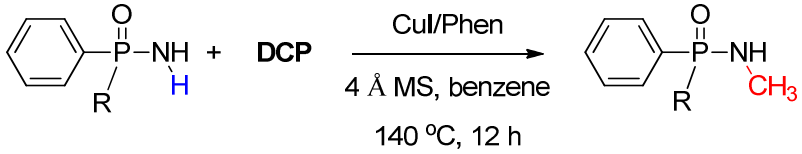




However, beyond our expectations, intramolecular coupling failed to happen under the oxidative conditions, even in the presence of other organic oxidants, such as AIBN (azobisisobutyronitrile), BPO (Dibenzoyl peroxide), DTBP or DDQ. Instead, *N*-methylated phosphonamides **4p** and **4q** were obtained successfully in 80% and 76% yields after separation, in which the oxidant DCP was considered to act as the methyl provider in the reaction.[12]

Under the modified conditions, the scope of the substrates was evaluated as shown in Table 3. Phosphinamide **1a** was readily methylated and corresponding product **4a** was isolated in 88% yield (entry 1). Chained alkoxy decorated phosphonamides, for instance, methoxy (entry 2), ethoxy (entry 3), isopropoxy (entry 4), *n*-butoxy (entry 5), methoxyethoxy (entry 6) and chloropropoxy (entry 7) were well-compatible in the system and the desired products **4b** – **4g** were separated in yields from 80% to 90%. Similarly, (un)substituted benzyl fused phosphonamides also were coupled with DCP and *N*-methylated molecules **4h** – **4k** were furnished in 67% - 82% yields (entries 8 – 11). Other phosphinamides, such as *P,P*-di-(*p*-tolyl) (entry 12) and *P,P*-di-(2-thiophenyl) (entry 13) phosphinamides **1l** and **1m** were successfully methylated under the oxidative conditions, providing the corresponding products **4l** and **4m** in 82% and 76% yields, respectively.

Table 3. Scope of Phosphonamides and Phosphinamides[a]



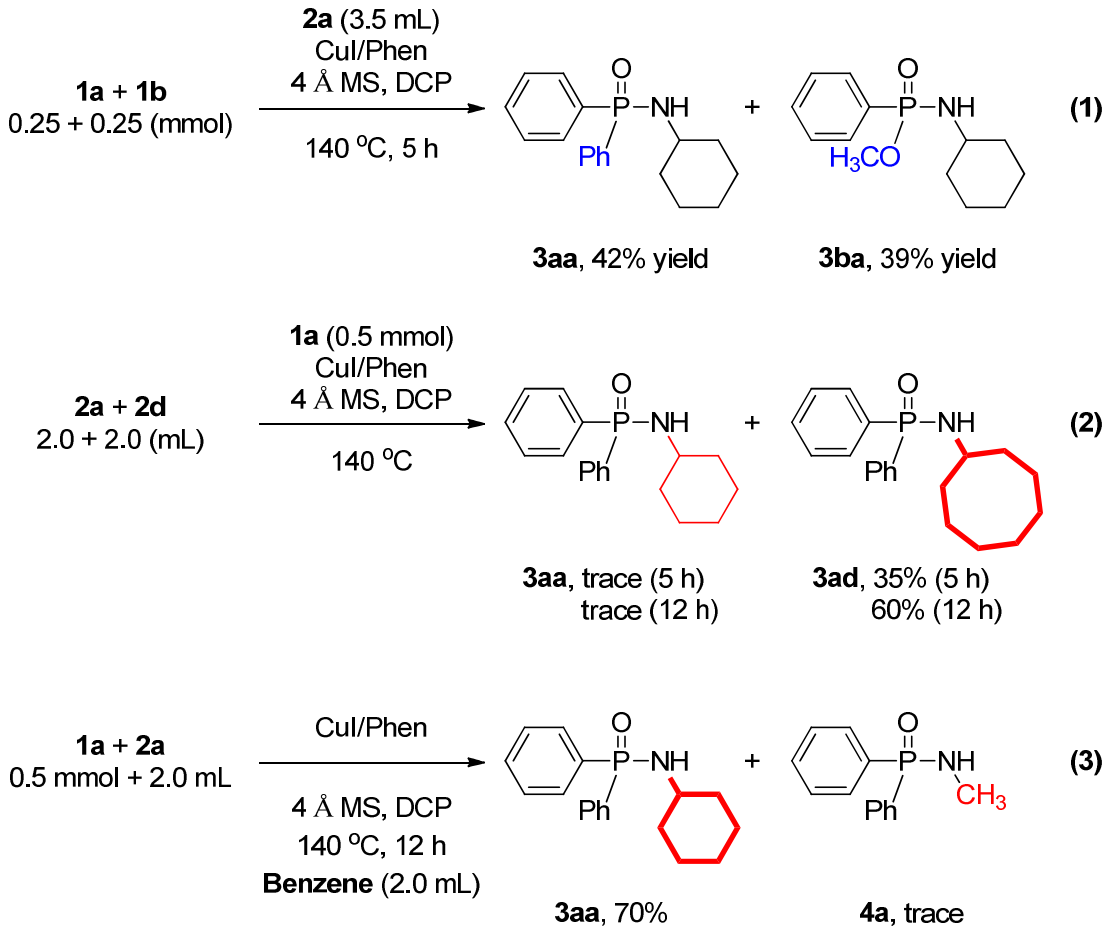
	1a - 1m		4a - 4m	
Entry	Ar	R	**1/4**	Yield[b]
1	C_6H_5	C_6H_5	**1a/4a**	88%
2	C_6H_5	CH_3O	**1b/4b**	90%
3	C_6H_5	C_2H_5O	**1c/4c**	85%
4	C_6H_5	*i*PrO	**1d/4d**	86%
5	C_6H_5	C_4H_9O	**1e/4e**	92%
6	C_6H_5	$CH_3O(CH_2)_2O$	**1f/4f**	82%
7	C_6H_5	$Cl(CH_2)_3O$	**1g/4g**	80%
8	C_6H_5	$C_6H_5CH_2O$	**1h/4h**	82%
9	C_6H_5	$3\text{-}FC_6H_4CH_2O$	**1i/4i**	68%

10	C_6H_5	4-$ClC_6H_4CH_2O$	**1j/4j**	72%
11	C_6H_5	2-$BrC_6H_4CH_2O$	**1k/4k**	67%
12	4-$CH_3C_6H_4$	4-$CH_3C_6H_4$	**1l/4l**	88%
13	2-Thiophenyl	2-Thiophenyl	**1m/4m**	78%

[a]**1** (0.5 mmol), CuI (10 mol%), Phen (10 mol%), 4 Å MS (powdered, 200 wt%), DCP (2.0 equiv.) in benzene (3.5 mL) at 140 °C in sealed tube for 12 h. [b]Isolated yields.

Subsequently, competitive reactions were carried out as shown in Scheme 3. *P*,*P*-diphenyl phosphinamide (**1a**) and *P*-phenyl-*P*-methoxy phosphonamide (**1b**) were mixed in an equal equivalent (0.25 mmol) to react with **2a** (3.5 mL) to check the difference in the potencies of the amino groups. After 5 hours, the *N*-cyclohexy products **3aa** and **3ba** were isolated in 42% and 39% yields, respectively, indicating that the two amino groups exhibited almost the same activities in the protocol (Eq. **1**)).

Scheme 3. Competitive reactions

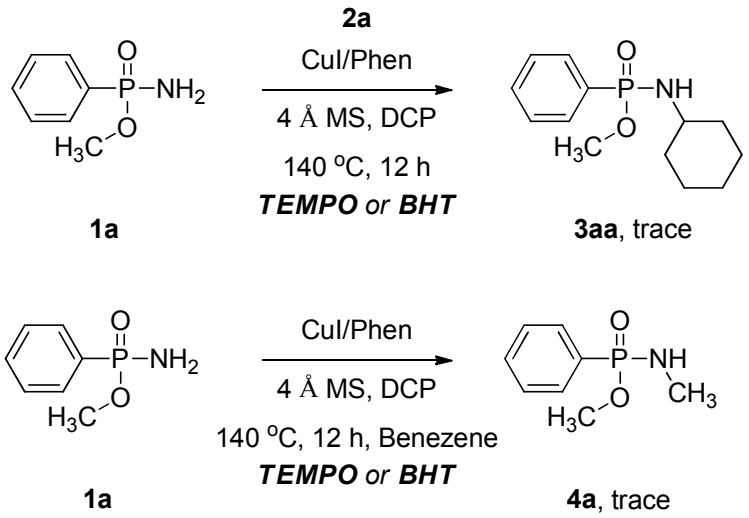


It was noteworthy that reaction between **1a** and a mixture of **2a** (2.0 mL) and **2d** (2.0 mL) providing trace **3aa** while **3ad** was isolated in 35% and 60% yields for 5 and 12 hours, respectively (Eq. **2**)).

Involvement of **2a** under the standard conditions of methylation reaction (Eq. **3)**), formation of **4a** was depressed significantly while *N*-cyclohexyl product **3aa** was isolated smoothly in 70% yield. The results of Eq. **B** and Eq. **C** might be relative to the difference in the stabilities of the radical particles which were generated in the system.[11a]

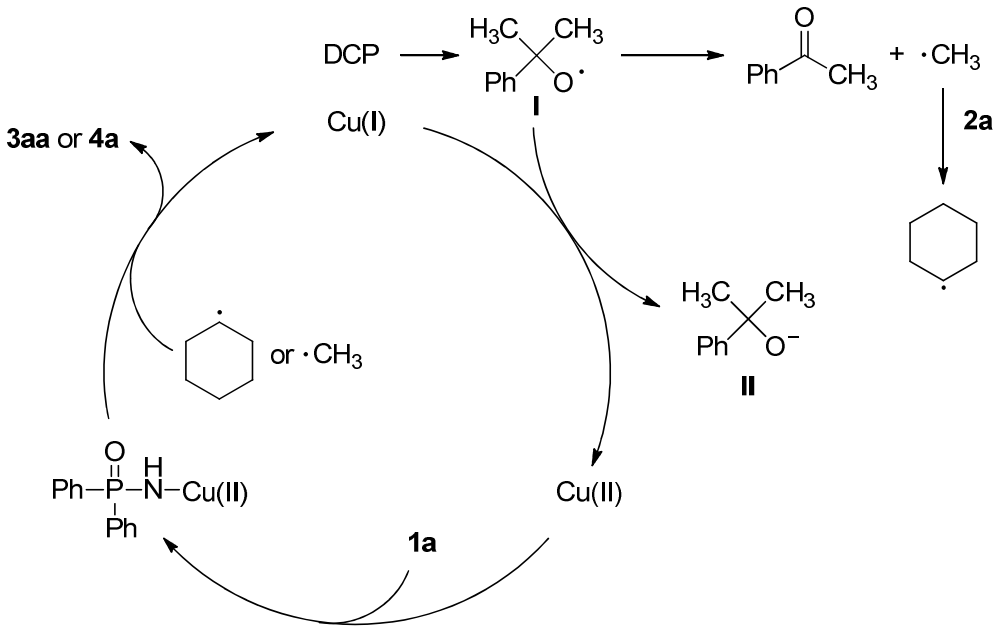
To take a deeper insight into the CuI-mediated alkylation (methylation) reactions, control reactions between **1a** and **2a** were conducted for better understandings (Scheme 4). Additions of either TEMPO (2,2,6,6-tetramethylpiperidine 1-oxyl) or BHT (butylated hydroxytoluene) as the radical particle scavangers to the reactions depressed the formation of **3aa** or **4a** significantly, for only trace of the desired products were observed after 12 h. However, attempts for the isolation of the TEMPO-adducts failed probably due to the instabilities of the intermediates in the system.

Scheme 4. Control reactions



Based on the results of the control reactions and literature explorations,[9e,12] plausible radical mechanism of the coupling protocols, which was exemplified by the reactions of **1a** and **2a** for the formations of **3aa** and **4a**, was proposed as shown in Scheme 5. Firstly, homo-cleavage of DCP took place easily for the generation of a radical particle **I**. With the assistance of newly-generated radical intermediate **I**, Cu(I) was readily oxidized into a Cu(II) species, leading to another anion particle **II**. Meanwhile, rearrangement of the radical particle **I** allowed the formation of acetophenone and a methyl

radical particle readily in the system. And cyclohexyl radical particle was facilely generated if the reaction was conducted in the existence of cyclohexane. Then, the *in-situ* formed Cu(II) coordinated with the amide group of the substrate **1a**, giving a key intermediate **A**. Successively, the intermediate **A** coupled with the radical particle easily to afford the final *N*-alkylated product **3aa** or **4a**, which relied on the usage of cyclohexane in the system, releasing a Cu(I) for the completion of the catalytic cycle.



Scheme 5. Plausible mechanism

CONCLUSIONS

In conclusion, we have developed a CuI-catalyzed selective alkylation or methylation of phosphinamides and phosphonamides in the assistance of dicumyl peroxide, which played multiple roles as the oxidant or methyl radical source in the transformation. The reaction provided a general methodology towards kinds of *N*-alkyl phosphinamides and phosphonamides of great significance in high yields. And further explorations for the synthetical and clinical applications of the products were still on-going in our labartory.

EXPERIMENTAL SECTION

General information

All product mixtures were analyzed by thin layer chromatography glass-backed silica TLC plates with a fluorescent indicator from Branch of Qingdao Haiyang Chemical CO. LTD. UV-active compounds were detected with a UV lamp (λ = 254 nm). For flash column chromatography, silica gel (200 - 300 mesh) was used as stationary phase and a mixture of *n*-hexane and ethyl acetate was used as eluent. ^{1}H and ^{13}C NMR spectra were recorded on a Varian INOVA-400 in deuterated chloroform at 25 °C with residue solvent peaks as internal standards (δ = 7.26 ppm for ^{1}H-NMR and δ = 77.16 ppm for ^{13}C-NMR). Chemical shifts δ□are reported in ppm, and spin-spin coupling constants (*J*) are given in Hz, while multiplicities are abbreviated by s (singlet), d (doublet), t (triplet), q (quartet) and m (multiplet) and some C-P couplings were ignored due to complexity. Mass spectra were recorded on a ThermoFinnigan MAT95XP microspectrometer and High Resolution Mass Spectra (HRMS) were recorded on Agilent Technologies Accurate Mass Q-TOF 6530 microspectrometer. Melting points were recorded on a national standard melting point apparatus (Model: Taike XT-4) and were uncorrected.

General procedure for the synthesis of *N*-alkyl phosphonamides and phosphinamides 3

A Schlenk tube (35 mL) equipped with a magnetic bar was loaded with the amides **1** (0.25 mmol), copper iodide (4.8 mg, 0.025 mmol), 1,10-phenanthroline (4.5 mg, 0.025 mmol), dicumyl peroxide (135 mg, 0.5 mmol), and 4 Å molecular sieve (200 wt%) in dry alkane **2** (20 mmol), then the reaction mixture was allowed to stir at 140 °C for 12 h. After cooling to room temperature, the mixture was filtered through a short celite pad and washed with dichloromethane (15 mL × 3). The filtrate was concentrated, and the oily crude product was purified by column chromatography using silica gel (200 – 300 mesh) as stationary phase and a mixture of *n*-hexane and ethyl acetate (2:1) as eluent to give the *N*-alkyl phosphonamides and phosphinamides **3** (*R_f* = ca.0.3 otherwise noted).

General procedure for the synthesis of *N*-methyl phosphonamides and

phosphinamides 4

A Schlenk tube (35 mL) equipped with a magnetic bar was loaded with the amides **1** (0.25 mmol), copper iodide (4.8 mg, 0.025 mmol), 1,10-phenanthroline (4.5 mg, 0.025 mmol), dicumyl peroxide (135 mg, 0.5 mmol), and 4 Å molecular sieve (200 wt%) in dry benzene (3.5 mL), then the reaction mixture was allowed to stir at 140 °C for 12 h. After cooling to room temperature, the mixture was filtered through a short celite pad and washed with dichloromethane (15 mL × 3). The filtrate was concentrated, and the oily crude product was purified by column chromatography using silica gel (200 – 300 mesh) as stationary phase and a mixture of *n*-hexane and ethyl acetate (1:1) as eluent to give the *N*-methyl phosphonamides and phosphinamides **4** (*R_f* = ca. 0.1 otherwise noted).

*N-Cyclohexyl-P,P-diphenylphosphinic amide (**3aa**)*. White solid (54.1 mg, 90%), m.p.: 186 - 189 ^{o}C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.90 (dd, *J* = 11.7, 7.7 Hz, 4H), 7.52 – 7.39 (m, 6H), 3.08 – 2.92 (m, 1H), 2.83 – 2.70 (m, 1H), 2.12 – 2.01 (m, 2H), 1.73 – 1.60 (m, 2H), 1.53 (d, *J* = 12.1 Hz, 1H) 1.30 – 1.01 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 133.4 ($J_{C\text{-}P}$ = 129.1 Hz), 132.2 ($J_{C\text{-}P}$ = 9.4 Hz), 131.8 ($J_{C\text{-}P}$ = 2.8 Hz), 128.6 ($J_{C\text{-}P}$ = 12.5 Hz), 50.7 ($J_{C\text{-}P}$ = 1.6 Hz), 36.8 ($J_{C\text{-}P}$ = 4.9 Hz), 22.5, 25.3 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.0 (ppm). IR (in KBr): ν = 3128, 2927, 2856, 1446, 1196, 1097, 993, 916, 692, 573, 515 (cm^{-1}). MS (EI) m/z (%): 77.0 (14), 98.1 (41), 142.0 (13), 201.0 (100), 202.0 (26), 216.0 (32), 256.1 (60), 299.1 (28). HRMS (ESI) (m/z) [M+ H^+]: Calcd. for $C_{18}H_{23}NOP$: 300.1517; Found 300.1512.

*N-Cyclohexyl-P-methoxyl-P-phenylphosphonic amide (**3ba**)*. White solid (107.3 mg, 85%), m.p.: 85 - 86 ^{o}C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.75 (dd, *J* = 12.7, 7.8 Hz, 2H), 7.48 – 7.33 (m, 3H), 3.65 (d, *J* = 11.1 Hz, 3H), 2.98 – 2.78 (m, 2H), 1.87 – 1.69 (m, 2H), 1.64 – 1.53 (m, 2H), 1.46 (d, *J* = 11.6 Hz, 1H), 1.23 – 0.99 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.7 ($J_{C\text{-}P}$ = 2.7 Hz), 131.4 ($J_{C\text{-}P}$ = 9.7 Hz), 131.3 ($J_{C\text{-}P}$ = 172.8 Hz), 128.3 ($J_{C\text{-}P}$ = 14.2 Hz), 51.0 ($J_{C\text{-}P}$ = 5.7 Hz), 49.9, 35.9 ($J_{C\text{-}P}$ = 17.8 Hz), 25.3, 25.0 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.9 (ppm). MS (EI): m/z (%): 98.1 (21), 155.0 (59), 172.1 (14), 210.1 (100), 211.1 (12), 224.1 (7), 253.1 (26), 280.9 (33). IR (in KBr): ν = 3178, 2926, 2851, 1448, 1198, 1082, 972, 918, 692, 568, 525 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{13}H_{21}NO_2P$: 254.1310; Found. 254.1302.

*N-Cyclohexyl-P-ethoxyl-P-phenylphosphonic amide (**3ca**).* White solid (106.8 mg, 80%), m.p.: 91 - 92 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.80 (dd, *J* = 12.6, 7.5 Hz, 2H), 7.53 – 7.46 (m, 1H), 7.46 – 7.38 (m, 2H), 4.15 – 4.00 (m, 2H), 3.04 – 2.88 (m, 1H), 2.72 – 2.56 (m, 1H), 1.88 – 1.76 (m, 2H), 1.68 – 1.58 (m, 2H), 1.51 (d, *J* = 11.9 Hz, 1H), 1.32 (t, *J* = 7.0 Hz, 3H), 1.28 – 1.01 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.9 (J_{C-P} = 172.3 Hz), 131.7 (J_{C-P} = 2.9 Hz), 131.6 (J_{C-P} = 9.7 Hz), 128.4 (J_{C-P} = 14.2 Hz), 60.6 (J_{C-P} = 5.5 Hz), 50.0, 36.1 (J_{C-P} = 13.8 Hz), 25.5, 25.1, 16.5 (J_{C-P} = 6.8 Hz) (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 21.4 (ppm). MS (EI): m/z (%): 77.0 (5), 98.1 (8), 141.0 (17), 186.1 (9), 196.0 (13), 224.1 (100), 225.1 (13), 238.1 (13), 267.1 (33). IR (in KBr): ν = 3190, 2925, 2848, 1453, 1212, 1131, 972, 908, 826, 756, 695, 567, 513 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{23}NO_2P$: 268.1466; Found 268.1459.

*N-Cyclohexyl-P-isopropoxyl-P-phenylphosphonic amide (**3da**).* White solid (109.6 mg, 78%), m.p.: 101 - 102 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.79 (dd, *J* = 12.8, 7.5 Hz, 2H), 7.50 – 7.37 (m, 3H), 4.75 – 4.61 (m, 1H), 3.04 – 2.90 (m, 1H), 2.66 – 2.50 (m, 1H), 1.88 – 1.76 (m, 2H), 1.68 – 1.58 (m, 2H), 1.55 – 1.46 (m, 1H), 1.35 (d, *J* = 6.1 Hz, 3H), 1.25 (d, *J* = 6.1 Hz, 3H), 1.23 – 1.03 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 132.8 (J_{C-P} = 172.0 Hz), 131.6 (J_{C-P} = 9.7 Hz), 131.6 (J_{C-P} = 3.0 Hz), 128.3 (J_{C-P} = 14.1 Hz), 69.3 (J_{C-P} = 5.5 Hz), 50.0, 36.1 (J_{C-P} = 6.1 Hz), 25.5, 25.1 (J_{C-P} = 2.2 Hz), 24.4 (J_{C-P} = 4.5 Hz), 24.2 (J_{C-P} = 4.1 Hz) (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 20.1 (ppm). MS (EI): *m*/*z* (%): 56.1 (25), 77.1 (18), 98.1 (47), 141.1 (25), 158.1 (27), 196.1 (100), 238.1 (38), 239.1 (16), 281.1 (18). IR (in KBr): ν = 3187, 2927, 2840, 1442, 1213, 1108, 1022, 954, 914, 832, 740, 683, 553, 511 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{15}H_{25}NO_2P$: 282.1623; Found 282.1615 .

P-Butoxyl-N-cyclohexyl-P-phenylphosphonic amide (***3ea***). White solid (120.9 mg, 82%), m.p.: 75 - 77 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.77 (dd, *J* = 12.6, 7.4 Hz, 2H), 7.49 – 7.43 (m, 1H), 7.43 – 7.35 (m, 2H), 4.03 – 3.92 (m, 2H), 3.00 – 2.86 (m, 1H), 2.78 – 2.60 (m, 1H), 1.86 – 1.72 (m, 2H), 1.68 – 1.55 (m, 4H), 1.48 (d, *J* = 11.5 Hz, 1H), 1.43 – 1.32 (m, 2H), 1.26 – 1.00 (m, 5H), 0.89 (t, *J* = 7.3 Hz, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.9 (J_{C-P} = 172.4 Hz), 131.6 (J_{C-P} = 2.8 Hz), 131.5 (J_{C-P} = 9.7 Hz), 128.3 (J_{C-P} = 14.1 Hz), 64.2 (J_{C-P} = 5.7 Hz), 50.0, 36.0 (J_{C-P} = 16.8 Hz), 32.6 (J_{C-P} = 6.9 Hz), 25.4, 25.1, 18.9, 13.7 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 21.3 (ppm). MS (EI): *m*/*z* (%): 56.1 (40), 77.1 (28), 98.1 (86), 141.1 (47), 158.1 (41), 196.1 (89), 252.2 (100), 295.2 (31). IR (in KBr): ν = 3194, 2927, 2850, 1447, 1214, 1125, 1022, 909, 755, 566, 512 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. For $C_{16}H_{27}NO_2P$: 296.1779; Found 296.1788.

N-Cyclohexyl-P-(2-methoxyethoxyl)-P-phenylphosphonic amide (**3fa**): White solid (113.4 mg, 76%), m.p.: 70 - 71 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.80 (dd, *J* = 12.9, 7.5 Hz, 2H), 7.50 – 7.44 (m, 1H), 7.44 – 7.36 (m, 2H), 4.24 – 4.15 (m, 1H), 4.11 – 4.02 (m, 1H), 3.61 – 3.55 (m, 2H), 3.35 (s, 3H), 3.05 – 2.84 (m, 2H), 1.87 – 1.76 (m, 2H), 1.66 – 1.56 (m, 2H), 1.49 (d, *J* = 12.0 Hz, 1H), 1.26 – 1.01 (m, 5H) (ppm). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 131.8 (J_{C-P} = 173.9 Hz), 131.8 (J_{C-P} = 2.9 Hz), 131.6 (J_{C-P} = 9.9 Hz), 128.4 (J_{C-P} = 14.3 Hz), 72.0 (J_{C-P} = 6.3 Hz), 63.3 (J_{C-P} = 5.7 Hz), 59.0, 49.9, 36.0 (J_{C-P} = 2.7 Hz), 25.4, 25.0 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.2 (ppm). MS (EI): *m*/*z* (%): 57.1 (22), 59.1 (37), 77.1 (18), 98.1 (64), 140.1 (18), 155.1 (21), 158.1 (23), 196.1 (25), 199.1 (100), 240.1 (19), 254.1 (35), 297.2 (22). IR (in KBr): ν = 3184, 2926, 2848, 1450, 1207, 1126, 1045, 960, 918, 818, 748, 692, 567, 536 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{15}H_{25}NO_3P$: 298.1572; Found. 298.1576.

P-(3-Chloropropoxyl)-N-cyclohexyl-P-phenylphosphonic amide (**3ga**): White solid (139.1 mg, 88%), m.p.: 62 - 63 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.77 (dd, *J* = 12.8, 7.3 Hz, 2H), 7.52 – 7.46 (m, 1H), 7.46 – 7.38 (m, 2H), 4.14 (q, *J* = 6.2 Hz, 2H), 3.65 (t, *J* = 6.2 Hz, 2H), 3.03 – 2.90 (m, 1H), 2.82 – 2.65 (m, 1H), 2.16 – 2.06 (m, 2H), 1.88 – 1.75 (m, 2H), 1.68 – 1.57 (m, 2H), 1.50 (d, *J* = 12.1 Hz, 1H), 1.28 – 1.01 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.9 (J_{C-P} = 2.9 Hz), 131.5 (J_{C-P} = 172.5 Hz), 131.4 (J_{C-P} = 9.7 Hz), 128.5 (J_{C-P} = 14.2 Hz), 61.0 (J_{C-P} = 5.4 Hz), 50.1, 41.2, 36.0 (J_{C-P} = 16.9 Hz), 33.4 (J_{C-P} = 6.8 Hz), 25.4, 25.1 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 21.7 (ppm). MS (EI): *m*/*z* (%): 56.1 (9), 77.0 (14), 98.1 (33), 141.0 (35), 196.1 (18), 272.0 (100), 274.0 (33), 315.1 (21), 317.1 (7). IR (in KBr): ν = 3197, 2924, 2850, 1448, 1213, 1117, 1034, 970, 914, 746, 563 (cm^{-1}). HRMS (ESI) (m/z)[M + H^+]: Calcd. for $C_{15}H_{24}ClNO_2P$: 316.1233; Found. 316.1226.

P-Benzyloxyl-N-cyclohexyl-P-phenylphosphonic amide (**3ha**): White solid (133.7 mg, 81%), m.p.: 111 - 112 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.82 (dd, *J* = 12.9, 7.7 Hz, 2H), 7.53 – 7.47 (m, 1H), 7.47 – 7.40 (m, 2H), 7.40 – 7.27 (m, 5H), 5.13 – 4.99 (m, 2H), 3.06 – 2.93 (m, 1H), 2.80 – 2.66 (m, 1H), 1.87 – 1.76 (m, 2H), 1.67 – 1.57 (m, 2H), 1.55 – 1.46 (m, 1H), 1.26 – 1.02 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 137.0 (J_{C-P} = 7.5 Hz), 131.9 (J_{C-P} = 3.0 Hz), 131.6 (J_{C-P} = 9.8 Hz), 131.6 (J_{C-P} = 172.6 Hz), 128.6, 128.5 (J_{C-P} = 14.3 Hz), 128.2, 127.8, 66.0 (J_{C-P} = 5.2 Hz), 50.1, 36.0 (J_{C-P} = 14.8 Hz), 25.4, 25.1 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.1 (ppm). MS (EI): *m*/*z* (%): 65.1 (6), 91.1 (68), 98.1 (10), 141.0 (8), 158.1 (5), 238.1 (100), 239.1 (14), 286.1 (46), 287.1 (8), 329.2 (21). IR (in KBr): ν = 3160, 2928, 2851, 1452, 1213, 1122, 1038, 924, 852, 788, 748, 689, 553, 512 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{19}H_{24}NO_2P$: 330.1623; Found. 330.1629.

N-Cyclohexyl-P-(3-fluorobenzyloxyl)-P-phenylphosphonic amide (**3ia**): White solid (131.4 mg, 76%), m.p.: 101 - 102 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.83 (dd, *J* = 13.0, 7.3 Hz, 2H), 7.55 – 7.48 (m, 1H), 7.48 – 7.41 (m, 2H), 7.34 – 7.27 (m, 1H), 7.17 – 7.06 (m, 2H), 7.04 – 6.95 (m, 1H), 5.12 – 4.98 (m, 2H), 3.08 – 2.94 (m, 1H), 2.87 – 2.70 (m, 1H), 1.88 – 1.77 (m, 2H), 1.68 – 1.59 (m, 2H), 1.56 – 1.48 (m, 1H), 1.27 – 1.04 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 163.0 (J_{C-F} = 246.3 Hz), 139.6 (J_{C-P} = 7.5 Hz), 132.0 (J_{C-P} = 3.0 Hz), 131.6 (J_{C-P} = 9.8 Hz), 131.3 (J_{C-P} = 172.6 Hz), 130.2 (J_{C-P} = 8.2 Hz), 128.5 (J_{C-P} = 14.3 Hz), 123.0 (J_{C-P} = 3.0 Hz), 115.0 (J_{C-P} = 21.1 Hz), 114.4 (J_{C-P} = 22.1 Hz), 65.1 (J_{C-P} = 5.0 Hz), 50.1, 36.0 (J_{C-P} = 15.8 Hz), 25.4, 25.1 (ppm). ^{19}F NMR (376 MHz, $CDCl_3$) δ = -112.8 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.3 (ppm). MS (EI): *m*/*z* (%): 56.1 (11), 77.1 (11), 98.1 (22), 109.1 (83), 141.1 (13), 158.1 (13), 196.1 (20), 238.1 (100), 239.1 (17), 304.1 (60), 347.2 (19). IR (in KBr): ν = 3167, 2927, 2852, 1591, 1454, 1211, 1132, 1034, 922, 854, 787, 744, 688, 548, 511 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{19}H_{23}FNO_2P$: 348.1529; Found. 348.1535.

P-(4-Chlorobenzyloxyl)-N-cyclohexyl-P-phenylphosphonic amide (**3ja**): White solid (163.3 mg, 90%), m.p.: 114 - 115 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.80 (dd, *J* = 12.9, 7.7 Hz, 2H), 7.55 – 7.48 (m, 1H), 7.47 – 7.40 (m, 2H), 7.31 (bs, 4H), 5.08 – 4.96 (m, 2H), 3.05 – 2.92 (m, 1H), 2.76 – 2.63 (m, 1H), 1.87 – 1.76 (m, 2H), 1.68 – 1.58 (m, 2H), 1.55 – 1.47 (m, 1H), 1.28 – 1.03 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 135.5 (J_{C-P} = 7.2 Hz), 134.1, 132.0 (J_{C-P} = 3.0 Hz), 131.6 (J_{C-P} = 9.8 Hz), 131.3 (J_{C-P} = 172.5 Hz), 129.2, 128.8, 128.6 (J_{C-P} = 14.3 Hz), 65.2 (J_{C-P} = 5.1 Hz), 50.1, 36.0 (J_{C-P} = 15.3 Hz), 25.4, 25.1 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.4 (ppm). MS (EI): *m*/*z* (%): 91.1 (15), 98.1 (19), 125.0 (100), 127.0 (31), 141.1 (13), 238.1 (97), 239.1 (13), 320.1 (26), 363.2 (20). IR (in KBr): ν = 3184, 2924, 2850, 1444, 1211, 1134, 1047, 998, 857, 763, 559, 523 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{19}H_{24}ClNO_2P$: 364.1233, Found. 364.1228.

P-(2-Bromobenzyloxyl)-N-cyclohexyl-P-phenylphosphonic amide (**3ka**): White solid (152.3 mg, 75%), m.p.: 92 - 93 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.84 (dd, *J* = 12.9, 7.6 Hz, 2H), 7.56 – 7.47 (m, 3H), 7.46 – 7.39 (m, 2H), 7.30 (t, *J* = 7.5 Hz, 1H), 7.15 (t, *J* = 7.6 Hz, 1H), 5.22 – 5.13 (m, 1H), 5.13 – 5.05 (m, 1H), 3.08 – 2.94 (m, 1H), 2.92 – 2.82 (m, 1H), 1.87 – 1.76 (m, 2H), 1.67 – 1.57 (m, 2H), 1.54 – 1.45 (m, 1H), 1.25 – 1.01 (m, 5H) (ppm). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 136.3 (J_{C-P} = 8.2 Hz), 132.7, 131.9 (J_{C-P} = 2.9 Hz), 131.5 (J_{C-P} = 9.8 Hz), 131.4 (J_{C-P} = 173.3 Hz), 129.5, 129.2, 128.5 (J_{C-P} = 14.3 Hz), 127.6, 122.6, 65.4 (J_{C-P} = 4.6 Hz), 50.1, 36.0 (J_{C-P} = 19.0 Hz), 25.4, 25.1 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.2 (ppm). MS (EI): *m*/*z* = 90.1 (16), 98.1 (13), 169.0 (54), 171.0 (53), 238.1 (51), 246.1 (14), 328.2 (100), 329.2 (21), 364.0 (22), 366.0 (21), 407.1 (2), 409.1 (2). IR (in KBr): ν = 3192,

2924, 2848, 1443, 1215, 1117, 1051, 1012, 858, 746, 683, 555, 517 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{19}H_{24}BrNO_2P$: 408.0728; Found. 408.0719.

N-Cyclohexyl-P,P-di-p-tolylphosphinic amide (**3la**). White solid (165.3 mg, 85%), m.p.: 135 - 136 ^oC. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.76 (dd, *J* = 11.2, 7.9 Hz, 4H), 7.22 (d, *J* = 7.4 Hz,4H), 3.04 – 2.90 (m, 1H), 2.78 – 2.66 (m, 1H), 2.35 (s, 6H), 2.06 – 1.99 (m, 2H), 1.68 – 1.60 (m, 2H), 1.51 (d, *J* = 12.1 Hz,1H), 1.26 – 1.06 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 142.1 (J_{C-P} = 2.6 Hz), 132.2 (J_{C-P} = 9.7 Hz), 130.3 (J_{C-P} = 131.8 Hz), 129.3 (J_{C-P} = 12.9 Hz), 50.5, 36.8 (J_{C-P} = 4.9 Hz), 25.5, 25.2, 21.6 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.7(ppm). MS (EI): *m/z* (%): 91.1 (30), 98.1 (44), 229.1 (100), 244.1 (29), 284.1 (45), 327.2 (12).IR(in KBr): ν = 3120, 2929, 2853, 1442, 1189, 1090, 1002, 915, 697, 567, 515 (cm^{-1}).HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{20}H_{27}NOP$: 328.1825; Found 328.1828.

N-cyclohexyl-P,P-di(thiophen-2-yl)phosphinic amide (**3ma**). White solid (120.1 mg, 78%), m.p.: 156 - 157 ^oC. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.74 –7.56 (m, 4H), 7.18–7.05 (m, 2H), 3.17– 2.99 (m, 2H), 2.08– 1.99 (m, 2H),1.71– 1.60 (m, 2H), 1.52 (d, *J* = 12.1Hz, 1H), 1.26– 1.05 (m, 5H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 136.8(J_{C-P} = 11.2 Hz), 134.4 (J_{C-P} = 152.1 Hz), 133.7 (J_{C-P} = 5.8 Hz), 128.4 (J_{C-P} = 15.6 Hz), 50.9, 36.6 (J_{C-P} = 5.0 Hz), 25.4, 25.2(ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 8.7(ppm). MS (EI): *m/z* (%): 83.0 (41), 98.1 (60), 213.0 (100), 228.0 (22), 268.0 (43), 311.1 (11). IR(in KBr): ν = 3142, 2931, 2850, 1442, 1201, 1095, 987, 920, 853, 721, 565 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{18}NOPS_2$: 312.0646; Found 312.0641.

N-Cyclohexyl-N-methyl-P,P-diphenylphosphinic amide (**3na**): White solid (152.3 mg, 75%), m.p.: 92 - 93 ^oC. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.92 – 7.75 (m, 4H), 7.53 – 7.36 (m, 6H), 3.21 – 3.05 (m, 1H), 2.51 (d, *J* = 11.4 Hz, 3H), 1.80 – 1.66 (m, 4H), 1.63 – 1.47 (m, 3H), 1.16 – 0.91 (m, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 132.6 (J_{C-P} = 128.7 Hz), 132.3 (J_{C-P} = 9.2 Hz), 131.6 (J_{C-P} = 2.6 Hz), 128.5 (J_{C-P} = 12.4 Hz), 55.2 (J_{C-P} = 2.6 Hz), 31.2 (J_{C-P} = 3.6 Hz), 28.2 (J_{C-P} = 3.6 Hz), 26.0, 25.6 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 30.8 (ppm). MS (EI): *m/z* (%): 77.1 (21), 112.2 (65), 201.1 (100), 202.1 (30), 216.1 (20), 218.1 (25), 256.2 (46), 313.2 (15). IR (in KBr): ν = 3192, 2924, 2848, 1566, 1444, 1213, 1124, 1053, 1009, 918, 860, 746, 683, 555, 515 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{19}H_{25}NOP$: 314.1674; Found. 314.1668.

N-Cyclohexyl-N,P,P-triphenylphosphinic amide (**3oa**): White solid (152.3 mg, 75%), m.p.: 92 - 93 ^oC. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.88 (dd, *J* = 11.1, 7.8 Hz, 4H), 7.39 – 7.22 (m, 8H), 7.12 (t, *J* = 7.4 Hz, 2H), 7.04 (t, *J* = 7.2 Hz, 1H), 3.51 – 3.36 (m, 1H), 2.09 (d, *J* = 11.6 Hz, 2H), 1.66 (d, *J* = 12.6 Hz, 2H), 1.43 (d, *J* = 12.8 Hz, 1H), 1.31 – 1.06 (m, 4H), 0.90 – 0.73 (m, 1H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$)

δ = 139.2 (J_{C-P} = 1.5 Hz), 132.6 (J_{C-P} = 8.7 Hz), 132.6 (J_{C-P} = 5.8 Hz), 132.5 (J_{C-P} = 130.6 Hz), 131.3 (J_{C-P} = 2.7 Hz), 128.2, 128.1 (J_{C-P} = 12.5 Hz), 126.6, 58.1 (J_{C-P} = 3.5 Hz), 33.4 (J_{C-P} = 3.4 Hz), 26.1, 25.2 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 26.2 (ppm). MS (EI): *m*/*z* (%): 77.1 (15), 174.2 (100), 175.2 (14), 201.1 (57), 202.1 (11), 292.1 (13), 293.1 (14), 332.2 (7), 375.3 (4). IR (in KBr): ν = 3194, 2984, 2855, 1445, 1113, 1075, 997, 918, 854, 750, 692, 547 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{24}H_{27}NOP$: 376.1830; Found. 376.1834.

*N-Cyclopentyl-P,P-diphenylphosphinic amide (**3ab**).* White solid (123.1 mg, 86%), m.p.: 161 - 162 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.89 (dd, *J* = 11.2, 7.8 Hz, 4H), 7.52 – 7.38 (m, 6H), 3.56 – 3.41 (m, 1H), 2.91 – 2.76 (m, 1H), 2.01 – 1.88 (m, 2H), 1.72 – 1.58 (m, 2H), 1.54 – 1.40 (m, 4H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 133.1 (J_{C-P} = 129.2 Hz), 132.3 (J_{C-P} = 9.4 Hz), 131.8 (J_{C-P} = 2.7 Hz), 128.6 (J_{C-P} = 12.5 Hz), 53.4 (J_{C-P} = 1.7 Hz), 35.8 (J_{C-P} = 5.2 Hz), 23.3 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.2 (ppm). MS (EI): *m*/*z* (%): 77.1 (11), 84.1 (72), 142.1 (29), 201.1 (100), 202.1 (40), 216.1 (36), 256.1 (30), 285.1 (11). IR (in KBr): ν = 3178, 2928, 2850, 1448, 1207, 1114, 1049, 753, 687, 555, 514 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{17}H_{20}NOP$: 286.1361; Found. 286.1365.

*N-Cycloheptyl-P,P-diphenylphosphinic amide (**3ac**).* White solid (124.4 mg, 79%), m.p.: 134 - 135 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.89 (dd, *J* = 11.6, 7.7 Hz, 4H), 7.54 – 7.34 (m, 6H), 3.29 – 3.13 (m, 1H), 2.99 – 2.78 (m, 1H), 2.12 – 1.98 (m, 2H), 1.63 – 1.40 (m, 8H), 1.40 – 1.28 (m, 2H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 133.2 (J_{C-P} = 129.5 Hz), 132.2 (J_{C-P} = 9.3 Hz), 131.8 (J_{C-P} = 2.6 Hz), 128.6 (J_{C-P} = 12.5 Hz), 52.8 (J_{C-P} = 1.7 Hz), 38.4 (J_{C-P} = 4.9 Hz), 28.2, 23.7 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 21.9 (ppm). MS (EI): *m*/*z* (%): 77.1 (18), 112.1 (24), 201.1 (100), 202.1 (34), 216.1 (42), 256.2 (30), 313.2 (12). IR (in KBr): ν = 3184, 2926, 2845, 1448, 1215, 1120, 1059, 854, 746, 683, 555, 515 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{19}H_{25}NOP$: 314.1674; Found. 314.1679.

N-Cyclooctyl-P,P-diphenylphosphinic amide (**3ad**). White solid (106.4 mg, 65%), m.p.: 106 - 107 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.89 (dd, *J* = 11.7, 7.7 Hz, 4H), 7.54 – 7.36 (m, 6H), 3.34 – 3.15 (m, 1H), 2.98 – 2.79 (m, 1H), 2.04 – 1.92 (m, 2H), 1.70 – 1.56 (m, 4H), 1.56 – 1.37 (m, 8H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 133.2 (J_{C-P} = 129.5 Hz), 132.2 (J_{C-P} = 9.3 Hz), 131.8 (J_{C-P} = 2.7 Hz), 128.6 (J_{C-P} = 12.5 Hz), 51.6 (J_{C-P} = 1.8 Hz), 34.9 (J_{C-P} = 4.9 Hz), 27.6, 25.4, 23.4 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.0 (ppm). MS (EI): *m*/*z* (%): 77.0 (9), 106.1 (9), 126.1 (13), 201.0 (100), 202.0 (32), 218.0 (21), 243.0 (18), 256.1 (46), 327.1 (17). IR (in KBr): ν = 3187, 2930, 2851, 1446, 1213, 1100, 1048, 755, 691, 568, 517 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{20}H_{27}NOP$: 328.1830; Found. 328.1823.

N-(Hexan-3-yl)-P,P-diphenylphosphinic amide (**3ae**) and *N-(hexan-2-yl)-P,P-diphenylphosphinic amide* (**3ae'**): Yellowish thick oil (112.7 mg, 75%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.98 – 7.76 (m, 4H), 7.51 – 7.34 (m, 6H), 3.23 – 3.08 (m, 0.63H), 3.05 – 2.93 (m, 0.34H), 2.77 – 2.66 (m, 1H), 1.62 – 1.16 (m, 8H), 0.91 – 0.78 (m, 4H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 133.23 (J_{C-P} = 129.2 Hz), 132.89 (J_{C-P} = 124.1 Hz), 132.27 (J_{C-P} = 9.4 Hz), 132.13 (J_{C-P} = 9.5 Hz), 131.78 (J_{C-P} = 2.6 Hz), 131.76 (J_{C-P} = 2.6 Hz), 128.52 (J_{C-P} = 12.5 Hz), 128.49 (J_{C-P} = 12.5 Hz), 52.62 (J_{C-P} = 2.0 Hz), 47.74 (J_{C-P} = 1.7 Hz), 39.52 (J_{C-P} = 6.3 Hz), 38.51 (J_{C-P} = 5.3 Hz), 29.45 (J_{C-P} = 4.6 Hz), 28.16, 23.96 (J_{C-P} = 4.1 Hz), 22.62, 18.83, 14.17, 14.08, 9.68 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 21.93, 21.68 (ppm). MS (EI): *m*/*z* (%): 77.1 (17), 201.1 (100), 202.1 (18), 244.1 (71), 258.2 (19), 272.2 (18), 286.2 (5), 301.2 (1). IR (in KBr): ν = 3178, 2920, 2839, 1447, 1217, 1129, 1072, 993, 864, 746, 690, 554 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{18}H_{25}NOP$: 302.1674; Found. 302.1683.

N-Methyl-P,P-diphenylphosphinic amide (**4a**): Yellowish thick oil (101.9 mg, 88%). R_f = 0.2 (*n*-hexane:EtOAc = 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.93 – 7.82 (m, 4H), 7.51 – 7.38 (m, 6H), 2.90 (bs, 1H), 2.65 (dd, *J* = 12.1, 5.3 Hz, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 132.2 (J_{C-P} = 129.0 Hz), 132.2 (J_{C-P} = 9.4 Hz), 131.9 (J_{C-P} = 2.0 Hz), 128.7 (J_{C-P} = 12.5 Hz), 26.9 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 25.3 (ppm). MS (EI): *m*/*z* (%): 77.1 (21), 154.1 (23), 155.1 (20), 201.1 (36), 202.1 (100), 230.1 (21), 231.1 (23). IR (in KBr): ν = 3192, 3066, 2904, 2819, 1473, 1431, 1180, 1113, 1069, 839, 696, 561, 517 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{13}H_{15}NOP$: 232.0891; Found. 232.0897.

P-Methoxyl-N-methyl-P-phenylphosphonic amide (**4b**): Yellowish thick oil (83.6 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.78 – 7.68 (m, 2H), 7.50 – 7.35 (m, 3H), 3.70 (d, *J* = 9.7 Hz, 3H), 3.28 (bs, 1H), 2.55 – 2.46 (m, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.8, 131.4 (J_{C-P} = 9.5 Hz), 130.0 (J_{C-P} = 173.2 Hz), 128.4 (J_{C-P} = 14.2 Hz), 50.9 (J_{C-P} = 5.0 Hz), 27.1 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 25.8 (ppm). MS (EI): *m*/*z* (%): 77.1 (68), 154.1 (44), 141.0 (52), 155.1 (47), 156.1 (100), 184.1 (31), 185.1 (47). IR (in KBr): ν = 3224, 2965, 2927, 1621, 1450, 1372, 1224, 1072, 990, 872, 745, 702, 558 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_8H_{13}NO_2P$: 186.0684; Found. 186.0693.

P-Ethoxyl-N-methyl-P-phenylphosphonic amide (**4c**). Yellowish thick oil (83.6 mg, 90%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.77 (dd, *J* = 12.3, 7.5 Hz, 2H), 7.52 – 7.39 (m, 3H), 4.15 – 4.01 (m, 2H), 2.90 (bs, 1H), 2.54 (dd, *J* = 11.8, 5.8 Hz, 3H), 1.34 (t, *J* = 7.0 Hz, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.8 (J_{C-P} = 1.8 Hz), 131.4 (J_{C-P} = 9.6 Hz), 130.6 (J_{C-P} = 173.1 Hz), 128.4 (J_{C-P} = 14.2 Hz), 60.4 (J_{C-P} = 5.7 Hz), 27.2, 16.4 (J_{C-P} = 6.6 Hz) (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 24.2 (ppm). MS (EI): *m*/*z*

(%): 77.1 (99), 78.1 (100), 94.0 (37), 106.1 (17), 141.0 (88), 142.0 (72), 154.1 (24) 170.1 (48), 171.1 (40), 198.1 (15), 199.1 (25). IR (in KBr): ν = 3215, 2970, 2939, 1653, 1443, 1378, 1210, 1114, 1007, 854, 763, 692, 558, 524 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_9H_{15}NO_2P$: 200.0840; Found. 200.0846.

P-Isopropoxyl-N-methyl-P-phenylphosphonic amide (**4d**). Yellowish thick oil (91.7 mg, 86%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.74 (dd, *J* = 12.1, 7.8 Hz, 2H), 7.48 – 7.35 (m, 3H), 4.78 – 4.63 (m, 1H), 3.09 (bs, 1H), 2.49 (dd, *J* = 11.9, 5.6 Hz, 3H), 1.33 (d, *J* = 6.1 Hz, 3H), 1.28 (d, *J* = 6.1 Hz, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.6 (J_{C-P} = 2.8 Hz), 131.4 (J_{C-P} = 9.6 Hz), 131.1 (J_{C-P} = 173.0 Hz), 128.3 (J_{C-P} = 14.1 Hz), 69.1 (J_{C-P} = 5.7 Hz), 27.2, 24.2 (J_{C-P} = 4.1 Hz), 24.1 (J_{C-P} = 4.4 Hz) (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 23.1 (ppm). MS (EI): *m/z* (%): 77.1 (54), 78.1 (47), 94.0 (9), 106.1 (17), 141.0 (34), 142.0 (68), 154.1 (53) 155.1 (34), 172.1 (100), 213.1 (11). IR (in KBr): ν = 3236, 2980, 2931, 1649, 1439, 1381, 1217, 1128, 995, 893, 845, 750, 702, 559 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{10}H_{17}NO_2P$: 214.0997; Found. 214.0989.

P-Butoxyl- N-methyl-P-phenylphosphonic amide (**4e**). Yellowish thick oil (104.7 mg, 92%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.77 (dd, *J* = 12.3, 7.7 Hz, 2H), 7.52 – 7.46 (m, 1H), 7.46 – 7.39 (m, 2H), 4.07 – 3.98 (m, 2H), 2.87 (bs, 1H), 2.54 (dd, *J* = 11.7, 5.4 Hz, 3H), 1.71 – 1.62 (m, 2H), 1.47 – 1.35 (m, 2H), 0.92 (t, *J* = 7.3 Hz, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.7 (J_{C-P} = 1.7 Hz), 131.4 (J_{C-P} = 9.5 Hz), 130.6 (J_{C-P} = 173.4 Hz), 128.4 (J_{C-P} = 14.2 Hz), 64.1 (J_{C-P} = 5.5 Hz), 32.6 (J_{C-P} = 6.7 Hz), 27.2, 19.0, 13.7 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 24.1 (ppm). MS (EI): *m/z* (%): 77.1 (74), 78.1 (36), 91.1 (20), 105.1 (16), 123.0 (20), 141.0 (48), 142.0 (27), 154.1 (36), 172.1 (100), 199.0 (30), 216.0 (50), 227.1 (4). IR (in KBr): ν = 3201, 2957, 2917, 1655, 1445, 1223, 1008, 885, 845, 776, 695, 563 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. $C_{11}H_{18}NO_2P$ 228.1153, Found. 228.1161.

P-(2-Methoxyethoxyl)-N-methyl-P-phenylphosphonic amide (**4f**). Yellowish thick oil (91.6 mg, 80%). R_f = 0.1 (*n*-hexane:EtOAc = 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.80 (dd, *J* = 12.8, 7.6 Hz, 2H), 7.54 – 7.48 (m, 1H), 7.47 – 7.40 (m, 2H), 4.27 – 4.09 (m, 2H), 3.62 (t, *J* = 4.3 Hz, 2H), 3.37 (s, 3H), 2.99 – 2.83 (m, 1H), 2.57 (dd, *J* = 11.8, 5.7 Hz, 3H) (ppm). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 132.0 (J_{C-P} = 2.9 Hz), 131.7 (J_{C-P} = 9.8 Hz), 130.3 (J_{C-P} = 173.9 Hz), 128.5 (J_{C-P} = 14.3 Hz), 72.0 (J_{C-P} = 6.3 Hz), 63.5 (J_{C-P} = 5.8 Hz), 59.1, 27.2 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 24.9 (ppm). MS (EI): *m/z* (%): 58.0 (16), 77.0 (15), 107.1 (5), 142.0 (14), 154.1 (69), 172.1 (100), 186.1(5), 199.1 (10), 229.1 (2). IR (in KBr): ν = 3197, 2935, 2852, 1453, 1213, 1134, 1041, 924, 823, 754, 701, 562, 533 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{10}H_{17}NO_3P$: 230.0946; Found. 230.0954.

P-(3-Chloropropoxyl)-N-methyl-P-phenylphosphonic amide (**4g**). Yellowish thick oil (101.3 mg, 82%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.76 (dd, *J* = 12.8, 7.3 Hz, 2H), 7.54 – 7.40 (m, 3H), 4.23 – 4.12 (m, 2H), 3.67 (t, *J* = 6.2 Hz, 2H), 3.12 – 2.90 (m, 1H), 2.55 (dd, *J* = 11.8, 5.5 Hz, 3H), 2.20 – 2.10 (m, 2H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 132.0 (J_{C-P} = 2.8 Hz), 131.4 (J_{C-P} = 9.7 Hz), 130.1 (J_{C-P} = 173.5 Hz), 128.6 (J_{C-P} = 14.2 Hz), 60.9 (J_{C-P} = 5.5 Hz), 41.1, 33.4 (J_{C-P} = 6.7 Hz), 27.2 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 24.6 (ppm). MS (EI): *m*/*z* (%): 77.0 (72), 105.0 (56), 141.0 (38), 154.1 (86), 172.1 (40), 183.1 (23), 212.1 (100), 248.1 (2). IR (in KBr): ν = 3212, 2933, 2854, 1602, 1439, 1218, 1109, 1028, 983, 920, 739, 555 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{10}H_{15}ClNO_2P$: 248.0607; Found. 248.0617.

P-Benzyloxyl-N-methyl-P-phenylphosphonic amide (**4h**). Yellowish thick oil (106.7 mg, 82%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.79 (dd, *J* = 12.8, 7.4 Hz, 2H), 7.53 – 7.28 (m, 8H), 5.14 – 5.03 (m, 2H), 3.11 (bs, 1H), 2.51 (dd, *J* = 11.9, 5.7 Hz, 3H) (ppm). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 136.8 (J_{C-P} = 7.2 Hz), 132.0 (J_{C-P} = 2.9 Hz), 131.5 (J_{C-P} = 9.7 Hz), 130.2 (J_{C-P} = 173.3 Hz), 128.6, 128.5 (J_{C-P} = 14.4 Hz), 128.3, 127.8, 65.8 (J_{C-P} = 5.3 Hz), 27.2 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 25.0 (ppm). MS (EI): *m*/*z* (%): 65.1 (27), 77.1 (25), 78.1 (61), 91.1 (100), 141.0 (12), 155.1 (82), 167.1 (21), 261.1 (35). IR (in KBr): ν = 3168, 2930, 2854, 1600, 1455, 1203, 1132, 1035, 924, 856, 784, 745, 689 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{17}NO_2P$: 262.0997; Found. 262.1004.

P-(3-Fluorobenzyloxyl)-N-methyl-P-phenylphosphonic amide (**4i**). Yellowish thick oil (106.7 mg, 82%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.73 (dd, *J* = 12.6, 7.8 Hz, 2H), 7.48 – 7.41 (m, 1H), 7.40 – 7.32 (m, 2H), 7.23 (q, *J* = 7.4 Hz, 1H), 7.06 (dd, *J* = 12.9, 9.5 Hz, 2H), 6.92 (t, *J* = 8.1 Hz, 1H), 4.99 (d, *J* = 7.2 Hz, 2H), 3.24 (bs, 1H), 2.45 (dd, *J* = 11.7, 5.5 Hz, 3H) (ppm). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 162.9 (J_{C-F} = 246.2 Hz), 139.3 (J_{C-P} = 7.3 Hz), 132.1 (J_{C-P} = 2.9 Hz), 131.5 (J_{C-P} = 9.8 Hz), 130.2 (J_{C-P} = 8.2 Hz), 129.9 (J_{C-P} = 173.3 Hz), 128.6 (J_{C-P} = 14.3 Hz), 123.1 (J_{C-P} = 2.9 Hz), 115.1 (J_{C-P} = 21.1 Hz), 114.5 (J_{C-P} = 22.1 Hz), 64.9 (J_{C-P} = 5.0 Hz), 27.2 (ppm). ^{19}F NMR (375 MHz, $CDCl_3$) δ = -112.7 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 25.3 (ppm). MS (EI): *m*/*z* (%): 77.1 (25), 78.1 (66), 83.0 (25), 109.1 (100), 155.1 (85), 185.1 (14), 279.1 (42). IR (in KBr): ν = 3167, 2934, 2847, 1597, 1459, 1209, 1140, 1038, 924, 852, 790, 748, 684 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{15}FNO_2P$ 280.0903, Found. 280.0907.

P-(4-Chlorobenzyloxyl)-N-methyl-P-phenylphosphonic amide (**4j**). Yellowish thick oil (106.6 mg, 72%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.78 (dd, *J* = 12.3, 7.8 Hz, 2H), 7.53 – 7.47 (m, 1H), 7.46 – 7.39 (m, 2H), 7.31 (bs, 4H), 5.03 (d, *J* = 7.4 Hz, 2H), 3.14 (bs, 1H), 2.51 (dd, *J* = 11.3, 5.1 Hz, 3H) (ppm).

^{13}C NMR (100 MHz, $CDCl_3$) δ = 135.3 (J_{C-P} = 7.0 Hz), 134.1, 132.1 (J_{C-P} = 2.8 Hz), 131.5 (J_{C-P} = 9.8 Hz), 130.0 (J_{C-P} = 173.2 Hz), 129.2, 128.8, 128.6 (J_{C-P} = 14.3 Hz), 65.0 (J_{C-P} = 5.2 Hz), 27.2 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 25.2 (ppm). MS (EI): *m*/*z* (%): 77.0 (18), 78.0 (59), 89.0 (21), 125.0 (72), 127.0 (24), 155.1 (100), 295.0 (42), 297.0 (14). IR (in KBr): ν = 3172, 2931, 2850, 1593, 1460, 1207, 1132, 1037, 922, 852, 789, 746, 687 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{16}ClNO_2P$: 296.0607, Found. 296.0601.

P-(2-Bromobenzyl)oxyl- N-methyl-P-phenylphosphonic amide (**4k**): Yellowish thick oil (113.6 mg, 67%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.83 (dd, *J* = 12.9, 7.1 Hz, 2H), 7.58 – 7.48 (m, 3H), 7.48 – 7.40 (m, 2H), 7.31 (t, *J* = 7.4 Hz, 1H), 7.17 (t, *J* = 7.4 Hz, 1H), 5.24 – 5.10 (m, 2H), 3.12 (bs, 1H), 2.55 (dd, *J* = 12.0, 5.9 Hz, 3H) (ppm). ^{13}C NMR (101 MHz, $CDCl_3$) δ = 136.2 (J_{C-P} = 7.9 Hz), 132.7, 132.1 (J_{C-P} = 3.0 Hz), 131.5 (J_{C-P} = 9.8 Hz), 130.0 (J_{C-P} = 173.9 Hz), 129.6, 129.4, 128.6 (J_{C-P} = 14.3 Hz), 127.7, 122.7, 65.27 (J_{C-P} = 4.9 Hz), 27.3 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 25.0 (ppm). MS (EI): *m*/*z* = 77.1 (11), 78.1 (22), 89.1 (14), 90.1 (20), 154.1 (22), 155.1 (17), 169.0 (20), 171.0 (19), 229.1 (11), 260.1 (100), 261.1 (16), 339.0 (1), 341.0 (1). IR (in KBr): ν = 3183, 2924, 2853, 1595, 1452, 1216, 1122, 1040, 857, 746, 689, 557 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{16}BrNO_2P$: 340.0102; Found. 340.0110.

N-methyl-P,P-di-p-tolylphosphinic amide (**4l**). Yellowish thick oil (113.8 mg, 88%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.78 –7.69 (m, 4H), 7.22 (d, *J* = 6.9 Hz,4H), 2.85 (bs, 1H), 2.63 (dd, *J* = 11.8, 4.6 Hz, 3H), 2.34 (s, 6H)(ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 142.3(J_{C-P} = 1.8 Hz), 132.2 (J_{C-P} = 9.6 Hz), 129.4 (J_{C-P} = 12.8 Hz), 129.1 (J_{C-P} = 131.6 Hz), 26.8, 21.6 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 22.7(ppm). MS (EI): *m*/*z* (%): 91.1 (25), 168.1 (32), 229.1 (100), 230.1 (28), 259.1 (20). IR (in KBr): ν = 3187, 2910, 2821, 1441, 1182, 1109, 845, 695, 568, 517 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{15}H_{19}NOP$: 260.1204; Found 260.1201.

N-methyl-P,P-di(thiophen-2-yl)phosphinic amide (**4m**). Yellowish thick oil (95.2 mg, 78%). R_f = 0.1 (*n*-hexane:EtOAc = 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.72–7.55 (m, 4H), 7.15–7.03 (m, 2H), 3.48–3.24 (m, 1H), 2.72–2.53 (m, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 136.9(J_{C-P} = 11.1 Hz), 133.9 (J_{C-P} = 5.7 Hz), 133.2 (J_{C-P} = 152.2 Hz), 128.4 (J_{C-P} = 15.6 Hz), 27.0(ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 12.3(ppm). MS (EI): *m*/*z* (%): 83.0 (34), 160.0 (22), 213.0 (100), 214.0 (25), 243.0 (21). IR(in KBr): ν = 3162, 2907, 2825, 1403, 1225, 1180, 1108, 1029, 931, 851, 705, 661 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_9H_{10}NOPS_2$: 244.0020; Found 244.0026.

P-Cyclohexyloxyl-N-methyl-P-phenylphosphonic amide (**4p**). Yellowish thick oil (101.6 mg, 80%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.74 (dd, *J* = 12.3, 7.8 Hz, 2H), 7.47 – 7.34 (m, 3H), 4.49 – 4.36 (m, 1H), 3.11 (bs, 1H), 2.48 (dd, *J* = 11.7, 5.2 Hz, 3H), 1.99 – 1.82 (m, 2H), 1.76 – 1.62 (m, 2H), 1.59 – 1.40 (m, 3H), 1.37 – 1.14 (m, 3H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.5 (J_{C-P} = 2.6 Hz), 131.4 (J_{C-P} = 9.6 Hz), 131.3 (J_{C-P} = 173.3 Hz), 128.3 (J_{C-P} = 14.1 Hz), 73.9 (J_{C-P} = 5.7 Hz), 33.9 (J_{C-P} = 4.0 Hz), 27.2, 25.2, 23.7 (J_{C-P} = 8.2 Hz) (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 23.0 (ppm). MS (EI): *m*/*z* = 77.1 (12), 78.1 (7), 105.1 (20), 105.1 (3), 122.1 (4), 141.0 (6), 142.0 (7), 154.1 (16), 172.1 (100), 173.1 (8), 186.1 (3), 253.1 (1). IR (in KBr): ν = 3209, 2952, 2844, 1451, 1376, 1205, 1133, 976, 829, 748, 693, 555 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{13}H_{21}NO_2P$: 254.1310; Found. 254.1320.

P-Cyclohexylmethoxyl-N-methyl-P-phenylphosphonic amide (**4q**). Yellowish thick oil (101.9 mg, 76%). ^{1}H NMR (400 MHz, $CDCl_3$) δ = 7.78 (dd, *J* = 12.6, 7.3 Hz, 2H), 7.54 – 7.48 (m, 1H), 7.48 – 7.41 (m, 2H), 3.89 – 3.77 (m, 2H), 2.68 (bs, 1H), 2.55 (dd, *J* = 11.7, 5.6 Hz, 3H), 1.88 – 1.63 (m, 6H), 1.31 – 1.12 (m, 3H), 1.05 – 0.93 (m, 2H) (ppm). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 131.8 (J_{C-P} = 2.9 Hz), 131.5 (J_{C-P} = 9.5 Hz), 130.6 (J_{C-P} = 173.1 Hz), 128.5 (J_{C-P} = 14.1 Hz), 69.4 (J_{C-P} = 6.1 Hz), 38.6 (J_{C-P} = 6.8 Hz), 29.6 (J_{C-P} = 5.7 Hz), 27.3, 26.5, 25.8 (ppm). ^{31}P NMR (100 MHz, $CDCl_3$) δ = 23.8 (ppm). MS (EI): *m*/*z* (%): 77.1 (14), 91.1 (8), 105.1 (20), 105.1 (6), 141.0 (17), 142.0 (7), 159.0 (100), 172.1 (23), 184.1 (3), 221.1 (3). IR (in KBr): ν = 3214, 2985, 2901, 1650, 1444, 1215, 1119, 1003, 898, 852, 752, 695, 554 (cm^{-1}). HRMS (ESI) (m/z) [M + H^+]: Calcd. for $C_{14}H_{23}NO_2P$: 268.1466; Found 268.1459.

Supporting Information:

^{1}H and ^{13}C NMR spectra of all the compounds are available free of charge *via* the Internet at http://pubs.acs.org.

AKKNOWLEDGEMENT

We are grateful to the Natural Science Foundation of Hunan Province (No. 2017JJ3027), the Fundamental Research Funds for Hunan University (No. 531107040840).

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