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Synthesis of Novel Phosphorus-Substituted Stable Isoindoles by a Three-Component Coupling Reaction of *ortho*-Phthalaldehyde, 9,10-Dihydro-9-oxa-10-phosphaphenanthrene 10-Oxide, and Primary Amines

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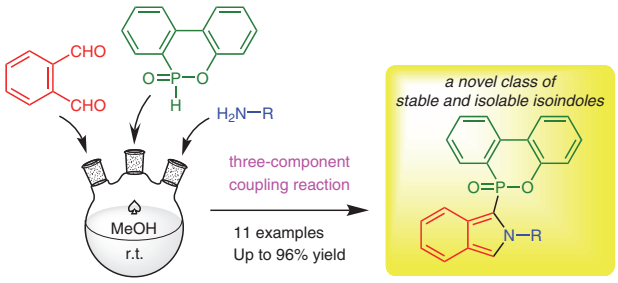

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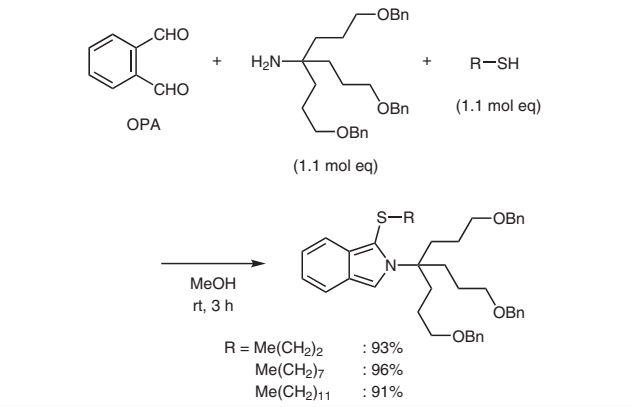
Abstract A three-component coupling reaction of *ortho*-phthalaldehyde, 9,10-dihydro-9-oxa-10-phosphaphenanthrene 10-oxide, and various primary amines readily afforded novel phosphorus-substituted stable isoindoles in good to excellent yields. The importance of the reversible ring-opening of 9,10-dihydro-9-oxa-10-phosphaphenanthrene 10-oxide by methanolysis in the three-component coupling reaction became apparent.

Key words OPA method, isoindoles, *ortho*-phthalaldehyde, 9,10-dihydro-9-oxa-10-phosphaphenanthrene 10-oxide, primary amines, isoindolin-1-ones, ring-opening, methanolysis

The three-component coupling reaction of *ortho*-phthalaldehyde (OPA), 2-mercaptoethanol, and a primary amine in aqueous alkaline medium is an efficient method for synthesizing isoindole,[1] an isomer of indole that is also called benzo[*c*]pyrrole. The analytical method used for primary amines based on the above reaction is known as the OPA method, and it plays an important role in modern amino acid analysis.[2] It should be noted that the isoindoles obtained by the OPA method are fluorescent compounds (λ_{ex} = 360 nm, λ_{em} = 455 nm), whereas OPA itself is intrinsically nonfluorescent and does not interfere with fluorescence analysis of the resulting isoindoles. However, isoindoles, unlike indoles, are generally unstable and difficult to purify and isolate by silica gel column chromatography, because they are 10π aromatic heterocycles with *ortho*-quinoid-like structures. R. Pino-Rios and M. Solà suggested that the inferior stability of isoindole compared to indole is a result of the decrease in benzene ring aromaticity as a manifestation of the Glidewell–Lloyd rule.[3] In 2012, a review by C. V. Stevens and co-workers mentioned two strategies for stabilizing isoindoles.[4] One is to sterically protect the isoindole ring by introducing a bulky substituent, and the second is to lower the highest occupied molecular orbital level of the isoindole ring by introducing an electron-withdrawing group. Recently, we reported the synthesis of novel stable isoindoles *via* the OPA method using bulky C_3-symmetric primary amines.[5] As shown in Scheme 1, OPA reacts with *O*-benzylated tris(hydroxypropyl)aminomethane and a bulky C_3-symmetric primary amine in the presence of several thiols to afford a novel class of stable and isolable isoindoles. The stability of a series of isoindoles was significantly influenced by the steric protection effect arising from the bulky nature of the C_3-symmetric primary amine. In a continuation of our interest in the synthesis of stable and isolable novel isoindoles based on the OPA method and their potential for biological activities, we herein report a facile synthesis of phosphorus-substituted stable isoindoles by a three-component coupling reaction of OPA, 9,10-dihydro-9-oxa-10-phosphaphenanthrene 10-oxide (DOPO), and various primary amines. While DOPO is commonly depicted as the aryl arylphosphinate structure in the H–P=O form, it is known to undergo tautomerization in solution, resulting in its P–OH form as aryl arylphosphonous acid. Therefore, the

phosphorus atom of DOPO exhibits both electrophilic and nucleophilic behavior.[6] The resulting isoindoles are presumably stabilized by steric and/or electronic effects due to the phenoxy(phenyl)phosphoryl substituent. To date, the synthesis of phosphorus-substituted stable isoindoles has been limited to the preparation of dialkoxyphosphoryl-substituted isoindoles from the corresponding dialkyl [amino(2-ethynylphenyl)methyl]phosphonates, as reported in the literature.[7]

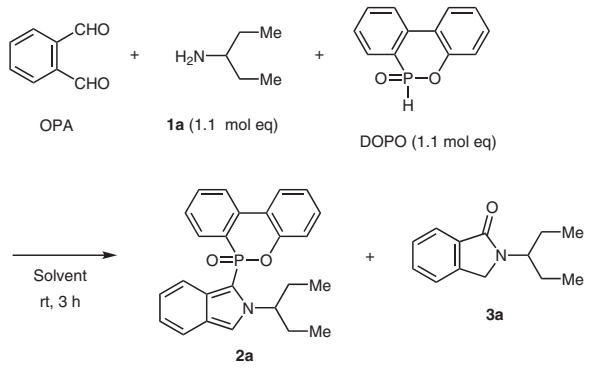


Scheme 1 The three-component coupling reaction of OPA, *O*-benzylated tris(hydroxypropyl)aminomethane, and thiols

To prepare novel phosphorus-substituted stable isoindoles, we investigated DOPO as a phosphorus nucleophile instead of the thiol nucleophile in the OPA method. In 1972, T. Saito patented DOPO as a novel class of cyclic organophosphorus compound.[8] It is now a commercially available chemical reagent and known as a typical flame-retardant agent.[6,9] Table 1 shows the three-component coupling reaction of OPA, DOPO, and 3-pentylamine (**1a**) in various anhydrous solvents at room temperature in the dark, using brown-tinted glassware. The reaction proceeded smoothly in anhydrous MeOH, and DOPO-isoindole **2a** was isolated in 70% yield by silica gel column chromatography (entry 1). In anhydrous EtOH and *i*-PrOH, the yields of DOPO-isoindole **2a** were 30% and ca. 16%, respectively, with some by-products of isoindolin-1-one **3a** (entries 2 and 3). However, when anhydrous MeCN, CH_2Cl_2, and THF were used (entries 4–6), the reaction afforded no DOPO-isoindole **2a**, and only isoindolin-1-one **3a** was obtained in moderate yields.

DOPO is a hygroscopic white powder and is known to be easily hydrolyzed to 2-(2-hydroxyphenyl)phenylphosphinic acid (HPPA) in open air; but HPPA is reversibly dehydrated to DOPO by drying under reduced pressure during heating, as shown in Scheme 2. In 1998, C. S. Wang et al. reported the four-step synthesis of DOPO starting from *ortho*-phenylphenol, and the final step was thermal dehydration of HPPA to DOPO by heating from its molten state (106 °C) to 160 °C under reduced pressure.[10] Therefore, it was presumed that reversible alcoholysis proceeded in anhydrous

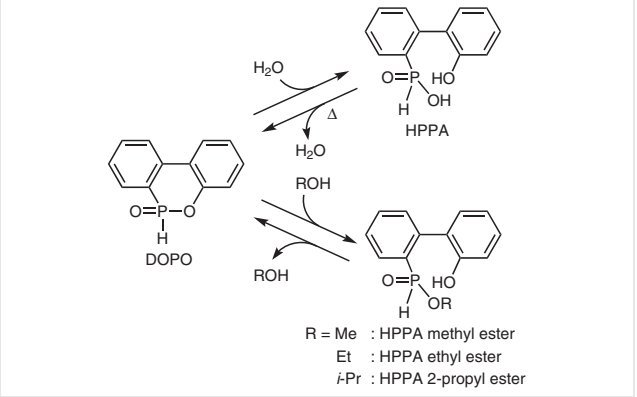
Table 1 Synthesis of DOPO-Isoindole **2a** by the Three-Component Coupling Reaction of OPA, DOPO, and 3-Pentylamine (**1a**) Based on the OPA Method



Entry	Solvent	Yield of **2a** (%)[a]	Yield of **3a** (%)[a]
1	MeOH	70	0
2	EtOH	30	ca. 8[b]
3	*i*-PrOH	ca. 16[b]	27
4	MeCN	0	35
5	CH_2Cl_2	0	42
6	THF	0	ca. 48[b]

[a] Isolated yield.
[b] Small amounts of impurities were included.

MeOH, EtOH, and *i*-PrOH to afford methyl 2-(2-hydroxyphenyl)phenylphosphinate (HPPA methyl ester), ethyl 2-(2-hydroxyphenyl)phenylphosphinate (HPPA ethyl ester), and 2-propyl 2-(2-hydroxyphenyl)phenylphosphinate (HPPA 2-propyl ester), respectively (Scheme 2). Since the phosphorus atoms of the ring-opened derivatives of DOPO, such as HPPA methyl ester, HPPA ethyl ester, and HPPA 2-propyl ester, are more nucleophilic than that of DOPO, it is assumed that they readily attacked the monoimine intermediate



Scheme 2 The reversible ring-opening of DOPO in H_2O and alcohols (MeOH, EtOH, and *i*-PrOH)

formed by the reaction of OPA and 3-pentylamine (**1a**) according to the plausible reaction mechanism of the OPA method.[11] Yasuda et al. reported that DOPO-aldehyde adducts or DOPO-ketone adducts were synthesized without using any bases by the reaction of HPPA with various aldehydes and ketones.[12] This suggests that the phosphorus atom of HPPA is highly nucleophilic.

To gain insight into the presence of ring-opened derivatives of DOPO in the coupling reaction, we conducted ^{1}H NMR spectroscopy on DOPO in MeOD-d_4, EtOD-d_6, and *i*-PrOD-d_8, as shown in Figure 1. Consequently, a distinct spectrum resembling HPPA, believed to be HPPA methyl ester, emerged prominently in the ^{1}H NMR spectrum of DOPO obtained 30 minutes after dissolution in MeOD-d_4. For comparison, the

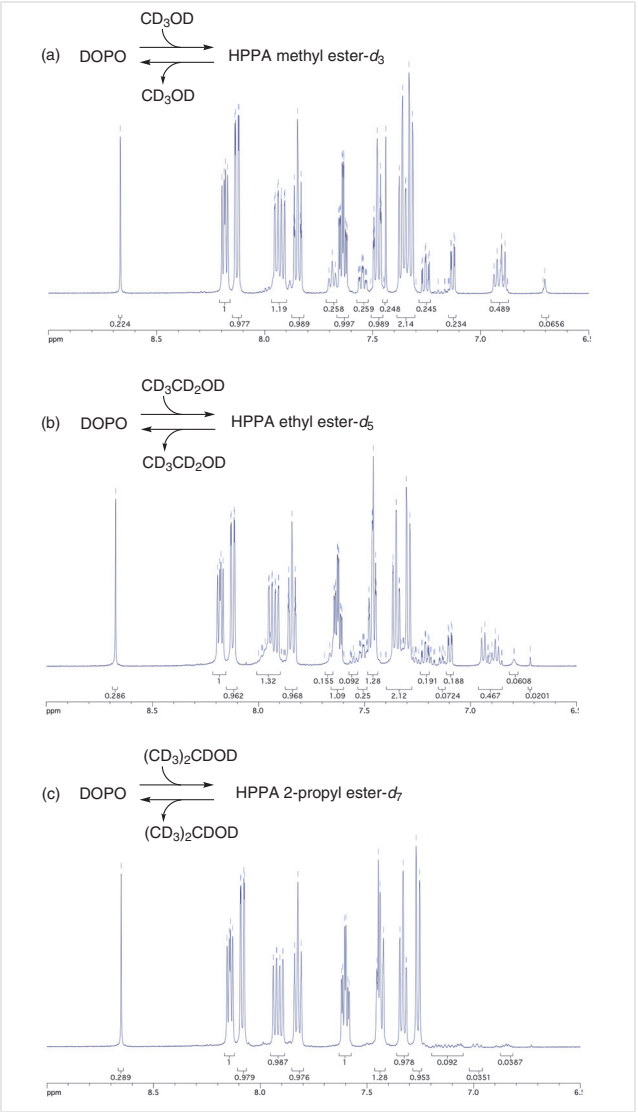


Figure 1 The aromatic region of ^{1}H NMR (500 MHz) spectra of DOPO 30 minutes after dissolution (a) in MeOD-d_4, (b) in EtOD-d_6, and (c) in *i*-PrOD-d_8

^{1}H NMR spectra of DOPO and HPPA in DMSO-d_6 are shown in Figure 2.[13] The characteristic doublet splitting of the P–H signal was observed from the ^{1}H NMR spectra of DOPO [δ = 8.12 (d, $^1J_{P,H}$ = 613.6 Hz)] and HPPA [δ = 7.19 (d, $^1J_{P,H}$ = 560.7 Hz)] in DMSO-d_6. Furthermore, the ^{1}H NMR spectrum of HPPA in DMSO-d_6 shows the mixture of HPPA and DOPO, suggesting that HPPA is easily converted into DOPO in DMSO-d_6. The protons on the phosphorus atoms of the ring-opened derivatives are unfortunately not observed, as shown in Figure 1, because they are readily exchanged in deuterated alcohol solvents. Comparing ^{1}H NMR spectra of DOPO 30 minutes after dissolution in some deuterated alcohols, the ring-opened derivative formed most rapidly in MeOD-d_4, and the formation rate decreased with an increase in the bulk of the alcohols. The difference in the rate of formation of the ring-opened derivative may be reflected in the yield of the three-component coupling reactions using some alcohols as solvents (Table 1, entries 1–3). Attempts to isolate HPPA methyl ester generated by methanolysis of DOPO in MeOH were not successful, as it readily reverted to DOPO during purification. This is probably due to the relative instability of HPPA methyl ester compared to HPPA.

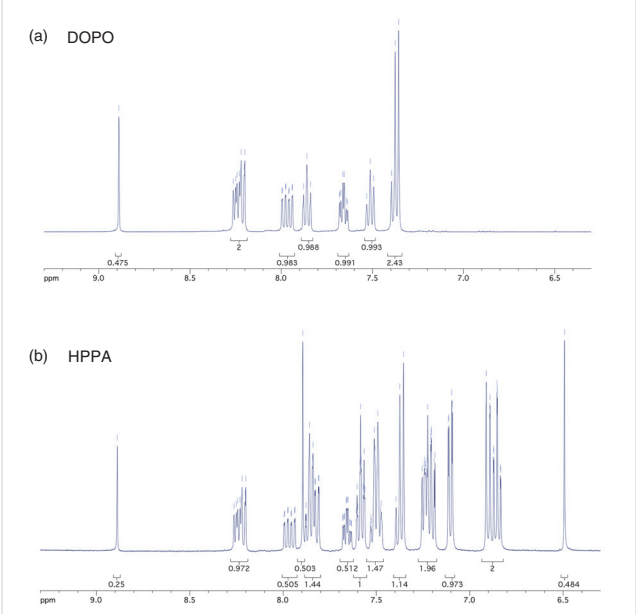
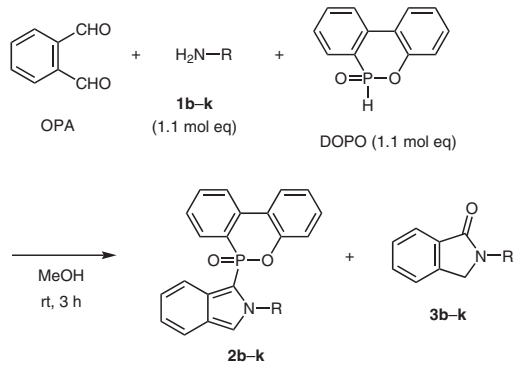
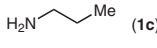
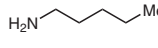
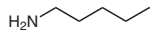
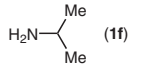
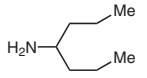
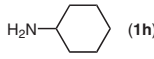
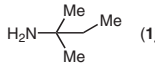
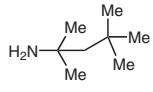


Figure 2 The aromatic region of ^{1}H NMR (400 MHz) spectra of (a) DOPO and (b) HPPA 30 minutes after dissolution in DMSO-d_6

To examine the scope and limitations of this three-component coupling reaction, various primary amines **1b–k** were subjected to the reaction with OPA and DOPO in anhydrous MeOH, as shown in Table 2. To our delight, the reaction with methylamine **1b**, the smallest primary amine, gave the stable DOPO-isoindole **2b** in 94% yield (entry 1). Unbranched primary aliphatic amines **1c–e** and branched

Table 2 Synthesis of DOPO-Isoindoles **2b–k** by the Three-Component Coupling Reaction of OPA, DOPO, and Primary Amines **1b–k** Based on the OPA Method



Entry	Primary amine **1b–k**	Yield (%)[a]	
		2b–k	**3b–k**
1[c]	H_2N—Me (**1b**)	94 (**2b**)	0 (**3b**)
2	 (**1c**)	84 (**2c**)	0 (**3c**)
3	 (**1d**)	67 (**2d**)	0 (**3d**)
4	 (**1e**)	67 (**2e**)	0 (**3e**)
5	 (**1f**)	85 (**2f**)	ca. 6 (**3f**)[b]
6	 (**1g**)	84 (**2g**)	ca. 11 (**3g**)[b]
7	 (**1h**)	91 (**2h**)	4 (**3h**)
8	 (**1i**)	96 (**2i**)	ca. 6 (**3i**)[b]
9[d]	 (**1j**)	81 (**2j**)	0 (**3j**)
10[e]	 (**1k**)	63 (**2k**)	0 (**3k**)

[a] Isolated yield.
[b] Small amounts of impurities were included.
[c] Methylamine (40% in MeOH) was used.
[d] 40 °C.
[e] Reflux.

primary aliphatic amines **1f–i** afforded DOPO-isoindoles **2c–i** in good to excellent yields (entries 2–8). However, bulky amines such as **1j** and **1k** required a higher reaction temperature of 40 °C and reflux, respectively (entries 9 and 10). All DOPO-isoindoles **2b–k** were found to be stable and were isolable by silica gel column chromatography, similar to DOPO-isoindole **2a**.

In conclusion, we have successfully prepared novel phosphorus-substituted stable isoindoles, 6-(2-alkyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-oxides **2a–k**, using the OPA method and employing various primary amines **1a–k**. The stability of the series of DOPO-isoindoles **2a–k** may be attributable to the steric and/or electronic effects of the phosphorus substituent derived from DOPO. Notably, the importance of the reversible ring-opening of DOPO by methanolysis in the three-component coupling reaction was also suggested by a detailed examination of the ^{1}H NMR spectral data.

All melting points were determined with a Yanagimoto micro melting-point apparatus and are uncorrected. IR spectra were obtained with a JASCO FT/IR-6200 IR Fourier transform spectrometer. ^{1}H NMR (400 MHz) spectra were recorded with a Bruker AV400N spectrometer. ^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra were recorded with a Bruker AV500 spectrometer. Chemical shifts are given in δ values (ppm) using TMS as an internal standard. HRMS (ESI) data were recorded with a Waters LCT Premier spectrometer. Elemental combustion analyses were performed with a J-SCIENCE LAB JM10. All reactions were monitored by TLC employing 0.25 mm silica gel plates (Merck 5715; 60 F_{254}). Flash column chromatography was carried out on silica gel [Silica Gel PSQ 60B (Fuji Silysia Chemical)].

Anhydrous EtOH and *i*-PrOH were used as purchased from FUJIFILM Wako Pure Chemical Corporation. Anhydrous MeOH, MeCN, CH_2Cl_2, and THF were used as purchased from Kanto Chemical. DOPO was dried under reduced pressure prior to use. All other reagents were used as purchased.

6-[2-(Pentan-3-yl)-2*H*-isoindol-1-yl]-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2a)

To a solution of OPA (51.3 mg, 0.382 mmol) in anhydrous MeOH (4 mL), 3-pentylamine (**1a**; 48.9 μL, 0.421 mmol) and DOPO (91 mg, 0.421 mmol) were added at 0 °C. After stirring in the dark for 3 h at room temperature, the reaction mixture was evaporated *in vacuo*. The oily residue was purified by flash column chromatography [Silica Gel PSQ 60B: $CHCl_3$–EtOAc (7:1)] to afford isoindole **2a**.

Yield: 107 mg (70%); white solid; mp 224.0–225.8 °C (colorless column, $CHCl_3$/*n*-hexane).

IR (KBr): 3098, 2964, 2874, 1931, 1821, 1581, 1476, 1429, 1320, 1304, 1214, 1120, 906, 758 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.10–8.05 (m, 2 H), 7.68–7.56 (m, 4 H), 7.55–7.50 (m, 1 H), 7.42–7.38 (m, 1 H), 7.36–7.26 (m, 3 H), 7.06–7.01 (m, 2 H), 4.81–4.74 (m, 1 H), 1.96–1.84 (m, 2 H), 1.83–1.74 (m, 1 H), 1.72–1.63 (m, 1 H), 0.84 (t, *J* = 7.4 Hz, 3 H), 0.53 (t, *J* = 7.4 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.2 (d, $^2J_{C,P}$ = 8.2 Hz), 135.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.7 Hz), 133.4 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 18.2 Hz), 132.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.4 Hz), 131.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.5 Hz), 130.4, 128.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.5 Hz), 127.6 (d, $^1J_{C,P}$ = 137.3 Hz), 125.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.8 Hz), 124.9,

124.4, 124.3, 123.4 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.9 Hz), 121.73 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.8 Hz), 121.66, 120.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.2 Hz), 120.11, 120.09, 117.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 8.9 Hz), 106.7 (d, $^1J_{C,P}$ = 190.3 Hz), 62.2, 29.9, 29.7, 10.5, 10.4.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{25}H_{25}NO_2P$: 402.1623; found: 402.1626.

Anal. Calcd for $C_{25}H_{24}NO_2P$: C, 74.80; H, 6.03; N, 3.49. Found: C, 74.63; H, 6.00; N, 3.51.

6-(2-Methyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2b)

Yield: 124 mg (94%); pale-yellow solid; mp 72.2–74.5 °C.

IR (KBr): 3060, 3032, 2955, 1582, 1509, 1477, 1327, 1224, 1186, 1119 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.07–8.01 (m, 2 H), 7.66–7.62 (m, 1 H), 7.60–7.55 (m, 2 H), 7.51–7.46 (m, 1 H), 7.43 (d, *J* = 4.2 Hz, 1 H), 7.40–7.36 (m, 1 H), 7.35–7.31 (m, 1 H), 7.30–7.26 (m, 2 H), 7.06–7.00 (m, 2 H), 4.01 (s, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.1 (d, $^2J_{C,P}$ = 8.2 Hz), 135.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.3 Hz), 134.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 18.0 Hz), 132.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.3 Hz), 130.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 13.1 Hz), 130.4, 128.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.6 Hz), 127.0 (d, $^1J_{C,P}$ = 137.6 Hz), 125.0, 124.64, 124.56, 124.5, 123.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.4 Hz), 123.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.3 Hz), 121.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.8 Hz), 121.8, 120.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.6 Hz), 120.0, 119.6, 106.0 (d, $^1J_{C,P}$ = 190.4 Hz), 38.3.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{21}H_{16}NO_2PNa$: 368.0816; found: 368.0809.

6-(2-Propyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2c)

Yield: 120 mg (84%); pale-yellow solid; mp 192.2–194.8 °C.

IR (KBr): 3410, 3123, 3053, 2960, 2874, 1968, 1479, 1328, 1230, 1121, 935, 755 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.11–8.05 (m, 2 H), 7.69–7.64 (m, 1 H), 7.63–7.60 (m, 1 H), 7.55 (d, *J* = 4.2 Hz, 1 H), 7.52–7.46 (m, 1 H), 7.42–7.38 (m, 1 H), 7.37–7.28 (m, 4 H), 7.04–6.96 (m, 2 H), 4.55–4.44 (m, 2 H), 2.05–1.90 (m, 2 H), 0.89 (t, *J* = 7.4 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.1 (d, $^2J_{C,P}$ = 8.2 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.3 Hz), 133.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 18.0 Hz), 132.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.3 Hz), 130.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 130.4, 128.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.9 Hz), 127.3 (d, $^1J_{C,P}$ = 138.0 Hz), 124.9, 124.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 124.5, 124.4, 123.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.0 Hz), 122.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.1 Hz), 121.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.8 Hz), 121.7, 120.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.6 Hz), 120.1, 119.5, 105.2 (d, $^1J_{C,P}$ = 190.1 Hz), 52.4, 25.8, 11.2.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{23}H_{21}NO_2P$: 374.1310; found: 374.1313.

6-(2-Pentyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2d)

Yield: 109 mg (67%); pale-brown solid; mp 57.2–60.0 °C.

IR (KBr): 3409, 3060, 2956, 2869, 1939, 1618, 1476, 1325, 1224, 1118, 902, 757 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.10–8.04 (m, 2 H), 7.68–7.64 (m, 1 H), 7.63–7.60 (m, 1 H), 7.54 (d, *J* = 4.2 Hz, 1 H), 7.52–7.46 (m, 1 H), 7.42–7.27 (m, 5 H), 7.04–6.97 (m, 2 H), 4.55–4.42 (m, 2 H), 1.98–1.82 (m, 2 H), 1.30–1.18 (m, 4 H), 0.83 (t, *J* = 6.9 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.1 (d, $^2J_{C,P}$ = 8.2 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.1 Hz), 134.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 17.6 Hz), 132.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.1 Hz), 130.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 130.4, 128.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.6 Hz), 127.3 (d, $^1J_{C,P}$ = 137.9 Hz), 124.9, 124.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 124.5, 124.4, 123.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.9 Hz), 122.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.0 Hz), 121.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.5 Hz), 121.7, 120.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.9 Hz), 120.1, 119.6, 105.2 (d, $^1J_{C,P}$ = 189.9 Hz), 50.9, 32.2, 28.8, 22.2, 13.9.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{25}H_{25}NO_2P$: 402.1623; found: 402.1603.

6-(2-Heptyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2e)

Yield: 110 mg (67%); pale-brown oil.

IR (neat): 3060, 2926, 2856, 1940, 1691, 1582, 1476, 1416, 1324, 1225, 1118, 904, 758 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.10–8.04 (m, 2 H), 7.68–7.64 (m, 1 H), 7.63–7.60 (m, 1 H), 7.54 (d, *J* = 4.1 Hz, 1 H), 7.52–7.46 (m, 1 H), 7.43–7.38 (m, 2 H), 7.36–7.31 (m, 1 H), 7.31–7.27 (m, 2 H), 7.04–6.98 (m, 2 H), 4.52–4.40 (m, 2 H), 1.97–1.80 (m, 2 H), 1.26–1.15 (m, 8 H), 0.84 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.1 (d, $^2J_{C,P}$ = 8.2 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.3 Hz), 134.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 18.1 Hz), 132.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.5 Hz), 130.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 130.4, 128.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.6 Hz), 127.3 (d, $^1J_{C,P}$ = 137.5 Hz), 124.9, 124.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 124.5, 124.4, 123.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.0 Hz), 122.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 8.9 Hz), 121.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.8 Hz), 121.7, 120.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.2 Hz), 120.1, 119.7, 105.1 (d, $^1J_{C,P}$ = 189.9 Hz), 50.9, 32.5, 31.7, 28.8, 26.7, 22.5, 14.0.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{29}NO_2P$: 430.1936; found: 430.1927.

6-(2-Isopropyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2f)

Yield: 118 mg (85%); white solid; mp 210.0–212.2 °C.

IR (KBr): 3550, 3414, 3112, 3062, 2980, 1637, 1618, 1432, 1237, 906, 758 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.10–8.04 (m, 2 H), 7.69–7.61 (m, 3 H), 7.54–7.48 (m, 1 H), 7.43–7.33 (m, 3 H), 7.32–7.27 (m, 2 H), 7.04–6.97 (m, 2 H), 5.36 (sept, *J* = 6.6 Hz, 1 H), 1.61 (d, *J* = 6.6 Hz, 3 H), 1.44 (d, *J* = 6.7 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.1 (d, $^2J_{C,P}$ = 8.2 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.0 Hz), 133.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 17.7 Hz), 132.7 (d, $^2J_{C,P}$ or $^3J_{C,P\,P}$ = 2.5 Hz), 130.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.9 Hz), 130.4, 128.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.6 Hz), 127.4 (d, $^1J_{C,P}$ = 138.0 Hz), 125.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.9 Hz), 125.0, 124.5, 124.4, 123.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.0 Hz), 122.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.6 Hz), 121.6, 120.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.2 Hz), 120.2, 119.7, 117.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.0 Hz), 104.9 (d, $^1J_{C,P}$ = 190.0 Hz), 50.9, 24.8, 24.3.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{23}H_{21}NO_2P$: 374.1310; found: 374.1299.

6-[2-(Heptan-4-yl)-2*H*-isoindol-1-yl]-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2g)

Yield: 138 mg (84%); white solid; mp 209.1–210.5 °C.

IR (KBr): 3402, 3099, 3082, 2961, 2933, 2873, 1475, 1422, 1218, 912, 757 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.10–8.04 (m, 2 H), 7.68–7.59 (m, 3 H), 7.57–7.54 (m, 1 H), 7.53–7.47 (m, 1 H), 7.42–7.38 (m, 1 H), 7.36–7.25 (m, 3 H), 7.05–6.99 (m, 2 H), 4.98 (quint, *J* = 6.4 Hz, 1 H), 1.90–1.78 (m, 2 H), 1.75–1.67 (m, 1 H), 1.66–1.57 (m, 1 H), 1.44–1.33 (m, 1 H), 1.14–0.97 (m, 2 H), 0.85 (t, *J* = 7.3 Hz, 3 H), 0.82–0.74 (m, 1 H), 0.69 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.1 (d, $^2J_{C,P}$ = 8.2 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.0 Hz), 133.4 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 18.3 Hz), 132.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.0 Hz), 131.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.6 Hz), 130.3, 128.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.6 Hz), 127.6 (d, $^1J_{C,P}$ = 137.8 Hz), 125.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 13.1 Hz), 124.9, 124.4, 124.2, 123.4 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.9 Hz), 121.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.7 Hz), 121.7, 120.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.7 Hz), 120.09, 120.05, 117.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.1 Hz), 106.3 (d, $^1J_{C,P}$ = 190.5 Hz), 59.5, 39.44, 39.39, 19.3, 19.2, 14.0, 13.8.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{27}H_{28}NO_2PNa$: 452.1755; found: 452.1747.

6-(2-Cyclohexyl-2*H*-isoindol-1-yl)-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2h)

Yield: 141 mg (91%); white solid; mp 175.2–177.0 °C (colorless column, EtOAc).

IR (KBr): 3051, 2961, 2944, 2860, 1961, 1926, 1810, 1702, 1448, 1316, 1231, 932, 755 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.11–8.05 (m, 2 H), 7.69–7.60 (m, 4 H), 7.57–7.51 (m, 1 H), 7.42–7.27 (m, 4 H), 7.07–7.01 (m, 2 H), 4.66–4.59 (m, 1 H), 2.28–2.22 (m, 1 H), 1.84–1.58 (m, 6 H), 1.21–0.96 (m, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.2 (d, $^2J_{C,P}$ = 8.2 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.2 Hz), 133.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 18.1 Hz), 132.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.5 Hz), 131.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 130.4, 128.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.5 Hz), 127.4 (d, $^1J_{C,P}$ = 136.5 Hz), 125.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 13.6 Hz), 124.9, 124.44, 124.38, 123.4 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.0 Hz), 121.621 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.6 Hz), 121.615, 120.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.2 Hz), 120.1, 120.0, 118.4 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 8.9 Hz), 105.3 (d, $^1J_{C,P}$ = 190.6 Hz), 58.8, 35.7, 35.1, 25.8, 25.3.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{26}H_{24}NO_2PNa$: 436.1442; found: 436.1418.

Anal. Calcd for $C_{26}H_{24}NO_2P$: C, 75.53; H, 5.85; N, 3.39. Found: C, 75.55; H, 5.88; N, 3.52.

6-[2-(*tert*-Butyl)-2*H*-isoindol-1-yl]-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2i)

Yield: 142 mg (96%); white solid; mp 81.2–83.3 °C.

IR (KBr): 3158, 2983, 2231, 1580, 1474, 1402, 1228, 1195, 1117, 891, 757 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.09–8.05 (m, 2 H), 7.84 (d, *J* = 5.0 Hz, 1 H), 7.63–7.58 (m, 2 H), 7.43–7.22 (m, 5 H), 6.94–6.90 (m, 1 H), 6.83–6.77 (m, 2 H), 2.09 (s, 9 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.2 (d, $^2J_{C,P}$ = 8.0 Hz), 135.7 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 17.2 Hz), 135.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.6 Hz), 132.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.6 Hz), 130.2, 129.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 129.0 (d, $^1J_{C,P}$ = 141.0 Hz), 128.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.8 Hz), 125.0, 124.5, 124.3, 123.5 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.0 Hz), 123.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 122.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.9 Hz), 121.11, 121.07 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.6 Hz), 121.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.2 Hz), 120.6, 119.3, 104.7 (d, $^1J_{C,P}$ = 181.5 Hz), 61.1, 31.8.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{24}H_{22}NO_2PNa$: 410.1286; found: 410.1289.

6-[2-(*tert*-Pentyl)-2*H*-isoindol-1-yl]-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2j)

Yield: 121 mg (81%); white solid; mp 92.5–94.0 °C.

IR (KBr): 3394, 2977, 2879, 1581, 1475, 1401, 1244, 1118, 900, 758 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.09–8.05 (m, 2 H), 7.80 (d, *J* = 5.0 Hz, 1 H), 7.63–7.58 (m, 2 H), 7.42–7.38 (m, 1 H), 7.37–7.24 (m, 4 H), 6.94–6.90 (m, 1 H), 6.82–6.76 (m, 2 H), 2.67–2.54 (m, 2 H), 2.03 (s, 3 H), 2.00 (s, 3 H), 0.81 (t, *J* = 7.4 Hz, 3 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.2 (d, $^2J_{C,P}$ = 7.9 Hz), 135.8 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 17.4 Hz), 135.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.5 Hz), 132.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.6 Hz), 130.2, 129.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 129.0 (d, $^1J_{C,P}$ = 140.9 Hz), 128.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 15.2 Hz), 125.0, 124.5, 124.3, 123.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.1 Hz), 123.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.8 Hz), 122.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.2 Hz), 122.0 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.3 Hz), 121.12 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.0 Hz), 121.07, 120.6, 119.4, 104.6 (d, $^1J_{C,P}$ = 186.3 Hz), 64.2, 34.6, 29.7, 29.5, 8.6.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{25}H_{24}NO_2PNa$: 424.1442; found: 424.1416.

6-[2-(2,4,4-Trimethylpenta-2-yl)-2*H*-isoindol-1-yl]-6*H*-dibenzo[*c*,*e*][1,2]oxaphosphinine 6-Oxide (2k)

Yield: 100 mg (63%); white solid; mp 90.0–92.3 °C.

IR (KBr): 3409, 2952, 2901, 1908, 1581, 1475, 1401, 1220, 1118, 895, 757 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 8.10–8.05 (m, 2 H), 7.86 (d, *J* = 5.0 Hz, 1 H), 7.64–7.59 (m, 2 H), 7.42–7.35 (m, 2 H), 7.32–7.24 (m, 3 H), 6.94–6.90 (m, 1 H), 6.81–6.71 (m, 2 H), 3.04 (brd, 1 H), 2.32 (d, *J* = 15.4 Hz, 1 H), 2.13 (s, 3 H), 2.06 (s, 3 H), 0.91 (s, 9 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 149.3 (d, $^2J_{C,P}$ = 8.1 Hz), 135.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 17.1 Hz), 135.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 5.6 Hz), 132.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 2.6 Hz), 130.2, 129.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 129.2 (d, $^1J_{C,P}$ = 141.7 Hz), 128.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 14.6 Hz), 125.0, 124.4, 124.3, 123.6 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 10.0 Hz), 123.2 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 12.7 Hz), 122.3 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 11.9 Hz), 121.9 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 9.6 Hz), 121.1 (d, $^2J_{C,P}$ or $^3J_{C,P}$ = 6.0 Hz), 121.0, 120.5, 119.6, 105.4 (d, $^1J_{C,P}$ = 186.1 Hz), 64.8, 52.9, 33.0, 32.0, 31.9, 31.0.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{28}H_{30}NO_2PNa$: 466.1912; found: 466.1905.

2-Isopropylisoindolin-1-one (3f)[14]

Yield: 4 mg (ca. 6%); pale-yellow solid; mp 85.1–86.7 °C.

IR (KBr): 2976, 2913, 2872, 1675, 1461, 1413, 1238 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.86–7.84 (m, 1 H), 7.52 (td, *J* = 7.4, 1.2 Hz, 1 H), 7.47–7.44 (m, 2 H), 4.69 (sept, *J* = 6.8 Hz, 1 H), 4.34 (s, 2 H), 1.30 (d, *J* = 6.8 Hz, 6 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 167.8, 141.2, 133.4, 131.0, 127.9, 123.5, 122.7, 45.0, 42.6, 20.8.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{11}H_{13}NONa$: 198.0895; found: 198.0880.

2-(Heptan-4-yl)isoindolin-1-one (3g)

Yield: 10 mg (ca. 11%); colorless oil.

IR (neat): 2956, 2932, 2871, 1682, 1469, 1455, 1410, 1210 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.87–7.84 (m, 1 H), 7.54–7.50 (m, 1 H), 7.48–7.43 (m, 2 H), 4.43 (quint, *J* = 7.4 Hz, 1 H), 4.25 (s, 2 H), 1.62–1.54 (m, 4 H), 1.37–1.19 (m, 4 H), 0.91 (t, *J* = 7.4 Hz, 6 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 168.9, 141.2, 133.2, 131.0, 127.9, 123.8, 122.7, 50.6, 45.0, 35.9, 19.5, 13.9.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{15}H_{21}NONa$: 254.1521; found: 254.1503.

2-Cyclohexylisoindolin-1-one (3h)[15]

Yield: 3.2 mg (4%); white solid; mp 78.0–79.0 °C.

IR (KBr): 2929, 2854, 2667, 1665, 1449, 1411, 1227 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.87–7.84 (m, 1 H), 7.53–7.50 (m, 1 H), 7.45 (t, *J* = 7.2 Hz, 2 H), 4.35 (s, 2 H), 4.29–4.22 (m, 1 H), 1.91–1.81 (m, 4 H), 1.76–1.70 (m, 1 H), 1.53–1.42 (m, 4 H), 1.22–1.12 (m, 1 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 167.8, 141.3, 133.4, 130.9, 127.9, 123.5, 122.7, 50.5, 46.0, 31.4, 25.62, 25.56.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{14}H_{17}NONa$: 238.1208; found: 238.1188.

2-(*tert*-Butyl)isoindolin-1-one (3i)[16]

Yield: 4.0 mg (ca. 6%); white solid; mp 61.0–63.5 °C.

IR (KBr): 2975, 2917, 2873, 1667, 1471, 1455, 1396, 1216 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.79 (d, *J* = 7.5 Hz, 1 H), 7.50 (td, *J* = 7.4, 1.2 Hz, 1 H), 7.45–7.39 (m, 2 H), 4.46 (s, 2 H), 1.57 (s, 9 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 168.8, 140.7, 134.5, 130.9, 127.8, 123.1, 122.3, 54.3, 48.5, 28.1.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{12}H_{15}NONa$: 212.1051; found: 212.1046.

2-(Pentan-3-yl)isoindolin-1-one (3a)[17]

To a solution of OPA (50.5 mg, 0.377 mmol) in anhydrous CH_2Cl_2 (4 mL), 3-pentylamine (**1a**; 48.0 μL, 0.414 mmol) and DOPO (89.5 mg, 0.414 mmol) were added at 0 °C. After stirring in the dark for 3 h at room temperature, the reaction mixture was evaporated *in vacuo*. The oily residue was purified by column chromatography [Silica Gel PSQ 60B: *n*-hexane/EtOAc (1:1)] to afford isoindolin-1-one **3a**.

Yield: 32 mg (42%); colorless oil.

IR (neat): 2964, 2933, 2875, 1682, 1469, 1454, 1410, 1214 cm^{-1}.

^{1}H NMR ($CDCl_3$, 500 MHz): δ = 7.88–7.85 (m, 1 H), 7.55–7.51 (m, 1 H), 7.48–7.44 (m, 2 H), 4.27–4.20 (m, 1 H), 4.25 (s, 2 H), 1.75–1.66 (m, 2 H), 1.63–1.53 (m, 2 H), 0.88 (t, *J* = 7.4 Hz, 6 H).

^{13}C NMR ($CDCl_3$, 125 MHz): δ = 169.2, 141.2, 133.2, 131.0, 127.9, 123.8, 122.7, 54.4, 45.0, 26.5, 10.9.

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{13}H_{17}NONa$: 226.1208; found: 226.1195.

Conflict of Interest

The authors declare no conflict of interest.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/a-2148-9433.

References

(1) (a) Joule, J. A.; Mills, K. In *Heterocyclic Chemistry, 5th ed*; Wiley: New York, **2010**, 447. (b) Eicher, T.; Hauptmann, S.; Speicher, A. In *The Chemistry of Heterocycles: Structures, Reactions, Synthesis, and Applications, 3rd ed*; Wiley-VCH: Weinheim, **2012**, 150.
(2) (a) Lee, K. S.; Drescher, D. G. *Int. J. Biochem.* **1978**, *9*, 457. (b) Hermanson, G. T. In *Bioconjugate Techniques, 2nd ed*; Elsevier: London, **2008**, 128.
(3) (a) El Bakouri, O.; Poater, J.; Feixas, F.; Solà, M. *Theor. Chem. Acc.* **2016**, *135*, 205. (b) Pino-Rios, R.; Solà, M. *J. Phys. Chem. A* **2021**, *125*, 230.
(4) Heugebaert, T. S. A.; Roman, B. I.; Stevens, C. V. *Chem. Soc. Rev.* **2012**, *41*, 5626.
(5) Nakao, M.; Nishikiori, N.; Nakamura, A.; Miyagi, M.; Shibata, N.; Kitaike, S.; Fukui, M.; Ito, H.; Sano, S. *SynOpen* **2018**, *2*, 50.
(6) Salmeia, K. A.; Gaan, S. *Polym. Degrad. Stab.* **2015**, *113*, 119.
(7) (a) Dieltiens, N.; Stevens, C. V. *Org. Lett.* **2007**, *9*, 465. (b) Ding, Q.; Ye, Y.; Fan, R.; Wu, J. *J. Org. Chem.* **2007**, *72*, 5439. (c) Bukšnaitienė, R.; Urbanaitė, A.; Čikotienė, I. *J. Org. Chem.* **2014**, *79*, 6532.
(8) Saito, T. UA Patent 3702878, **1972**.
(9) (a) Liu, Y. L. *Polymer* **2001**, *42*, 3445. (b) Wang, H.; Wang, S.; Du, X.; Wang, H.; Cheng, X.; Du, Z. *RSC Adv.* **2019**, *9*, 7411. (c) Chi, Z.; Guo, Z.; Xu, Z.; Zhang, M.; Li, M.; Shang, L.; Ao, Y. *Polym. Degrad. Stab.* **2020**, *176*, 109151. (d) Bifulco, A.; Varganici, C.-D.; Rosu, L.; Mustata, F.; Rosu, D.; Gaan, S. *Polym. Degrad. Stab.* **2022**, *200*, 109962.
(10) Wang, C.-S.; Shieh, J.-Y. *Polymer* **1998**, *39*, 5819.
(11) (a) Todorovic, M.; Schwab, K. D.; Zeisler, J.; Zhang, C.; Bénard, F.; Perrin, D. M. *Angew. Chem. Int. Ed.* **2019**, *58*, 14120. (b) Zhang, Y.; Zhang, Q.; Wong, C. T. T.; Li, X. *J. Am. Chem. Soc.* **2019**, *141*, 12274. (c) Maslivetc, V. A.; La Clair, J. J.; Kornienko, A. *RSC Adv.* **2022**, *12*, 6947.
(12) Yamada, Y.; Yasuda, H.; Saito, T. *J. Heterocycl. Chem.* **1990**, *27*, 845.
(13) Lai, H.; Li, X.; Liu, X.; Zhu, X.; Tan, X.; Xiong, P. *Chin. J. Magn. Reson.* **2017**, *34*, 61.
(14) Wan, J.; Wu, B.; Pan, Y. *Tetrahedron* **2007**, *63*, 9338.
(15) Rousseaux, S.; Gorelsky, S. I.; Chung, B. K. W.; Fagnou, K. *J. Am. Chem. Soc.* **2010**, *132*, 10692.
(16) Marosvölgyi-Haskó, D.; Takács, A.; Riedl, Z.; Kollár, L. *Tetrahedron* **2011**, *67*, 1036.
(17) Ryu, I.; Matsu, K.; Minakata, S.; Komatsu, M. *J. Am. Chem. Soc.* **1998**, *120*, 5838.