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General, mild and metal-free functionalization of indole and its derivatives through direct C3-selenylation

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TOC text:

Nature mimicking synthetic route allow for the preparation of C-3 indoyl selenoethers bearing labile functionalized alkyl substituents on selenium atom.

Key Topics: Indole chemistry, selenium, electrophilic substitution

ABSTRACT

A very mild method for the introduction of functionalized alkylselenyl group at C-3 position of the indole ring was developed. Proposed procedure consists of an electrophilic substitution of indole and its derivatives with bis(O,O-diisopropoxyphosphorothioyl) diselenide and subsequent cleavage of the P-Se bond with tetrabutylammonium fluoride in the presence of various electrophilic reagents. These method can be successfully applied, inter alia, for the preparation of amino acid and glucoside derivatives of 3-selenoindole.

INTRODUCTION

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The indole ring is a structural motif that is widely distributed among the naturally occurring and synthetic bioactive compounds.[1] By way of example, indole-based natural anticarcinogens can be isolated from cruciferous vegetables or deep water plants [2-3] while its derivatives obtained synthetically are commonly used as pharmaceuticals of diverse biological activities. For instance, oxindoles [4] are used as antimicrobial agents, while 2-arylindoles are COX-2 inhibitors, reducing the inflammation and pain.[5] Among them, 3-sulfenylated and 3-selenylated indoles are found to exhibit anticancer and anti-HIV activity. [6-10]. This ubiquity of indole across pharmaceuticals and natural products qualifies it as an attractive scaffold for novel drug development.

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Various synthetic methods for indole selenylation have been reported. Over the past few years, synthetic methods for the preparation of indoyl selenides have been drastically improved, but the reaction of indole with diorganyl diselenide in basic conditions remains the most common pathway. [11] Other commonly used selenylation methods are electrophilic substitution with organoselenium halides or phthalimides [12-15] and copper-catalyzed reaction with diorganyl diselenides [16]. However, despite their advantages, these methods have one common drawback: all methods require the usage of diaryl or dialkyl diselenides, and especially the preparation of the latter might be the major challenge of the synthetic procedure. Most of these reported procedures focus on the usage of diaryl diselenides, among which diphenyl diselenide is being the one most commonly used, [17-22] and thus omit the discussion of the difficulties related to the diselenide preparation. An alternative method of the synthesis involves the reaction of indole with *in-situ* prepared cyanogen triselenide, which is highly toxic. Obtained 3-selenocyanatoindole can be further reduced using



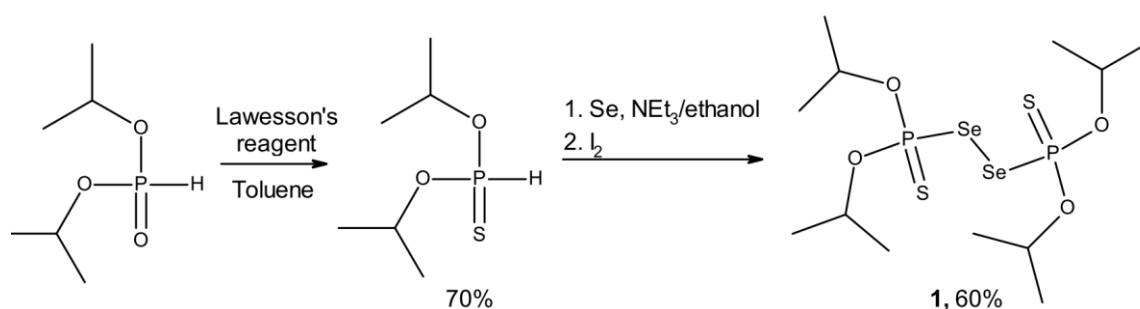
1 NaBH₄, finally forming sodium selenolate that can be used in the reaction with
2 electrophiles (eg. alkyl halides) to form indoylethyl selenoethers. [23] Finally, metal-
3 catalyzed indole and 5-deazapurine selenylation reactions were reported,
4 although harsh conditions of the processes (temperature ~110 °C) limit their
5 application in the synthesis. [24-27]
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11 As stated before, great deal of attention has been lately paid to synthesis
12 of indoylethyl thio- and selenoethers due to their potent therapeutic value. The most
13 prominent (and well known bioactive) group of indoylethyl thio- and selenoethers
14 contain aryl substituents on the chalcogen atom, eg. tubulin polymerization
15 inhibitors or PPAR gamma agonists.[28,29] The popularity of these scaffold is
16 due to the simplicity of the synthesis of aryl diselenides, which are used to
17 incorporate thio- and selenoaryl substituent into indole ring.[16] The recently
18 developed anti-HIV agents [10] composed of an indole ring bearing alkylselenyl
19 substituents shows that there is an urgent need to develop a simple and general
20 path for the synthesis of these potentially bioactive compounds.
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36 According to the known metabolic pathway, the selenium incorporation
37 into bioorganic compounds takes place with the participation of the
38 selenophosphate [30]. Inspired by nature, we decided to examine the
39 selenylation efficiency of indoles by selenophosphate analogue, namely,
40 bis(O,O-diisopropoxyphosphorothioyl) diselenide **1**. In present work we report
41 easy, selective and efficient method for introduction of protected selenole group
42 into indole scaffold. The formed indole O,O-diisopropoxyphosphorothioylselenyl
43 derivatives possess hydrolyzable Se-P bond, which can be selectively
44 deprotected in the presence of electrophilic substrate. Thus, our synthetic route
45 offers an efficient method to synthesize various alkyl selenoindoles, such as
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alkyl, aryl or acyl. The most prominent advantage of our method is mild reaction conditions, which allow us to obtain susceptible selenoindole derivatives, such as Se-(3-indolyl)-L-selenocysteine, an example of unnatural tryptophan-alike derivatives which are of a broad interest,[31-33] or 3-indolyl β -selenoglycosides that can be used as a glycosidase inhibitors.[34] The preparation of mentioned compounds would be difficult or even impossible with currently known methods of the selenoindole derivative synthesis. We also examine the scope of our synthetic procedure, showing that our method is suitable to efficiently introduce selenoether group not only into indole rings with various substituents, but also into 7-deazapurine derivatives, which are known to exhibit a significant cytostatic effect.[35] Bis(O,O-diisopropoxyphosphorothioyl) diselenide **1** used as selenium source is a crystalline, non hygroscopic, moisture, temperature and light stable solid with a long shelf life (it can be stored on shelf for 10 years without significant traces of degradation). It is also easy to prepare from readily available O,O-diisopropyl *H*-phosphonate (Scheme 1). [36]



Scheme 1. Preparation of bis(O,O-diisopropoxyphosphorothioyl) diselenide **1**

RESULTS AND DISCUSSION

Our research was focused on the development of an effective method for electrophilic selenylation of indole rings. For this purpose we used bis(O,O-diisopropoxyphosphorothioyl) diselenide **1**, which we have previously shown to

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be an easy to handle and stable source of electrophilic selenium. The initial reactions were performed using O,O-diisopropoxyphosphorothioylselenenyl bromide generated *in-situ* in the reaction of **1** with bromide at -78 °C in DCM followed by its reaction with indole. This method led us to obtain the desired product **2a**, however, in poor yields (12-15%). Suspecting that low yields were caused by a low nucleophilicity of indole moiety, we decided to increase indole nucleophilicity by the deprotonation of pyrrole ring instead of increasing the selenide electrophilicity. Treatment of indole with **1** in the presence of DBU in DCM at room temperature gave 3-selenylated indole **2a** in an almost quantitative yield. Addition of iodine allowed us to reduce the amount of **1** to 0.5 eq. and thereby increase selenium atom economy to 100%.

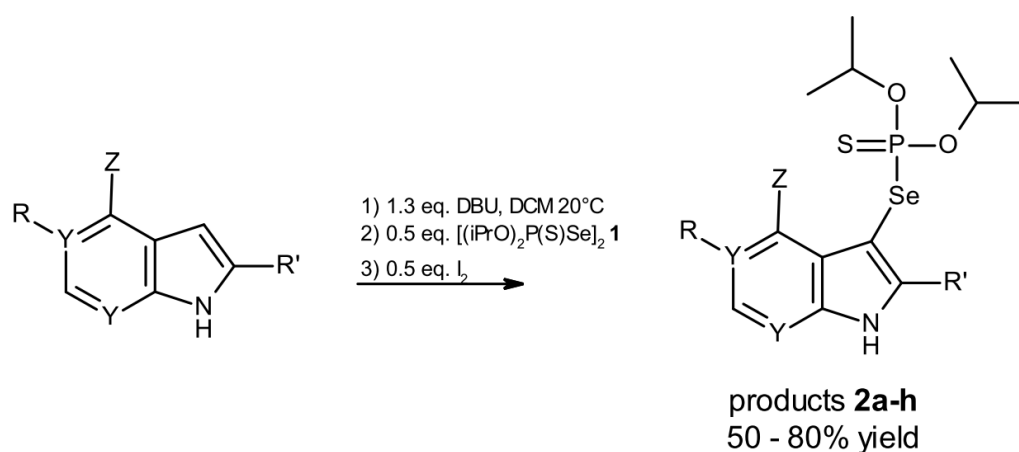
We then proceed to examine the suitability of this procedure (Table 1) for selenylation of substituted indoles. All tested compounds underwent selenylation at 3-position exclusively. We also successfully applied our selenylation procedure for 7-deazapurines, which are structurally similar to nucleobases, but share the same structure of the pyrrole ring with indole. Here we also observed only one product with the selenophosphate group attached to 7-position. The reaction yields of obtained products **2a-h** are shown in Table 1. To further examine the scope of our method, we performed the same procedure for other activated aromatic systems, such as carbazole, dibenzazepine, pyrrole, furan, thiophene and benzotriazole. In most cases we either observed only trace amount of product (furan and thiophene) or did not observe formation of any product at all (carbazole and dibenzazepine). On the other hand, reaction with pyrrole anion led to multiple products, and in case of benzotriazole the reaction went through N-phosphorothioylation accompanied with a loss of selenium to



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give benzotriazol-1-yl-phosphonothioic acid O,O-diisopropyl ester as the sole product. The reaction of **1** with indole also did not proceed in the absence of DBU. These results further emphasize that additional activation of electron-rich aromatic ring is indispensable for the reaction with poorly electrophilic diselenide **1** and provide that our procedure leads selectively to C-selenylation of a pyrrole ring.

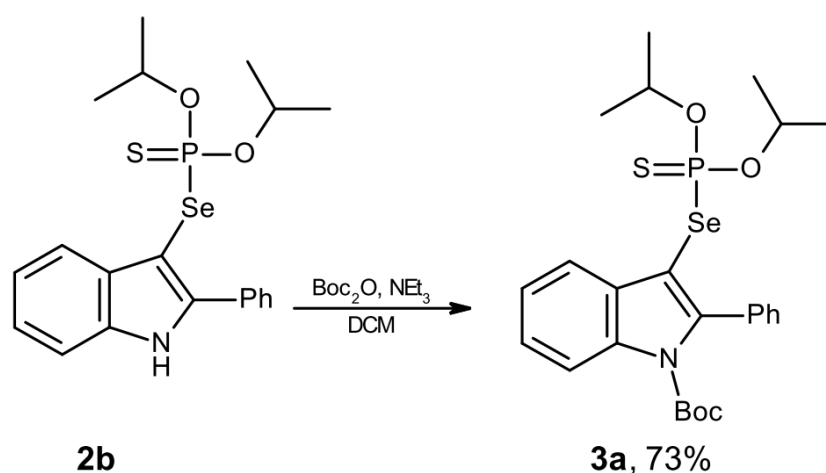
Table 1. Synthesis of 3-[(O,O-diisopropoxyphosphorothioyl)seleno]indoles **2a-2h** using bis(O,O-diisopropoxyphosphorothioyl) diselenide **1**



	R	R'	Y	Z	yield
2a	H	H	C	H	75%
2b	H	Ph	C	H	78%
2c	Br	H	C	H	56%
2d	Cl	H	C	H	66%
2e	F	H	C	H	80%
2f	CN	H	C	H	60%
2g	-	H	N	Cl	50%
2h	-	H	N	OMe	67%

*Yields are given for isolated products.

Encouraged by the efficacy of the selenylation process we tried to deprotect the selenide **2b** [37] through the selective cleavage of P-Se bond. To select an appropriate nucleophilic agent for this reaction, we examined the efficiency of the thiophosphate removal from S-(2,4-dinitrophenyl) phosphorodithioic acid O,O-diisopropyl ester as a model compound. Our model compound reacted with nucleophiles, forming colorful 2,4-dinitrobenzenethiolate as a product. We examined the cleavage of P-S bond with ammonium fluoride, tetrabutylammonium hydroxide (TBAOH), tetrabutylammonium fluoride (TBAF), ammonia, dimethylamine, sodium methanolate, DBU, potassium hydroxide, potassium trimethylsilanolate, N-methylmorpholine N-oxide and sodium propionaldehyde oximate. Similarly as in case of phosphoroselenoic acid Se-esters,[38] here also only TBAF caused the rapid appearance of the intensive color of the thiolate.



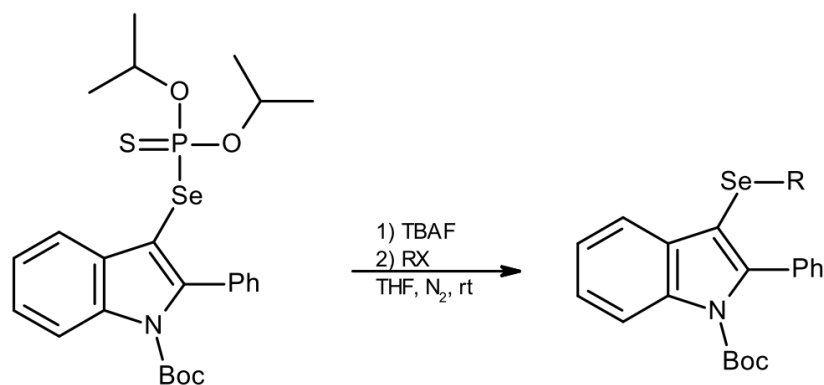
Scheme 2. *Tert*-butoxycarbonylation of **2b**

However, it turned out that the reaction of TBAF with **2b** in DCM in the presence of methyl iodide led to the formation of multiple products. We assumed that the side reactions could be initiated by the removal of the acidic N-H proton from

1 pyrrole ring under the basic reaction conditions. Therefore we decided to protect
2 the pyrrole nitrogen atom with Boc group. After *N*-Boc protection of **2b** (Scheme
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5 2) the reaction with TBAF proceeded to give exclusively the product of P-Se
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7 cleavage. We determined the amount of TBAF needed for the full and rapid
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9 deprotection of selenole to be 1.8 eq by TLC analysis of the reaction mixtures
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11 (Table S1). When reaction was performed in DCM in the presence of methyl
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13 iodide as the terminating electrophile only desired product **4a** was formed.
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15 Surprisingly, the same reaction with benzyl bromide led to the mixture of **4c** and
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17 chloromethylated derivative. Moreover when *n*-butyl bromide was used as an
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19 electrophile, generated selenolate reacted with DCM exclusively to give Se-
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21 chloromethylated product instead of **4d**. Thus, to suppress the unwanted side
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23 reaction caused by the solvent, we changed reaction environment to THF, what
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25 allowed us to perform reactions with other less reactive electrophilic agents. In
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27 case of compounds **4i** and **4k** the yield was poor and we observed multiple
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29 products formation, including diselenides and *N*-Boc dehydroalanine methyl ester
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31 as selenolates oxidation and *O*-tosyl serine elimination products, respectively. To
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33 avoid this undesired side-reactions, we added ascorbic acid to buffer the reaction
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35 mixture and ensure reducing conditions. This procedures (Procedure A and B in
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37 experimental part) allowed us to obtain products **4a-4l** (Table 2) in yields from
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39 71% to 93%.

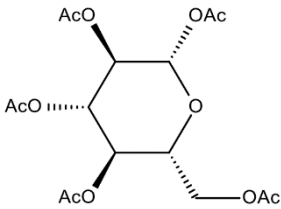
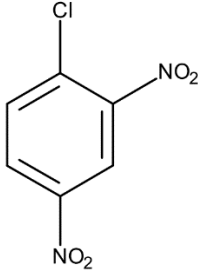
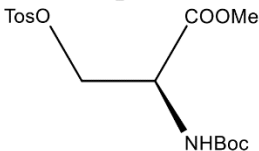
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49 Table 2 Synthesis of Se-substituted *N*-*tert*-butoxycarbonyl-3-selenoindoles **4a-4l**
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3a

products **4a-4l**
71 - 93% yield

	RX	yield		RX	yield
4a	CH ₃ I	80%	4g	Cl(CH ₂) ₄ Br	77%
4b	(CH ₃) ₂ CHI	79%	4h	ClCH ₂ COOCH ₂ CH ₃	78%
4c	BnBr	86%	4i*		85%
4d	n-BuBr	93%	4j		78%
4e	CH ₂ =CHCH ₂ Br	71%	4k*		90%
4f	ClCH ₂ (CH ₂) ₂ CN	76%	4l	BrCH ₂ C(O)CH ₃	75%

* compounds 4i and 4k were prepared according to procedure B, other compounds were

prepared following the procedure A.

CONCLUSIONS

In summary, we have developed an efficient method for the C(3) selenylation of indole and its analogues using bis(O,O-

1 diisopropoxyphosphorothioyl) diselenide 1 as selenium source and TBAF as
2 nucleophilic reagent for P-Se bond cleavage, followed by treating the resulting
3 selenolate with a variety of electrophiles. Due to a mild conditions, this
4 selenylation can be successfully performed in the presence of a simple functional
5 groups, such as halides, nitriles and ethers. We show that this procedure is also
6 suitable to functionalize 7-deazapurines, allowing to synthesize a novel purine
7 analogues. Reaction products were obtained under mild reaction conditions, with
8 high yields and under short reaction times. Finally, we were able to obtain
9 selenoindoyl derivatives of amino acid and glycoside which can be used as a
10 scaffold for a new class of bioactive compounds.
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26 **EXPERIMENTAL SECTION**

27 **General information:**

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29 The products were purified using column chromatography on silica gel (60 Å,
30 230-400 mesh). NMR spectra were recorded on a Bruker AVANCE 400 MHz
31 spectrometer, operating at 400 MHz (¹H NMR), 100 MHz (¹³C NMR), 160 MHz
32 (³¹P NMR) and 80 MHz (⁷⁷Se NMR) in CDCl₃ as a solvent. All NMR spectra are
33 included in supporting information. Multiplicities were marked as: s (singlet), d
34 (doublet), t (triplet), q (quartet), quint (quintet), hept (heptet), m (multiplet), app. t
35 (apparent triplet). High resolution mass spectra were recorded on a Waters
36 XEVO-G2 XS Q-TOF mass spectrometer equipped with an electrospray ion
37 source.
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52 **General procedure for thiophosphoselenylation of indoles, compounds 2a-**

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1 To a solution of indole (0.2 g, 1.71 mmol) in 10 ml of dry DCM was added DBU
2 (335 μ l, 2.24 mmol). To the resulting solution was added bis(O,O-
3 diisopropoxyphosphorothioyl) diselenide **1** (0.447 g, 0.86 mmol) in DCM (2 ml).
4 The reaction mixture was then stirred for 5 min at room temperature and 0.6M
5 solution of iodine in DCM (1.45 ml, 0.87 mmol) was added. After complete
6 consumption of the starting material, as monitored by TLC, the reaction mixture
7 was diluted with 40 ml of DCM and washed with a 5% citric acid solution (20 ml),
8 a 10% sodium thiosulfate solution (20 ml) and water (20 ml). The organic layer
9 was dried over MgSO₄ and concentrated in vacuo. The product was purified by
10 silica gel column chromatography (hexane:EtOAc; 10:1) to give compounds **2a-h**
11 as white solids.
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29 **Procedure for the synthesis of N-tertbutoxycarbonyl-3-[(O,O-**
30 **diisopropoxyphosphorothioyl)seleno]-2-phenylindole, compound 3a**
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32 To a solution of **2b** (3 g, 7 mmol) in 30 ml of dry DCM was added di-*tert*-butyl
33 dicarbonate (4.8 g, 22 mmol) and DMAP (0.086g, 0.7 mmol). The reaction
34 mixture was stirred for 5 hours at room temperature under nitrogen atmosphere.
35 The product was purified by silica gel column chromatography (hexane:EtOAc;
36 25:1) to give compound **3a** as slightly yellow oil which solidified upon standing.
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General procedure for the synthesis of Se-substituted (Procedure A)

N-tertbutoxycarbonyl-3-seleno-2-phenylindole, compounds 4a-h, 4j, 4l

Compound **3a** (100 mg, 0.18 mmol) was diluted in 2 ml of anhydrous THF under nitrogen atmosphere. Electrophilic reagent (0.198 mmol) was placed into a reaction flask and then was added 0.1M tetrabutylammonium fluoride (330 μ l,



0.33 mmol). The reaction mixture was stirred for 10 minutes and monitored by TLC. The product was purified by silica gel column chromatography (hexane:chloroform; 5:1) to give compounds **4a-h**, **4j**, **4l**.

General procedure for the synthesis of Se-substituted (Procedure B) N-*tert*butoxycarbonyl-3-seleno-2-phenylindole, compounds 4i, 4k

Compound **3a** (100 mg, 0.18 mmol) was dissolved in anhydrous THF (1 ml) under nitrogen atmosphere and 0.1M tetrabutylammonium fluoride (330 μ l, 0.33 mmol) was added. The reaction mixture turned yellow immediately and, after 5 min of stirring, a suspension of finely grinded ascorbic acid (32 mg, 0.18 mmol) in 1 ml of anhydrous THF was added. After stirring for 1 min a solution of electrophilic reagent (0.198 mmol) in 1 ml of anhydrous THF was added. The reaction mixture was stirred for 30 minutes and monitored by TLC. The product was purified by silica gel column chromatography (1:1 n-hexane/chloroform) to give pure compound **4k**.

In case of compound **4i**, the crude product was dissolved in 15 ml of ethyl acetate and the solution was filtered through thin silica pad (2g of SiO₂). The silica pad was additionally washed with 5 ml of ethyl acetate and washings were concentrated. The resulting residue was dissolved in acetone (3 ml) and 80 mg of thiourea was added to remove unreacted 2,3,4,6-Tetra-O-acetyl- α -D-glucopyranosyl bromide. The mixture was heated to reflux for 5 min, cooled to rt and concentrated in vacuo. The product was purified by silica gel column chromatography (1:1 n-hexane/chloroform) to give compound **4i** with a purity of approximately 90% (as determined by ¹H NMR).



1 **Caution:** Special care should be taken during operating and disposal of
2 chromatographic fractions containing (iPrO)₂PSF due to its potential neurotoxic
3 effects. For this reason, fractions not containing products **4** were collected and
4 neutralized by passing through a short pad of silica gel pretreated with Cu-
5 TMEDA complex. **[39,40]**
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10 **3-[(O,O-diisopropoxyphosphorothioyl)seleno]indole (2a)**

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16 δ H(400 MHz; CDCl₃; Me₄Si) 8.50 (1H, br s), 7.73-7.76 (1H, m), 7.37-7.47 (2H,
17 m), 7.18-7.27 (2H, m), 4.80-4.93 (2H, hpt, J = 6 Hz, OCH), 1.28 (12H, 2 x d, J =
18 6 Hz, CH₃). δ C(100 MHz; CDCl₃; Me₄Si) 135.9, 130.9, 130.9, 129.9, 129.8,
19 122.8, 122.0, 120.75, 120.7, 120.5, 119.8, 111.3, 96.6 (d, ²J_{CP} = 8.4 Hz, C3),
20 73.8, 73.6, 23.8, 23.7, 23.5, 23.4. δ P(160 MHz; CDCl₃; H₃PO₄) 79.2 (s, and Se
21 satellites: ¹J_{PSe} = 498 Hz). HRMS (ESI): calcd for C₁₄H₂₁NO₂PSSe [M+H]⁺:
22 378.0190, found: 378.0218.
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36 **3-[(O,O-diisopropoxyphosphorothioyl)seleno]-2-phenylindole (2b)**

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39 Colourless crystals, mp: 111 °C (from ethyl acetate/n-hexane). δ H(400 MHz;
40 CDCl₃; Me₄Si) 11.00 (1H, br s), 8.00 (2H, m), 7.80 (1H, m), 7.41-7.53 (4H, m),
41 7.17-7.25 (2H, m), 4.65-4.75 (2H, hpt, J = 6 Hz, OCH), 1.15 (12H, 2 x d, J = 6 Hz,
42 CH₃). δ C(100 MHz; CDCl₃; Me₄Si) 142.5, 142.4, 135.9, 132.2, 132.1, 129.2,
43 129.1, 128.6, 128.5, 123.0, 121.5, 121.0, 111.0, 95.2 (d, ²J_{CP} = 8.3 Hz, C3), 73.5,
44 73.4, 23.7, 23.6, 23.4, 23.3. δ P(160 MHz; CDCl₃; H₃PO₄) 79.4 (s, and Se
45 satellites: ¹J_{PSe} = 504 Hz). δ Se(80 MHz; CDCl₃; (PhSe)₂) 272.2 (d, ¹J_{SeP} = 507
46 Hz). HRMS (ESI): calcd for C₂₀H₂₅NO₂PSSe [M+H]⁺: 454.0503, found:
47 454.0528.
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5-Bromo-3-[(O,O-diisopropoxyphosphorothioyl)seleno]indole (2c)

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δ H(400 MHz; CDCl₃; Me₄Si) 8.50 (1H, br s, H1), 7.90 (1H, m), 7.45 (1H, m), 7.27-7.35 (2H, m), 4.82-4.94 (2H, hpt, J = 6 Hz, OCH), 1.29 (12H, 2 x d, J = 6 Hz, CH₃). δ C(100 MHz; CDCl₃; Me₄Si) 134.6, 132.0 (d, ³J_{CP} = 5 Hz, C2), 131.7 (d, ³J_{CP} = 1 Hz, C9), 125.8, 123.4, 114.1, 112.6, 96.6 (d, ²J_{CP} = 8.4 Hz, C3), 73.8, 73.6, 23.8, 23.7, 23.5, 23.4. HRMS (ESI): calcd for C₁₄H₂₀BrNO₂PSSe [M+H]⁺: 455.9295, found: 455.9290.

5-Chloro-3-[(O,O-diisopropoxyphosphorothioyl)seleno]indole (2d)

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δ H(400 MHz; CDCl₃; Me₄Si) 8.50 (1H, br s), 7.75 (1H, m), 7.45-7.48 (1H, dd, ¹J = 3.8 Hz, ²J = 2.7 Hz), 7.32-7.35 (1H, d, J = 9 Hz), 7.19-7.23 (1H, dd, ¹J = 2 Hz, ²J = 8.6 Hz), 4.82-4.94 (2H, hpt, J = 6 Hz, OCH), 1.29 (12H, 2 x d, J = 6 Hz, CH₃). δ C(100 MHz; CDCl₃; Me₄Si) 134.3, 132.2 (d, ³J_{CP} = 5 Hz, C2), 131.1, 126.6, 123.3, 120.3, 112.4, 96.5 (d, ²J_{CP} = 8.3 Hz, C3), 73.9, 73.8, 23.8, 23.7, 23.5, 23.4.

HRMS (ESI): calcd for C₁₄H₂₀ClNO₂PSSe [M+H]⁺: 411.9801, found: 411.9802.

3-[(O,O-diisopropoxyphosphorothioyl)seleno]-5-fluoroindole (2e)

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δ H(400 MHz; CDCl₃; Me₄Si) 8.50 (1H, br s), 7.28-7.52 (3H, m), 6.95-7.05 (1H, m), 4.82-4.94 (2H, hpt, J = 6 Hz, OCH), 1.29 (12H, 2 x d, J = 6 Hz, CH₃). δ C(100 MHz; CDCl₃; Me₄Si) 158.6 (d, ¹J_{CF} = 236 Hz, C5), 132.7 (d, ⁴J_{CP} = 5 Hz, C2), 132.4 (C8), 131.2 (dd, ³J_{CF} = 5 Hz, ³J_{CP} = 1 Hz, C9), 112.2 (d, ³J_{CF} = 10 Hz, C7), 111.4 (d, ²J_{CF} = 27 Hz, C4), 105.5 (d, ²J_{CF} = 24 Hz, C6), 96.5 (dd, ²J_{CP} = 8.4 Hz,



$^4J_{CF} = 5.0$ Hz, C3), 73.8, 73.6, 23.8, 23.7, 23.5, 23.4. HRMS (ESI): calcd for $C_{14}H_{19}FNO_2PSSe$ $[M+H]^+$: 396.0096, found: 396.0120.

5-Cyano-3-[(O,O-diisopropoxyphosphorothioyl)seleno]indole (2f)

δH (400 MHz; $CDCl_3$; Me_4Si) 8.90 (1H, br s), 8.14 (1H, s), 7.55 (1H, dd, $^1J = 2.5$ Hz, $^2J = 3$ Hz), 7.49 (2H, d, $J = 1$ Hz), 4.82-4.94 (2H, hpt, $J = 6$ Hz, OCH), 1.29 (12H, 2 x d, $J = 6$ Hz, CH_3). δC (100 MHz; $CDCl_3$; Me_4Si) 137.7, 133.0 (d, $^3J_{CP} = 5.5$ Hz, C2), 129.9, 126.4 125.7, 120.2, 112.4, 104.0, 97.9 (d, $^2J_{CP} = 8.4$ Hz, C3), 73.8, 73.6, 23.8, 23.7, 23.5, 23.4. HRMS (ESI): calcd for $C_{15}H_{19}N_2O_2PSSeNa$ $[M+Na]^+$: 424.9962, found: 424.9980.

6-Chloro-3-[(O,O-diisopropoxyphosphorothioyl)seleno]-7-deazapurine (2g)

δH (400 MHz; $CDCl_3$; Me_4Si) 11.30 (1H, br s), 8.80 (1H, s), 7.75 (1H, d, $J = 3.5$ Hz), 4.87-4.97 (2H, hpt, $J = 6$ Hz, OCH), 1.33 (12H, 2 x d, $J = 6$ Hz, CH_3). δC (100 MHz; $CDCl_3$; Me_4Si) 153.2, 152.3, 150.55, 133.7 (d, $^3J_{CP} = 5.65$ Hz, C2), 117.6 (d, $^3J_{CP} = 1.7$ Hz, C9), 95.6 (d, $^2J_{CP} = 8.6$ Hz, C3), 74.3, 74.2, 23.8, 23.7, 23.5, 23.4. δP (160 MHz; $CDCl_3$; H_3PO_4) 78.5 (s, and Se satellites: $^1J_{PSe} = 469$ Hz). HRMS (ESI): calcd for $C_{12}H_{17}ClN_3O_2PSSe$ $[M+H]^+$: 413.9705, found: 413.9714.

6-Methoxy-3-[(O,O-diisopropoxyphosphorothioyl)seleno]-7-deazapurine (2h)

δH (400 MHz; $CDCl_3$; Me_4Si) 12.30 (1H, br s), 8.50 (1H, s), 7.49 (1H, d, $J = 3.5$ Hz), 4.85-4.95 (2H, hpt, $J = 6$ Hz, OCH), 4.15 (3H, s, OCH_3), 1.32 (12H, 2 x d, $J = 6$ Hz, CH_3). δC (100 MHz; $CDCl_3$; Me_4Si) 163.7, 152.2, 150.6, 129.6 (d, $^3J_{CP} =$



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5.77 Hz, C2), 107.1 (d, $^3J_{CP} = 2.0$ Hz, C9), 94.2 (d, $^2J_{CP} = 8.4$ Hz, C3), 73.8, 73.7, 53.8, 23.8, 23.7, 23.4, 23.3. $\delta P(160$ MHz; $CDCl_3$; H_3PO_4) 78.8 (s, and Se satellites: $^1J_{PSe} = 484$ Hz). HRMS (ESI): calcd for $C_{13}H_{20}N_3O_3PSSe$ $[M+H]^+$: 410.0201, found: 410.0187.

***N*-tertbutoxycarbonyl-3-[(*O,O*-diisopropoxyphosphorothioyl)seleno]-2-phenylindole (3a)**

$\delta H(400$ MHz; $CDCl_3$; Me_4Si) 8.26 (1H, m), 7.8 (1H, m), 7.34-7.54 (7H, m), 4.55-4.6 (2H, hpt, $J = 6$ Hz, OCH), 1.25 (9H, s, CH_3C), 1.2 (12H, 2 x d, $J = 6$ Hz, CH_3CH). $\delta C(100$ MHz; $CDCl_3$; Me_4Si) 149.6, 146.7, 144.6 (d, $^2J_{CP} = 8.06$ Hz, C9), 136.6, 133.8 (d, $^4J_{CP} = 3$ Hz, C10), 131.4, 130.65, 130.6, 128.0, 127.4, 125.1, 123.0, 121.3, 115.0, 106.5 (d, $^2J_{CP} = 8.86$ Hz, C3), 85.2, 83.8, 73.4, 73.3, 27.5, 27.4, 23.7, 23.6, 23.4, 23.3. $\delta P(160$ MHz; $CDCl_3$; H_3PO_4) 80.5 (s, and Se satellites: $^1J_{PSe} = 477$ Hz). HRMS (ESI): calcd for $C_{25}H_{33}N_3O_4PSSe$ $[M+H]^+$: 554.1028, found: 554.1031.

***N*-tertbutoxycarbonyl-3-methylseleno-2-phenylindole (4a)**

$\delta H(400$ MHz; $CDCl_3$; Me_4Si) 8.26 (1H, m), 7.8 (1H, m), 7.37-7.54 (7H, m), 2.06 (3H, s, and Se satellites: $^2J_{HSe} = 16$ Hz), 1.25 (9H, s, CH_3C). $\delta C(100$ MHz; $CDCl_3$; Me_4Si) 149.7, 142.3, 136.7, 134.5, 131.2, 130.0, 128.0, 127.6, 126.0, 125.0, 123.2, 120.6, 115.2, 108.1, 83.6, 27.4, 8.3 (s, and Se satellites: $^1J_{CSe} = 62$ Hz, CH_3Se). $\delta Se(80$ MHz; $CDCl_3$; $(PhSe)_2$) 248.3 (t, $^2J_{HSe} = 16$ Hz). HRMS (ESI): calcd for $C_{20}H_{22}NO_3Se$ $[M+OH]^+$: 404.0759, found: 404.0759.

***N*-tertbutoxycarbonyl-3-isopropylseleno-2-phenylindole (4b)**

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δ H(400 MHz; CDCl₃; Me₄Si) 8.26 (1H, m), 7.80 (1H, m), 7.34-7.49 (7H, m), 3.17-3.28 (1H, hpt, J = 6.8 Hz, and Se satellites: ²J_{HSe} = 20 Hz), 1.25 (9H, s), 1.22 (6H, d, J = 6.8 Hz). δ C(100 MHz; CDCl₃; Me₄Si) 149.7, 143.4, 136.6, 134.5, 132.2, 130.3, 127.8, 127.5, 124.9, 123.2, 121.0, 115.1, 107.7, 83.5, 33.7 (s, and Se satellites: ¹J_{CSe} = 56.5 Hz, SeCH), 27.4, 24.3 (s, ²J_{CSe} = 13.5 Hz, SeCHCH₃). HRMS (ESI): calcd for C₂₂H₂₆NO₃Se [M+OH]⁺: 432.1072, found: 432.1080.

***N*-tertbutoxycarbonyl-3-benzylseleno-2-phenylindole (4c)**

δ H(400 MHz; CDCl₃; Me₄Si) 8.26 (1H, m), 7.80 (1H, m), 7.3-7.45 (5H, m), 6.9-7.15 (7H, m), 3.79 (2H, s, and Se satellites: ²J_{HSe} = 14 Hz), 1.25 (9H, s). δ C(100 MHz; CDCl₃; Me₄Si) 149.7, 143.7, 138.9, 136.6, 134.1, 131.5, 130.0, 128.7, 128.2, 127.7, 127.4, 126.6, 125.0, 123.2, 120.6, 115.2, 107.2, 83.5, 31.2 (s, and Se satellites: ¹J_{CSe} = 58.5 Hz, SeCH₂). HRMS (ESI): calcd for C₂₆H₂₆NO₃Se [M+OH]⁺: 480.1072, found: 480.1113.

***N*-tertbutoxycarbonyl-3-butylseleno-2-phenylindole (4d)**

δ H(400 MHz; CDCl₃; Me₄Si) 8.26 (1H, m), 7.80 (1H, m), 7.37-7.52 (7H, m), 2.58 (2H, t, J = 7.4 Hz, and Se satellites: ²J_{HSe} = 13 Hz), 1.35-1.45 (4H, m), 1.25 (9H, s), 0.75 (3H, t, J = 7.3 Hz). δ C(100 MHz; CDCl₃; Me₄Si) 149.7, 142.9, 136.7, 134.5, 131.8, 130.2, 127.8, 127.5, 125.0, 123.2, 120.8, 115.0, 107.2, 83.5, 32.2, 27.8 (s, and Se satellites: ¹J_{CSe} = 60 Hz, SeCH₂), 27.4, 22.5, 13.5. HRMS (ESI): calcd for C₂₃H₂₈NO₃Se [M+OH]⁺: 446.1229, found: 446.1243.

***N*-tertbutoxycarbonyl-3-allylseleno-2-phenylindole (4e)**

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δ H(400 MHz; CDCl₃; Me₄Si) 8.27 (1H, m), 7.76 (1H, m), 7.34-7.50 (7H, m), 5.70 (1H, ddt, ¹J = 17 Hz, ²J = 10 Hz, ³J = 7 Hz), 4.76 (1H, dd, ¹J = 1.5 Hz, ²J = 10 Hz), 4.71 (1H, dd, ¹J = 1.4 Hz, ²J = 17 Hz), 3.22 (2H, d, J = 7.5 Hz, and Se satellites: ²J_{HSe} = 13.6 Hz), 1.25 (9H, s). δ C(100 MHz; CDCl₃; Me₄Si) 149.7, 143.6, 136.6, 134.5, 134.3, 131.6, 130.4, 127.9, 127.5, 125.0, 123.2, 120.7, 116.5, 115.1, 107.0, 83.6, 30.2 (s, and Se satellites: ¹J_{CSe} = 56 Hz, CCH₂), 27.4. HRMS (ESI): calcd for C₂₂H₂₄NO₃Se [M+OH]⁺: 430.0916, found: 430.0948.

***N*-tertbutoxycarbonyl-3-[3-(cyanopropyl)seleno]-2-phenylindole (4f)**

δ H(400 MHz; CDCl₃; Me₄Si) 8.28 (1H, m), 7.74 (1H, m), 7.34-7.53 (7H, m), 2.65 (2H, t, J = 6.7 Hz, and Se satellites: ¹J_{HSe} = 16.3 Hz), 2.07 (2H, t, J = 7 Hz), 1.63 (2H, quint, J = 6.6 Hz), 1.25 (9H, s). δ C(100 MHz; CDCl₃; Me₄Si) 149.5, 143.7, 136.7, 134.1, 131.2, 130.2, 128.2, 127.8, 125.3, 123.5, 120.3, 119.0, 115.3, 105.6, 83.9, 27.4, 25.8 (s, and Se satellites: ¹J_{CSe} = 65 Hz, CH₂Se), 25.2, 16.2. HRMS (ESI): calcd for C₂₂H₂₃N₂O₃Se [M+H]⁺: 441.1076, found: 441.1004.

***N*-tertbutoxycarbonyl-3-(4-chlorobutyl)seleno-2-phenylindole (4g)**

δ H(400 MHz; CDCl₃; Me₄Si) 8.26 (1H, m), 7.80 (1H, m), 7.32-7.5 (7H, m), 3.30 (2H, t, J = 6.6 Hz), 2.50 (2H, t, J = 7 Hz, and Se satellites: ¹J_{HSe} = 14 Hz), 1.60-1.70 (2H, m), 1.5-1.6 (2H, m), 1.25 (9H, s). δ C(100 MHz; CDCl₃; Me₄Si) 149.6, 143.2, 136.7, 134.3, 131.6, 130.2, 127.9, 127.5, 125.1, 123.3, 120.5, 115.2, 106.7, 83.7, 44.3, 32.0, 27.4, 27.2, 26.9. HRMS (ESI): calcd for C₂₃H₂₇ClNO₃Se [M+OH]⁺: 480.0839, found: 480.0844.

***N*-tertbutoxycarbonyl-3-(ethoxycarbonylmethyl)seleno-2-phenylindole (4h)**

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δ H(400 MHz; CDCl₃; Me₄Si) 8.26 (1H, m), 7.74 (1H, m), 7.37-7.52 (7H, m), 3.91 (2H, q, J = 7 Hz), 3.16 (2H, s, and Se satellites: ¹J_{HSe} = 14.8 Hz), 1.25 (9H, s), 1.05 (3H, t, J = 7 Hz). δ C(100 MHz; CDCl₃; Me₄Si) 170.6, 149.6, 143.9, 136.6, 134.0, 131.2, 130.2, 128.1, 127.6, 125.1, 123.4, 120.5, 115.2, 106.2, 83.8, 61.1, 27.4, 26.7 (s, and Se satellites: ¹J_{CSe} = 69.40 Hz, CH₂Se), 13.8. HRMS (ESI): calcd for C₂₃H₂₆NO₅Se [M+OH]⁺: 476.0971, found: 476.0993.

***N*-tertbutoxycarbonyl-3-(2,3,4,6-tetra-O-acetyl-D-glucopyranosylseleno)-2-phenylindole (4i)**

δ H(400 MHz; CDCl₃; Me₄Si) 8.26 (1H, m), 7.72 (1H, m), 7.34-7.52 (7H, m), 5.10 (1H, dd, app. t, J = 9.0 Hz), 5.03 (1H, dd, app. t, J = 9.5), 4.98 (1H, dd, app. t, J = 9.0 Hz), 4.70 (1H, d, J = 10.3 Hz, H-1'), 4.15 (1H, dd, ¹J = 5.3 Hz, ²J = 12.2 Hz, H-6'), 4.08 (1H, dd, ¹J = 2.2 Hz, ²J = 12.2 Hz, H-6'), 3.49 (1H, ddd, ¹J = 2.2 Hz, ²J = 5.3 Hz, ³J = 10.0 Hz, H-5'), 2.05, 2.00, 1.99 and 1.83 (12H, 4 x s, CH₃C=O), 1.25 (9H, s, CH₃C). δ C(100 MHz; CDCl₃; Me₄Si) 170.65, 170.17, 169.47, 169.35, 149.53, 143.73, 136.65, 133.78, 131.44, 130.37, 128.07, 127.54, 125.25, 123.37, 121.01, 115.05, 105.96, 86.56, 83.92, 82.75, 73.66, 70.77, 68.27, 62.34, 27.09, 20.77, 20.60, 20.59, 20.56. δ Se(80 MHz; CDCl₃; (PhSe)₂) 238.1. HRMS (ESI): calcd for C₃₃H₃₈NO₁₁Se [M+H]⁺: 704.1605, found: 704.1607.

***N*-tertbutoxycarbonyl-3-(2,4-dinitrophenylseleno)-2-phenylindole (4j)**

δ H(400 MHz; CDCl₃; Me₄Si) 9.15 (1H, d, J = 2.4 Hz), 8.35 (1H, d, ¹J = 8.4 Hz), 8.06 (1H, dd, ¹J = 2.4 Hz, ²J = 8.9 Hz), 7.37-7.5 (5H, m), 7.28-7.35 (4H, m), 1.25 (9H, s). δ C(100 MHz; CDCl₃; Me₄Si) 149.2, 146.0, 145.5, 145.3, 144.5, 137.0, 132.9, 131.2, 130.0, 129.4, 128.8, 128.0, 126.7, 126.0, 124.1, 121.6, 120.1,

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115.6, 105.5, 84.7, 27.4. δ_{Se} (80 MHz; CDCl_3 ; $(\text{PhSe})_2$) 347.2. HRMS (ESI):
calcd for $\text{C}_{24}\text{H}_{22}\text{N}_3\text{O}_6\text{SeK}$ $[\text{M}+\text{K}]^+$:578.0227, found: 578.0270.

***N*-tertbutoxycarbonyl-3-[(2-[(tertbutoxycarbonyl)amino]-3-methoxy-3-oxopropyl)seleno]-2-phenylindole (4k)**

δ_{H} (400 MHz; CDCl_3 ; Me_4Si) 8.24 (1H, m), 7.73 (1H, m), 7.33-7.46 (7H, m), 4.99 (1H, d, $J = 8.8$ Hz, NH), 4.99 (1H, d, $J = 10.3$ Hz), 4.45 (1H, dt, $^1J = 5.0$ Hz, $^2J = 8.8$ Hz, H_α), 3.37 (3H, s, OCH_3), 3.11 (1H, dd, $^1J = 5.0$ Hz, $^2J = 13.2$ Hz), 2.99 (1H, dd, $^1J = 5.0$ Hz, $^2J = 13.2$ Hz), 1.34 (9H, s), 1.25 (9H, s). δ_{C} (100 MHz; CDCl_3 ; Me_4Si) 170.8, 154.7, 149.5, 143.1, 136.6, 134.1, 131.1, 130.1, 128.1, 127.7, 125.1, 123.4, 120.4, 115.3, 105.7, 83.7, 79.7, 53.4, 52.1, 28.1, 27.4; δ_{Se} (80 MHz; CDCl_3 ; $(\text{PhSe})_2$) 60.2. HRMS (ESI): calcd for $\text{C}_{28}\text{H}_{35}\text{N}_2\text{O}_7\text{Se}$ $[\text{M}+\text{OH}]^+$: 591.1604, found: 591.1629.

***N*-tertbutoxycarbonyl-3-(2-oxopropylseleno)-2-phenylindole (4l)**

δ_{H} (400 MHz; CDCl_3 ; Me_4Si) 8.28 (1H, m), 7.74 (1H, m), 7.34-7.53 (7H, m), 3.23 (2H, s, $^1J_{\text{HSe}} = 15\text{Hz}$), 1.96 (3H, s), 1.25 (9H, s). δ_{C} (100 MHz; CDCl_3 ; Me_4Si) 203.1, 149.5, 144.2, 136.7, 133.8, 130.9, 130.4, 128.1, 127.5, 125.3, 123.5, 120.2, 115.4, 105.8, 83.9, 35.9 (s, and Se satellites: $^1J_{\text{CSe}} = 66.$ Hz, CH_2Se), 27.5, 27.4. HRMS (ESI): calcd for $\text{C}_{22}\text{H}_{23}\text{NO}_3\text{Se}$ $[\text{M}+\text{H}]^+$: 430.0916, found: 430.0904.

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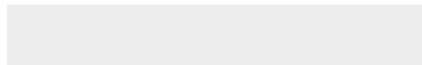
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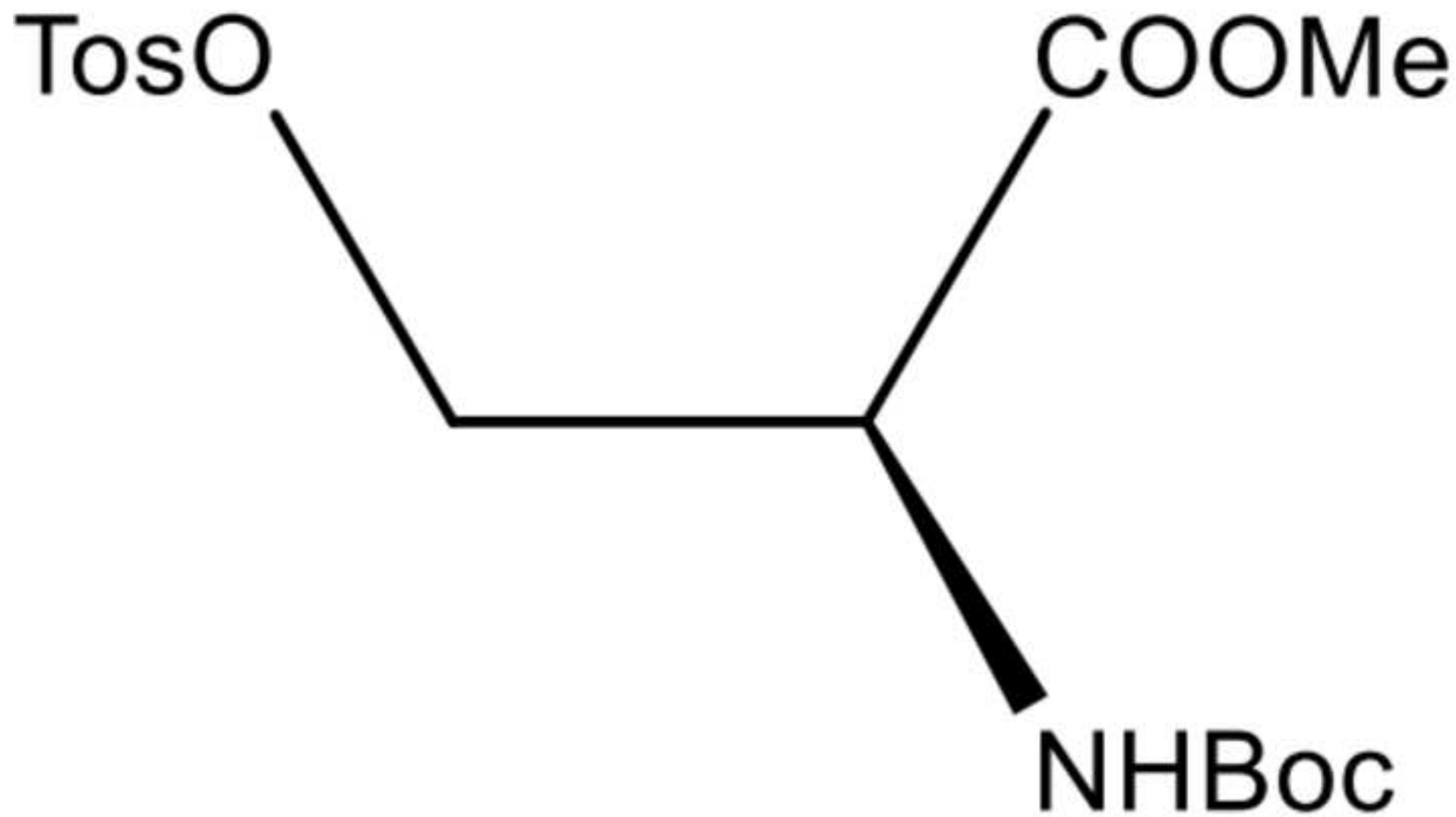


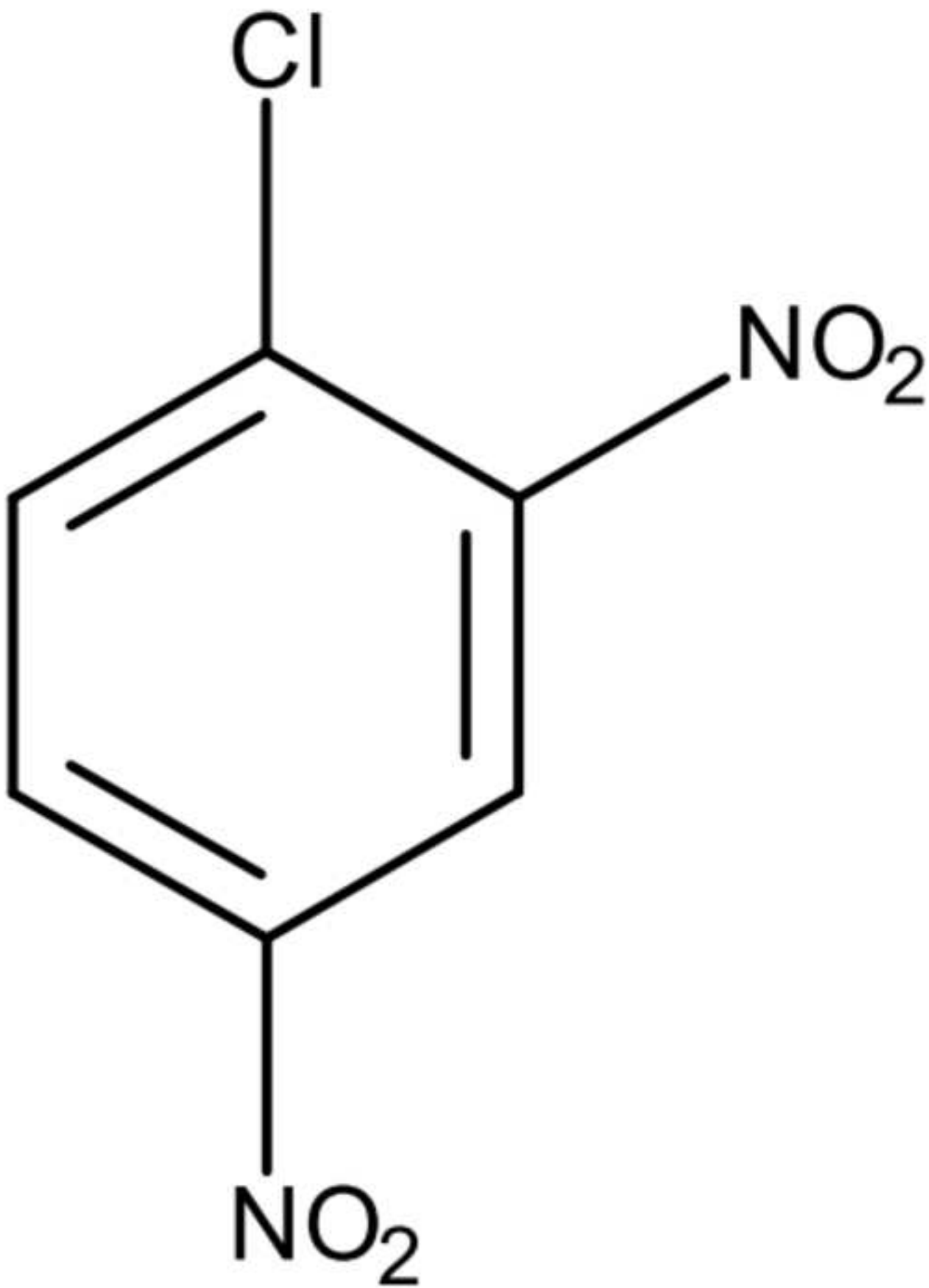


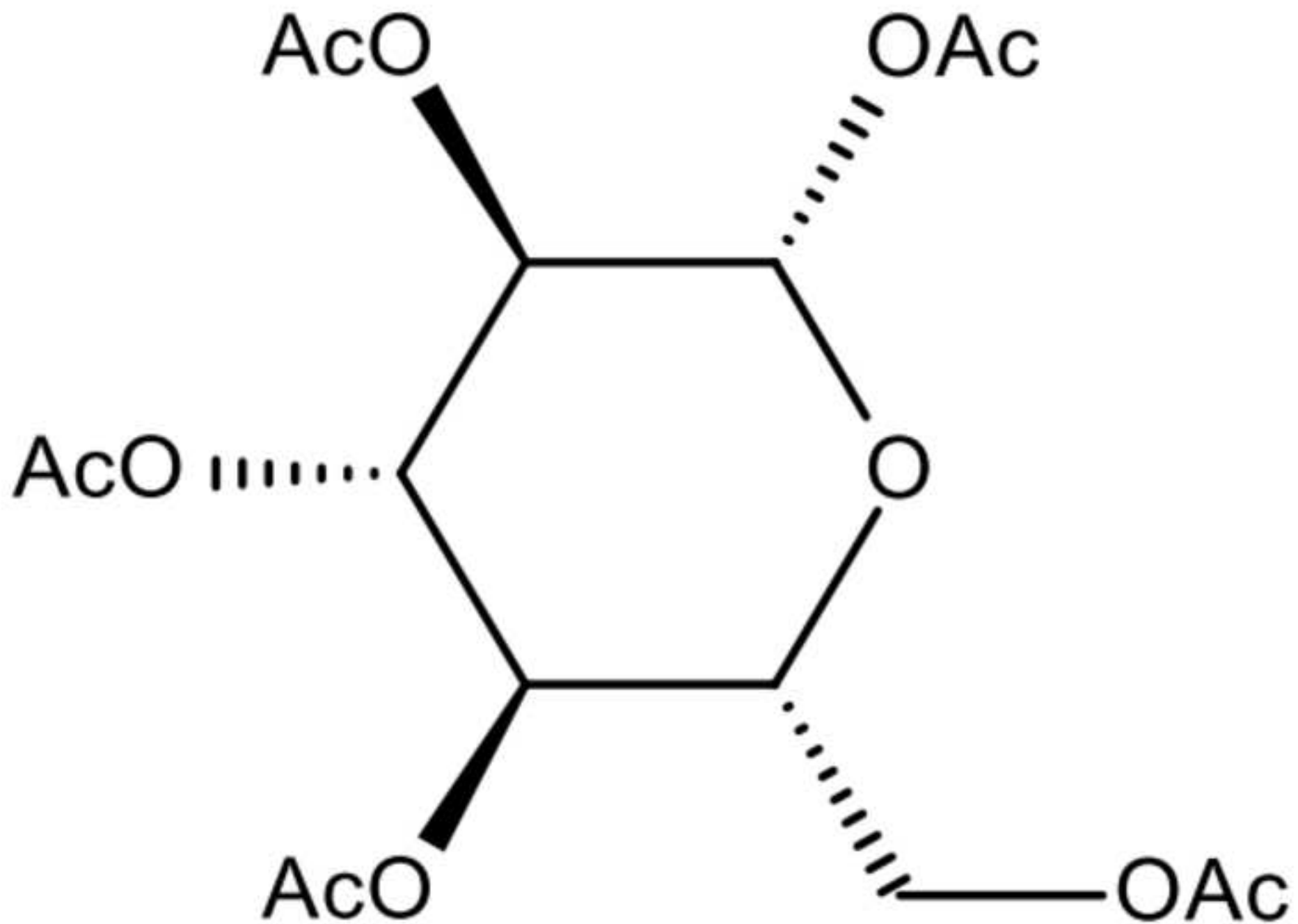
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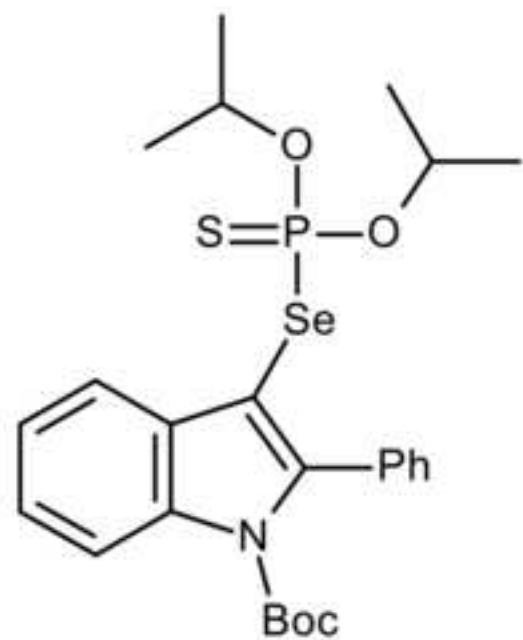




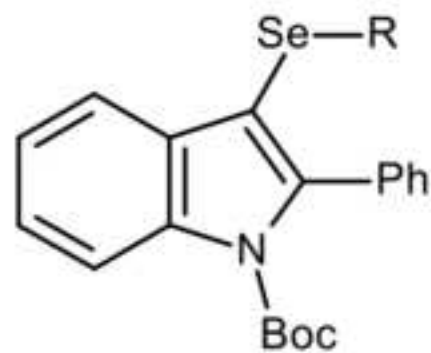
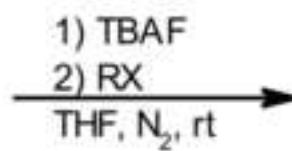




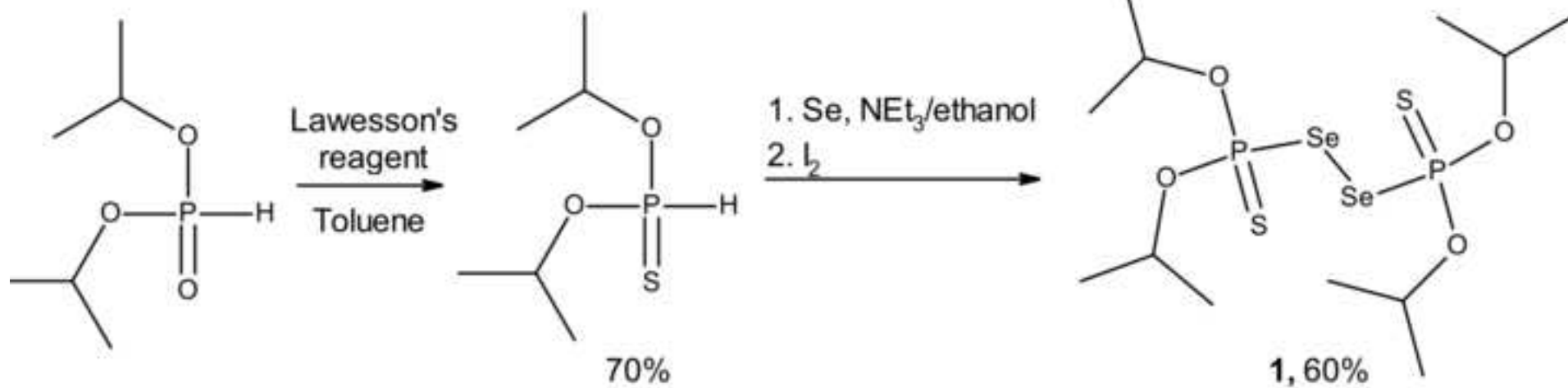


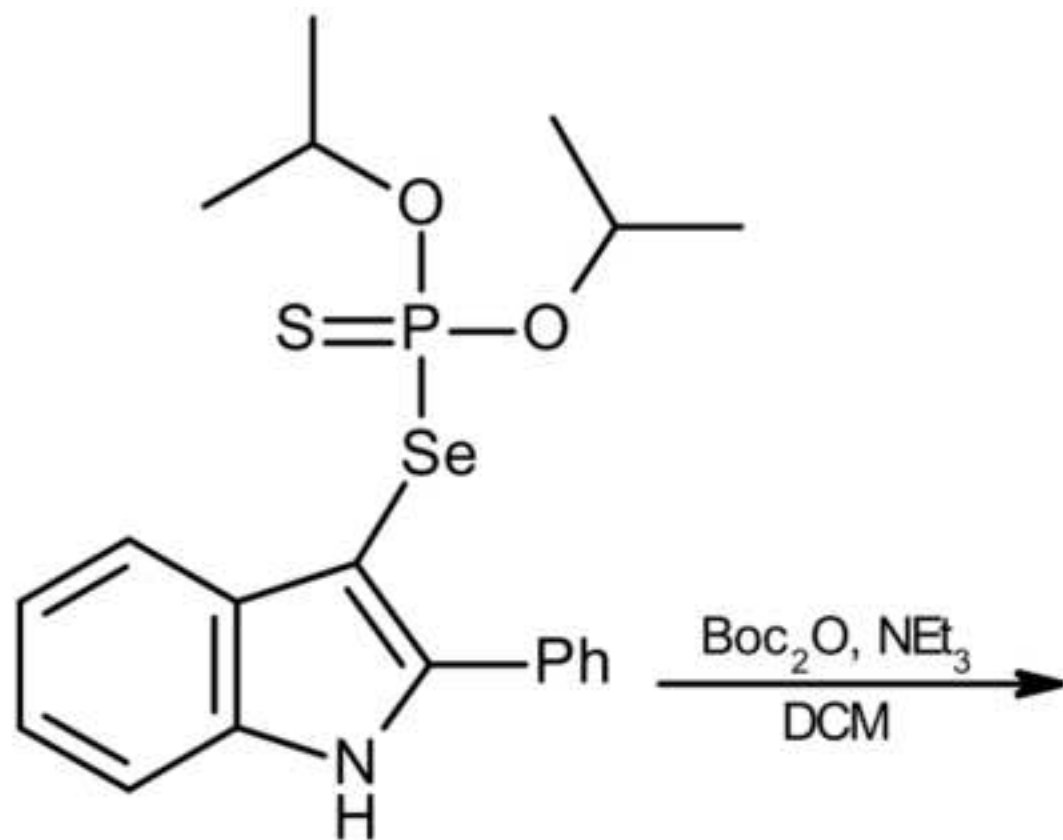


3a

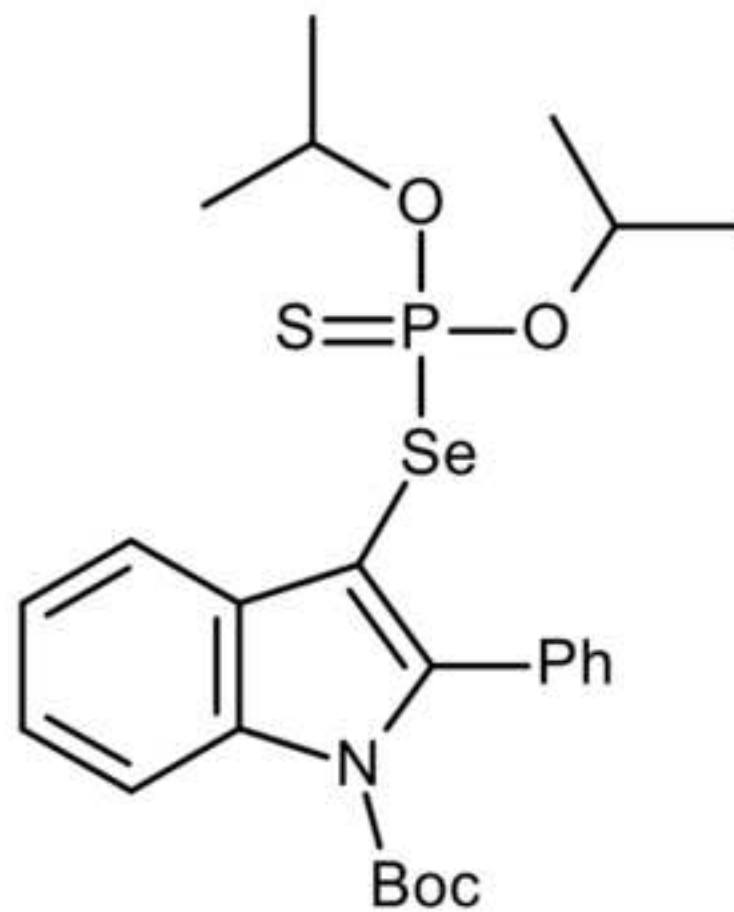


products **4a-4l**
71 - 93% yield

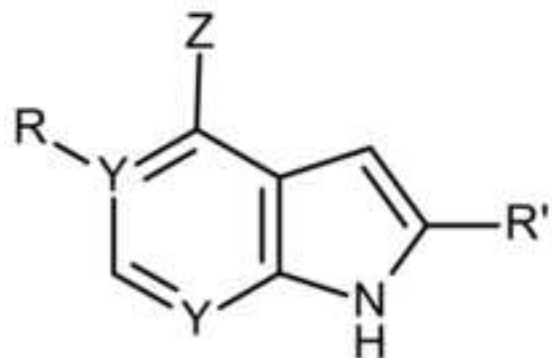




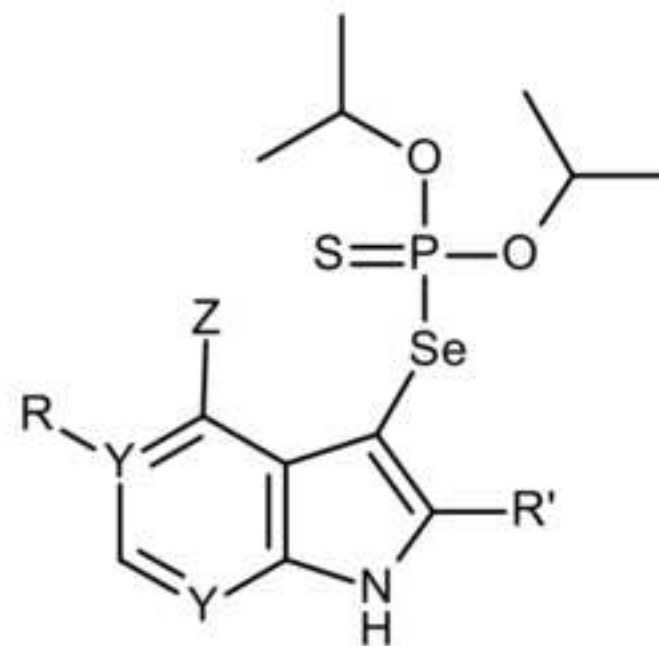
2b



3a, 73%



- 1) 1.3 eq. DBU, DCM 20°C
- 2) 0.5 eq. $[(iPrO)_2P(S)Se]_2$ **1**
- 3) 0.5 eq. I_2



products **2a-h**
50 - 80% yield