CHAPTER 2

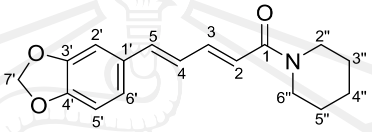
EXPERIMENTAL

Dichloromethane and amines (piperidine, pyrrolidine, diisopropylamine, dibutylamine and triethylamine) were dried over CaH_2 and distilled before used. Tetrahydrofuran (THF) was freshly distilled from sodium benzophenone ketyl under nitrogen. *n*-Butyllithium was purchased from Fluka as solution in hexanes, and titrated periodically according to the 2,5-dimethoxybenzyl alcohol method.[95] Flash column chromatography was performed employing Merck silica gel 60 and Merck silica gel 60H. Preparative thin layer chromatography (PLC) was carried out using Merck silica gel 60 PF_{254}. Melting points were determined with a Gallenkamp Electrothermal Melting Point apparatus and are uncorrected. Infrared spectra were recorded on a FT-IR model TENSER 27 (Bruker) spectrometer. Nuclear magnetic resonance spectra (^1H, ^{13}C) were recorded on Bruker DRX 400, 500 MHz spectrometers. All NMR spectra were measured in deuterochloroform ($CDCl_3$) and chemical shifts were reported as parts per million (ppm) relative to an internal $CHCl_3$. Coupling constants (*J* values) were measured in hertz (Hz). Splitting patterns were designated as follows: s, singlet; brs, broad singlet; d, doublet; dd, double doublet; ddd, doublet of double doublet; t, triplet; q, quartet; m, multiplet. Mass spectra (electrospray ionization mode, ESI-MS) were recorded on micromass Q-TOF-2^{Tm} (Waters) spectometer.

2.1 Extraction of piperine (75) and preparation of piperic acid (105)

2.1.1 Extraction 5-(3,4-methylenedioxy)phenyl-1-(1-piperidinyl)-2*E*,4*E*-pentadien-1-one (piperine, 75)

Black piper seeds (*P. nigrum* L.) (10.00 g) cultivated in Thailand were extracted in soxhlet extractor with refluxing EtOH (300 ml) for 1 h. The crude extract was evaporated to dryness and then purified by flash column chromatography on silica gel with elution of EtOAc/$\mathrm{CH_2Cl_2}$/hexane (2.0:0.5:7.5) to afford piperine (**75**) in 1% yield (0.078 g).



piperine (**75**)

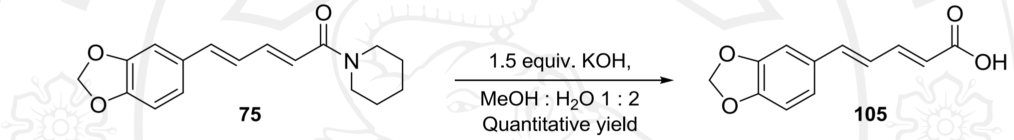
Table 2.1 Data of piperine (**75**)

Physical properties	
Yellow crystals Melting point (m.p.) 130.8–132.0 °C (EtOH) R_f = 0.27 (EtOAc/$\mathrm{CH_2Cl_2}$/hexane, 2.0:0.5:7.5)	
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $\mathrm{CDCl_3}$	
Chemical shift (δ, ppm)	Type of proton
1.54–1.71	m, 6H, $\mathrm{CH_2}$-3″, 4″, 5″
3.53	brs, 2H, $\mathrm{CH_2}$-2″or 6″
3.64	brs, 2H, $\mathrm{CH_2}$-2″or 6″
5.98	s, 2H, $\mathrm{CH_2}$-7′
6.44	d (J = 14.6 Hz), 1H, CH-2
6.89	dd (J = 8.0, 1.1 Hz), 1H, CH-6′
6.98	d (J = 1.0 Hz), 1H, CH-2′
7.40	ddd (J = 14.7, 8.2, 1.6 Hz), 1H, CH-3
6.70–6.83	m, 3H, CH-4, 5, 5′

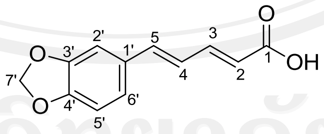
Table 2.1 Data of piperine (**75**) (continued)

NMR spectroscopy
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)
24.2(3) (CH_2-3″, 4″, 5″), 43.2, 46.1 (CH_2-2″, 6″), 100.8 (CH_2-7′), 105.2 (CH-2′), 108.0 (CH-5′), 119.6 (CH-6′), 122.1 (CH-2), 124.9 (CH-4), 130.6 (C_q-1′), 137.8 (CH-5), 142.1 (CH-3), 147.7, 147.8 (C_q-3′ or 4′), 165.0 (C_q-1)

2.1.2 Preparation of 5-(3,4-methylenedioxy)phenyl-2*E*,4*E*-pentadienoic acid (piperic acid, 105)[96]



Piperine (**75**, 101.85 g, 356.90 mmol) in a 250 ml round-bottomed flask equipped with a magnetic stirrer, MeOH/H_2O (1:2, 150 ml) were added. It was refluxed with KOH (1.5 equiv., 30.10 g, 535.40 mmol) allowed to 24 h. pH of the crude product was adjusted to 3-4 with 10% hydrochloric acid (HCl) until yellow solid was observed. The yellow solid was filtered and recrystallized with ethanol (EtOH) to give piperic acid (**105**) (77.89 g), 100% conversion from the starting material.



piperic acid (**105**)

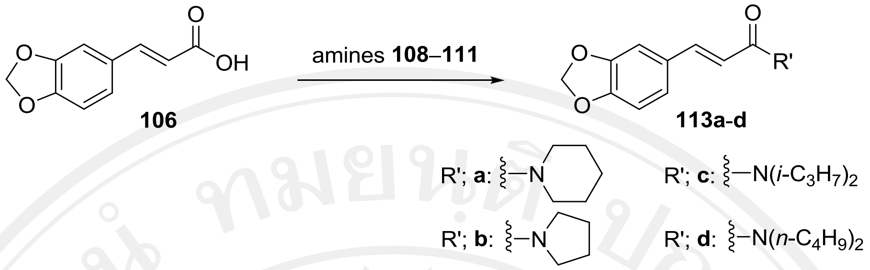
Table 2.2 Data of piperic acid (**105**)

Physical properties
Yellow crystals Melting point (m.p.) 206.0–208.1°C (EtOH)

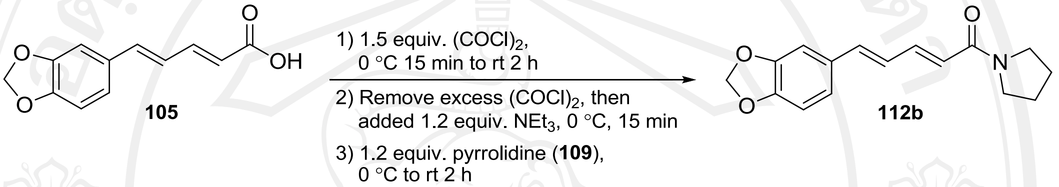
Table 2.2 Data of piperic acid (**105**) (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
5.92	d (*J* = 15.1 Hz), 1H, CH-2
6.05	s, 2H, CH_2-7′
6.92	d (*J* = 8.0 Hz), 1H, CH-5
6.96	s, 1H, CH-2′
6.97	d (*J* = 1.5 Hz), 1H, CH-6′
7.00	dd (*J* = 8.0, 1.5 Hz), 1H, CH-4
7.23	d (*J* = 1.5 Hz), 1H, CH-5′
7.25–7.32	m, 1H, CH-3
12.19	brs, 1H, OH
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
107.2 (CH_2-7′), 111.3 (CH-2′), 113.9 (CH-5′), 126.2 (CH-6′), 128.6 (CH-2), 130.4 (CH-4), 136.5 (C_q-1′), 145.6 (CH-5), 150.6 (CH-3), 152.2, 152.5 (C_q-3′ or 4′), 172.6 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{12}H_{10}O_4$	218.0579.$[M]^{+}$
Lock mass of $C_7H_{11}N_2O_2S$	215.0602 $[M+H]^{+}$
Calc. for $C_{12}H_{11}O_4$	219.0657 $[M+H]^{+}$
Found for $C_{12}H_{11}O_4$	219.0657 $[M+H]^{+}$

2.2 Preparation of pentadiene amide derivatives 112b-d from piperic acid (105)

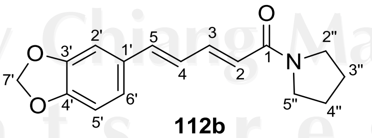


2.2.1 Preparation of 5-(3,4-methylenedioxy)phenyl-1-(1-pyrrolidinyl)-2*E*,4*E*-pentadien-1-one (112b)



General procedure I

Piperic acid (**105)** (5.00 g, 22.9 mmol) in a 100 ml round-bottomed flask equipped with a magnetic stirrer, fitted with a three-way stopcock with a septum cap and nitrogen inlet. CH_2Cl_2 20 ml was added. It was treated with oxalyl chloride ($(COCl)_2$) (1.5 equiv., 2.9 ml, 34.4 mmol) at 0 °C for 15 minutes to room temperature 2 h. After the period, excess oxalyl chloride ($(COCl)_2$) was removed under reduced pressure. CH_2Cl_2 and NEt_3 (2.0 equiv., 6.4 ml, 45.8 mmol) was added at 0 °C stirred for 15 minutes. Pyrrolidine (**109**) (2.5 equiv., 4.7 ml, 57.3 mmol) was added at 0 °C to room temperature 2 h. Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (1.0:9.0) affords pentadiene amide **112b** in 70% yield (4.34 g), 95% conversion from the starting material.



112b

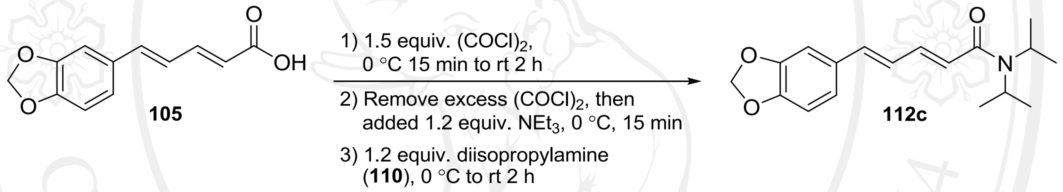
Table 2.3 Data of pentadiene amide **112b**

Physical properties	
White crystals Melting point (m.p.) 143.8–144.9 °C (CH_2Cl_2/hexane) R_f = 0.08 (EtOAc/hexane, 1.0:9.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1252	C–N stretching of amide
1590, 1443	C=C stretching of aromatic
1635	C=O stretching of amide
2971, 2875	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.92	brs, 4H, CH_2-3″, 4″
3.56	t (J = 6.8 Hz), 4H, CH_2-2″, 5″
5.96	s, 2H, CH_2-7′
6.24	d (J = 14.7 Hz), 1H, CH-2
6.66–6.84	m, 3H, CH-4, 5, 5′
6.89	dd (J = 8.0, 1.6 Hz), 1H, CH-6′
6.97	d (J = 1.6 Hz), 1H, CH-2′
7.48	dd (J = 14.8, 10.3 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
25.14(2) (CH_2-3″, 4″), 46.34(2) (CH_2-2″, 5″), 101.25 (CH_2-7′), 105.67 (CH-2′), 108.44 (CH-5′), 120.81 (CH-2), 122.64 (CH-6′), 125.07 (CH-4), 130.88 (C_q-1′), 139.09 (CH-5), 142.39 (CH-3), 148.20, 148.16 (C_q-3′ or 4′), 165.01 (C_q-1)	

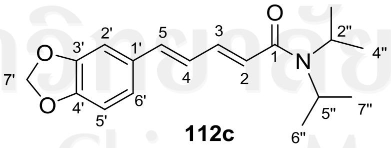
Table 2.3 Data of pentadiene amide **112b** (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{16}H_{18}NO_3$	272.1286 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{16}H_{17}NO_3Na$	294.1106 $[M+Na]^+$
Found for $C_{16}H_{17}NO_3Na$	294.1109 $[M+Na]^+$

2.2.2 Preparation of 5-(3,4-methylenedioxy)phenyl-1-(1-*N,N*-diisopropyl)-2*E*,4*E*-pentadien-1-one (112c)



According to the *general procedure I* in **2.2.1**, piperic acid (**105**) (1.23 g, 5.6 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 0.7 ml, 8.4 mmol), NEt_3 (2.0 equiv., 1.2 ml, 8.4 mmol), diisopropylamine (**110**) (1.5 equiv., 1.2 ml, 8.4 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) affords pentadiene amide **112c** in 82% yield (1.39 g), 99% conversion from the starting material.



112c

Table 2.4 Data of pentadiene amide **112c**

Physical properties
Yellow crystals Melting point (m.p.) 85.9–88.0 °C (CH_2Cl_2/hexane) R_f = 0.38 (EtOAc/hexane, 2.0:8.0)

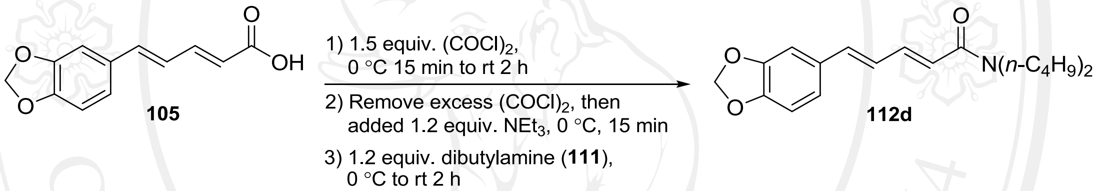
Table 2.4 Data of pentadiene amide **112c** (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1252	C–N stretching of amide
1443, 1589	C=C stretching of aromatic
1635	C=O stretching of amide
2968	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in CDCl$_3$	
Chemical shift (δ, ppm)	Type of proton
1.28	brs, 6H, CH$_3$-3″, 4″, 6″ or 7″
1.34	brs, 6H, CH$_3$-3″, 4″, 6″ or 7″
3.81	brs, 1H, CH-2″ or 5″
4.04	brs, 1H, CH-2″ or 5″
5.94	s, 2H, CH$_2$-7′
6.36	d (J = 14.6 Hz), 1H, CH-2
6.69–6.73	m, 2H, CH-4, 5′
6.75	d (J = 8.0 Hz), 1H, CH-5
6.87	dd (J = 8.1, 1.7 Hz), 1H, CH-6′
6.97	d (J = 1.6 Hz), 1H, CH-2′
7.42	ddd (J = 14.6, 6.2, 4.1 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)	
20.68(2), 20.47(2) (CH$_3$-3″, 4″, 6″, 7″), 45.72, 47.81 (CH-2″ or 5″), 101.17 (CH$_2$-7′), 105.58 (CH-2′), 108.37 (CH-5′), 122.33 (CH-2), 122.85 (CH-6′), 125.43 (CH-4), 131.02 (C$_q$-1′), 137.77 (CH-5), 141.31 (CH-3), 147.96, 148.10 (C$_q$-3′ or 4′), 166.21 (C$_q$-1)	

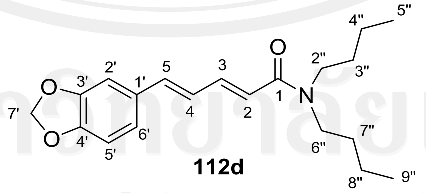
Table 2.4 Data of pentadiene amide **112c** (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{18}H_{24}NO_3$	302.1756 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{18}H_{23}NO_3Na$	324.1576 $[M+Na]^+$
Found for $C_{18}H_{23}NO_3Na$	324.1575 $[M+Na]^+$

2.2.3 Preparation of 5-(3,4-methylenedioxy)phenyl-1-(1-*N*,*N*-dibutyl)-2*E*,4*E*-pentadien-1-one (112d)



According to the *general procedure I* in **2.2.1**, piperic acid (**105**) (3.10 g, 14.2 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.8 ml, 21.3 mmol), NEt_3 (1.5 equiv., 3.0 ml, 21.3 mmol), dibutylamine (**111**) (1.5 equiv., 3.6 ml, 21.3 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords pentadiene amide **112d** in 86% yield (3.97 g), 98% conversion from the starting material.



112d

Table 2.5 Data of pentadiene amide **112d**

Physical properties
Yellow crystals Melting point (m.p.) 95.1–96.2 °C (CH_2Cl_2/hexane) R_f = 0.42 (EtOAc/hexane, 2.0:8.0)

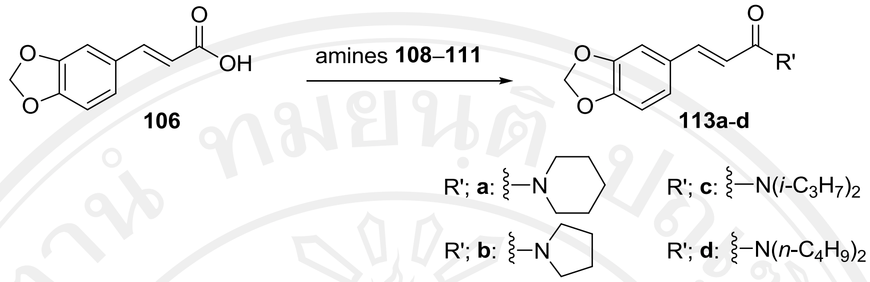
Table 2.5 Data of pentadiene amide **112d** (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1196	C–N stretching of amide
1447, 1594	C=C stretching of aromatic, double bond
1642	C=O stretching of amide
2874, 2932, 2960	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.85–1.02	m, 6H, CH_3-5″, 9″
1.26–1.41	m, 4H, CH_2-4″, 8″
1.43–1.66	m, 4H, CH_2-3″, 7″
3.30	t (J = 7.1 Hz), 2H, CH_2-2″ or 6″
3.37	t (J = 7.1 Hz), 2H, CH_2-2″ or 6″
5.94	s, 2H, CH_2-7′
6.33	d (J = 14.6 Hz), 1H, CH-2
6.66–6.80	m, 3H, CH-4, 5, 5′
6.87	dd (J = 8.1, 1.7 Hz), 1H, CH-6′
6.97	d (J = 1.6 Hz), 1H, CH-2′
7.42	ddd (J = 14.6, 6.5, 3.8 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
13.79(2) (CH_3-5″, 9″), 20.06, 20.18 (CH_2-4″ or 8″), 30.03, 31.84 (CH_2-3″ or 7″), 46.54, 47.85 (CH_2-2″ or 6″), 101.18 (CH_2-7′), 105.67 (CH-2′), 108.37 (CH-5′), 120.13 (CH-2), 122.43 (CH-6′), 125.29 (CH-4), 130.94 (C_q-1′), 138.34 (CH-5), 142.41 (CH-3), 148.08, 148.11 (C_q-3′ or 4′), 166.09 (C_q-1)	

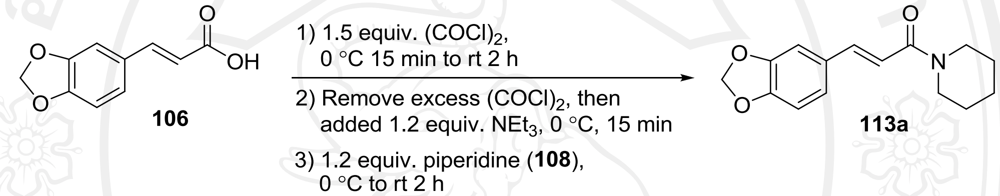
Table 2.5 Data of pentadiene amide **112d** (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{20}H_{28}NO_3$	330.2069 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{20}H_{27}NO_3Na$	352.1889 $[M+Na]^+$
Found for $C_{20}H_{27}NO_3Na$	352.1888 $[M+Na]^+$

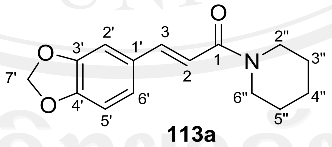
2.3 Preparation of *α,β*-unsaturated amide 113a-d from 3,4-methylenedioxy cinnamic acid (106)



2.3.1 Preparation of 3-(3,4-methylenedioxy)phenyl-1-(1-piperidinyl)-2*E*-propen-1-one (113a)



According to the *general procedure I* in **2.2.1**, 3,4-methylenedioxy cinnamic acid (**106**) (1.50 g, 7.8 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.0 ml, 11.7 mmol), NEt_3 (2.0 equiv., 2.2 ml, 15.6 mmol), piperidine (**108**) (2.5 equiv., 1.9 ml, 19.5 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords *α,β*-unsaturated amide **113a** in 96% yield (1.4896 g), 76% conversion from the starting material.



113a

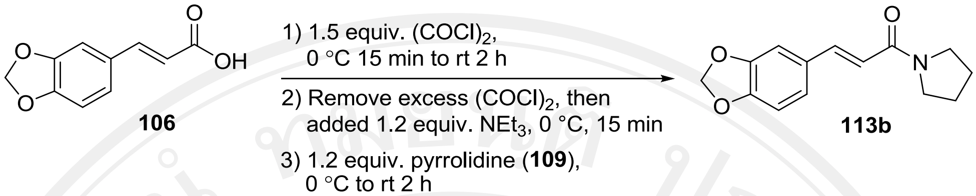
Table 2.6 Data of *α,β*-unsaturated amide **113a**

Physical properties
White crystals Melting point (m.p.) 89.0–89.9 °C (CH_2Cl_2/hexane) R_f = 0.30 (EtOAc/hexane, 2.0:8.0)

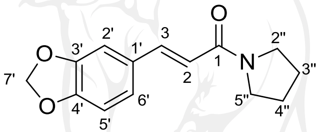
Table 2.6 Data of *α*,*β*-unsaturated amide **113a** (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1249	C–N stretching of amide
1490, 1597	C=C stretching of aromatic
1644	C=O stretching of amide
2856, 2936	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in CDCl$_3$	
Chemical shift (*δ*, ppm)	Type of proton
1.54–1.73	m, 6H, CH$_2$-3″, 4″, 5″
3.50–3.70	m, 4H, CH$_2$-2″, 6″
5.98	s, 2H, CH$_2$-7′
6.73	d (*J* = 15.3 Hz), 1H, CH-2
6.79	d (*J* = 8.0 Hz), 1H, CH-5′
6.99	dd (*J* = 8.1, 1.7 Hz), 1H, CH-6′
7.03	d (*J* = 1.7 Hz), 1H, CH-2′
7.57	d (*J* = 15.3 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)	
24.53, 26.15(2) (CH$_2$-3″, 4″, 5″), 45.48(2) (CH$_2$-2″, 6″), 101.41 (CH$_2$-7'), 106.37 (CH-2′), 108.50 (CH-5′), 114.69 (CH-6′), 123.95 (CH-2), 129.68 (C$_q$-1′), 143.14 (CH-3), 148.21, 148.99 (C$_q$-3′ or 4′), 165.73 (C$_q$-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 [M+Na]$^+$
Calc. for $C_{15}H_{17}NO_3Na$	282.1106 [M+Na]$^+$
Found for $C_{15}H_{17}NO_3Na$	282.1106 [M+Na]$^+$

2.3.2 Preparation of 3-(3,4-methylenedioxy)phenyl-1-(1-pyrrolidinyl)-2*E*-propen-1-one (113b)



According to the *general procedure I* in **2.2.1**, 3,4-methylenedioxy cinnamic acid (**106**) (1.00 g, 5.2 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 0.7 ml, 7.8 mmol), NEt_3 (2.0 equiv., 1.4 ml, 10.4 mmol), pyrrolidine (**109**) (2.5 equiv., 1.1 ml, 13.0 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (1.0:9.0) as eluent, affords *α,β*-unsaturated amide **113b** in 83% yield (1.0552 g), 100% conversion from the starting material.



113b

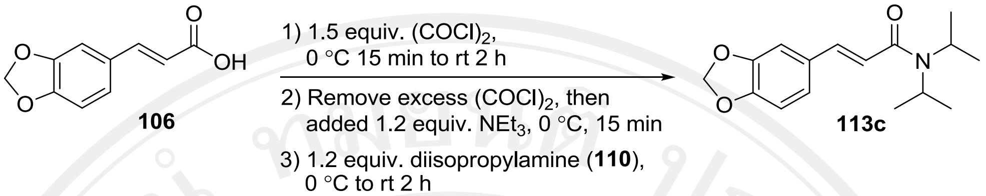
Table 2.7 Data of *α,β*-unsaturated amide **113b**

Physical properties	
White crystals Melting point (m.p.) 151.9–152.3 °C (CH_2Cl_2/hexane) R_f = 0.10 (EtOAc/hexane, 1.0:9.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1254	C–N stretching of amide
1491, 1596	C=C stretching of aromatic
1648	C=O stretching of amide
2875, 2971	C–H stretching

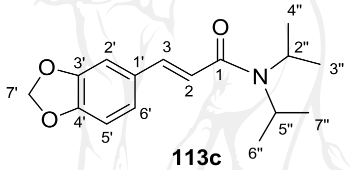
Table 2.7 Data of *α*,*β*-unsaturated amide **113b** (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.93	brs, 4H, CH_2-3′′, 4′′
3.58	t (J = 6.7 Hz), 4H, CH_2-2′′, 5′′
5.97	s, 2H, CH_2-7′
6.54	d (J = 15.4 Hz), 1H, CH-2
6.78	d (J = 8.0 Hz), 1H, CH-5′
6.99	dd (J = 8.0, 1.6 Hz), 1H, CH-6′
7.02	d (J = 1.6 Hz), 1H, CH-2′
7.61	d (J = 15.4 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.48, 25.67 (CH_2-3′′ or 4′′), 46.26(2) (CH_2-2′′, 5′′), 101.35 (CH_2-7′), 106.35 (CH-2′), 108.43 (CH-5′), 116.67 (CH-6′), 123.84 (CH-2), 129.67 (C_q-1′), 141.53 (CH-3), 148.13, 148.91 (C_q-3′ or 4′), 164.82 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{14}H_{16}NO_3$	245.1052 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{14}H_{15}NO_3Na$	268.0950 $[M+Na]^+$
Found for $C_{14}H_{15}NO_3Na$	268.0952 $[M+Na]^+$

2.3.3 Preparation of 3-(3,4-methylenedioxy)phenyl-1-(1-*N*,*N*-diisopropyl) -2*E*-propen-1-one (113c)



According to the *general procedure I* in **2.2.1**, 3,4-methylenedioxy cinnamic acid (**106**) (2.00 g, 10.4 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.3 ml, 15.6 mmol), NEt_3 (1.5 equiv., 2.2 ml, 15.6 mmol), diisopropylamine (**110**) (1.5 equiv., 2.2 ml, 15.6 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords *α*,*β*-unsaturated amide **113c** in 76% yield (2.10 g), 96% conversion from the starting material.



113c

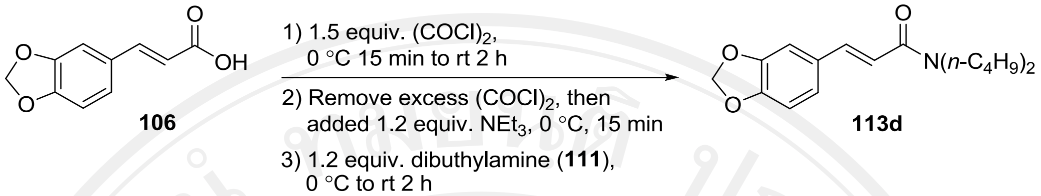
Table 2.8 Data of *α*,*β*-unsaturated amide **113c**

Physical properties	
Yellow liquid R_f = 0.41 (EtOAc/hexane, 2.0:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1250	C–N stretching of amide
1489, 1607	C=C stretching of aromatic
1645	C=O stretching of amide
2871, 2958	C–H stretching

Table 2.8 Data of *α*,*β*-unsaturated amide **113c** (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in CDCl$_3$	
Chemical shift (*δ*, ppm)	Type of proton
1.35	brs, 12H, CH$_3$-3″, 4″, 6″, 7″
3.86	brs, 1H, CH-2″ or 5″
4.09	brs, 1H, CH-2″ or 5″
5.99	s, 2H, CH$_2$-7′
6.67	d (*J* = 15.3 Hz), 1H, CH-2
6.79	d (*J* = 8.0 Hz), 1H, CH-5′
6.98	dd (*J* = 8.0, 1.6 Hz), 1H, CH-6′
7.02	d (*J* = 1.6 Hz), 1H, CH-2′
7.51	d (*J* = 15.3 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)	
20.65(2), 21.66(2) (CH$_3$-3″, 4″, 6″, 7″), 45.84, 47.84 (CH$_2$-2″ or 5″), 101.32 (CH$_2$-7′), 106.26 (CH-2′), 108.45 (CH-5′), 115.63 (CH-6′), 123.35 (CH-2), 130.12 (C$_q$-1'), 140.68 (CH-3), 148.12, 148.64 (C$_q$-3′ or 4′), 166.20 (C$_q$-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for C$_{16}$H$_{22}$NO$_3$	276.1599 [M+H]$^+$
Lock mass of C$_{12}$H$_{14}$N$_4$O$_4$SNa	333.0633 [M+Na]$^+$
Calc. for C$_{16}$H$_{21}$NO$_3$Na	298.1419 [M+Na]$^+$
Found for C$_{16}$H$_{21}$NO$_3$Na	298.1420 [M+Na]$^+$

2.3.4 Preparation of 3-(3,4-methylenedioxy)phenyl-1-(1-*N*,*N*-dibutyl)-2*E*-propen-1-one (113d)



According to the *general procedure I* in **2.2.1**, 3,4-methylenedioxy cinnamic acid (**106**) (2.01 g, 10.4 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.3 ml, 15.7 mmol), NEt_3 (1.5 equiv., 2.2 ml, 15.7 mmol), dibutylamine (**111**) (1.5 equiv., 2.6 ml, 15.7 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords *α,β*-unsaturated amide **113d** in 73% yield (2.31 g), 99% conversion from the starting material.

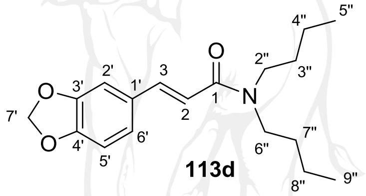


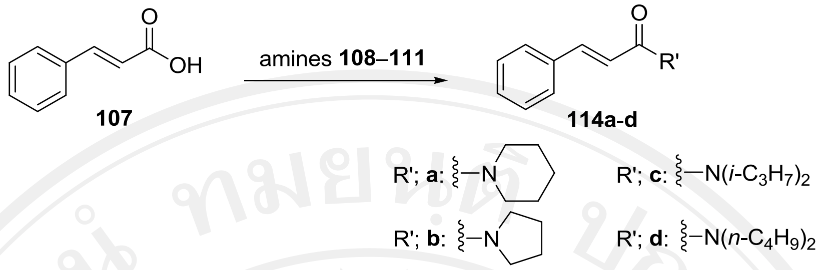
Table 2.9 Data of *α,β*-unsaturated amide **113d**

Physical properties	
White crystals Melting point , 137.1–141.3 °C (CH_2Cl_2/hexane) R_f = 0.43 (EtOAc/hexane, 2.0:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1254	C–N stretching of amide
1492, 1588	C=C stretching of aromatic
1641	C=O stretching of amide
2907, 2964	C–H stretching

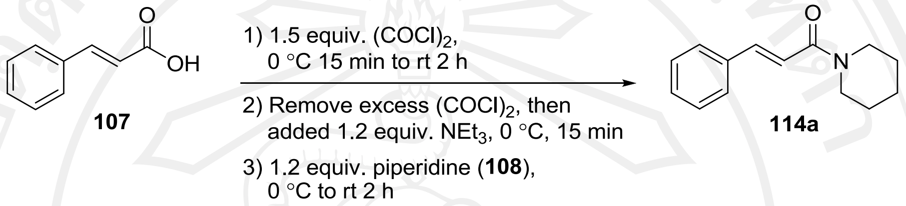
Table 2.9 Data of *α*,*β*-unsaturated amide **113d** (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
0.91–1.01	m, 6H, CH_3-5″, 9″
1.30–1.44	m, 4H, CH_2-4″, 8″
1.51–1.68	m, 4H, CH_2-3″, 7″
3.32–3.46	m, 4H, CH_2-2″, 6″
5.99	s, 2H, CH_2-7′
6.66	d (*J* = 15.4 Hz), 1H, CH-2
6.80	d (*J* = 8.0 Hz), 1H, CH-5′
6.95–7.04	m, 2H, CH-2′, 6′
7.61	d (*J* = 15.3 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
13.80, 13.86 (CH_3-5″ or 9″), 20.07, 20.26 (CH_2-4″ or 8″), 30.06, 31.92 (CH_2-3″ or 7″), 46.64, 47.88 (CH_2-2″ or 6″), 101.33 (CH_2-7′), 106.27 (CH-2′), 108.46 (CH-5′), 115.80 (CH-6′), 123.62 (CH-2), 129.92 (C_q-1′), 141.86 (CH-3), 148.12, 148.78 (C_q-3′ or 4′), 166.06 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{16}H_{22}NO_3$	304.1912 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{16}H_{21}NO_3Na$	326.1732 $[M+Na]^+$
Found for $C_{16}H_{21}NO_3Na$	326.1732 $[M+Na]^+$

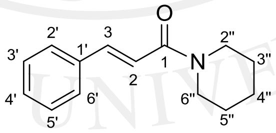
2.4 Preparation of *α,β*-unsaturated amide 114a-d from cinnamic acid (107)



2.4.1 Preparation of 3-phenyl-1-(1-piperidinyl)-2*E*-propen-1-one (114a)



According to the *general procedure I* in **2.2.1**, cinnamic acid (**107**) (1.50 g, 10.1 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.3 ml, 15.2 mmol), NEt_3 (2.0 equiv., 2.8 ml, 20.2 mmol), piperidine (**108**) (2.5 equiv., 2.5 ml, 25.3 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords *α,β*-unsaturated amide **114a** in 84% yield (1.71 g), 93% conversion from the starting material.



114a

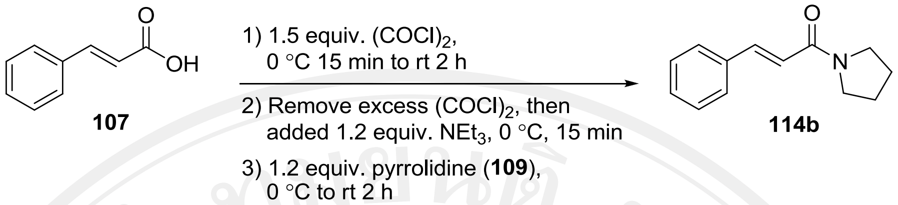
Table 2.10 Data of *α,β*-unsaturated amide **114a**

Physical properties
White crystals Melting point (m.p.) 121.2–122.0 °C (CH_2Cl_2/hexane) R_f = 0.43 (EtOAc/hexane, 2.0:8.0)

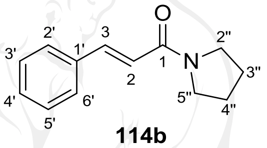
Table 2.10 Data of *α*,*β*-unsaturated amide **114a** (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1248	C–N stretching of amide
1498, 1586	C=C stretching of aromatic, double bond
1643	C=O stretching of amide
2862, 2934	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.56–1.72	m, 6H, CH_2-3″, 4″, 5″
3.59–3.67	m, 4H, CH_2-2″, 6″
6.90	d (J = 15.5 Hz), 1H, CH-2
7.30–7.40	m, 3H, CH-3′, 4′, 5′
7.49–7.55	m, 2H, CH-2′, 6′
7.65	d (J = 15.5 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.55(2), 26.13 (CH_2-3″, 4″, 5″), 45.25(2) (CH_2-2″, 6″), 117.38 (CH-2), 127.67(2), 128.71(2), 129.43 (CH-2′, 3′, 4′, 5′, 6′), 135.38 (C_q-1′), 142.51 (CH-3), 165.42 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{14}H_{18}NO$	216.1388 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{14}H_{17}NONa$	238.1208 $[M+Na]^+$
Found for $C_{14}H_{17}NONa$	238.1209 $[M+Na]^+$

2.4.2 Preparation of 3-phenyl-1-(1-pyrrolidinyl)-2*E*-propen-1-one (114b)



According to the *general procedure I* in **2.2.1**, cinnamic acid (**107**) (3.20 g, 21.9 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 2.8 ml, 32.9 mmol), NEt_3 (2.0 equiv., 6.1 ml, 43.9 mmol), pyrrolidine (**109**) (2.5 equiv., 4.5 ml, 54.8 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (0.5:9.5) as eluent, affords *α,β*-unsaturated amide **114b** in 70% yield (3.10 g), 85% conversion from the starting material.



114b

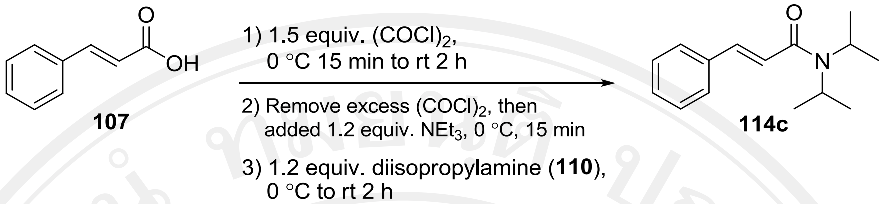
Table 2.11 Data of *α,β*-unsaturated amide **114b**

Physical properties	
White crystals Melting point (m.p.) 101.2–102.3 °C (CH_2Cl_2/hexane) R_f = 0.18 (EtOAc/hexane, 0.5:9.5)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1196	C–N stretching of amide
1447, 1598	C=C stretching of aromatic
1656	C=O stretching of amide
2876, 2973	C–H stretching

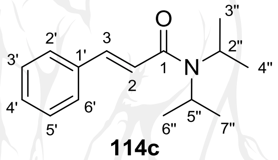
Table 2.11 Data of *α*,*β*-unsaturated amide **114b** (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
1.89	p (*J* = 6.6 Hz), 2H, CH_2-3″ or 4″
2.00	p (*J* = 6.6 Hz), 2H, CH_2-3″ or 4″
3.54–3.66	m, 4H, CH_2-2″, 5″
6.74	d (*J* = 15.5 Hz), 1H, CH-2
7.30–7.41	m, 3H, CH-3′, 4′, 5′
7.53	d (*J* = 7.2 Hz), 2H, CH-2′, 6′
7.70	d (*J* = 15.5 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.33, 26.14 (CH_2-3″ or 4″), 46.02, 46.56 (CH_2-2″ or 5″), 118.88 (CH-2), 127.81(2), 128.74(2), 129.48 (CH-2′, 3′, 4′, 5′, 6′), 135.38 (C_q-1′), 141.67 (CH-3), 164.69 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{13}H_{16}NO$	202.1232 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{13}H_{15}NONa$	224.1051 $[M+Na]^+$
Found for $C_{13}H_{15}NONa$	224.1052 $[M+Na]^+$

2.4.3 Preparation of 3-phenyl-1-(1-*N*,*N*-diisopropyl)-2*E*-propen-1-one (114c)



According to the *general procedure I* in **2.2.1**, cinnamic acid (**107**) (2.00 g, 13.5 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.7 ml, 20.2 mmol), NEt_3 (1.5 equiv., 2.8 ml, 20.2 mmol), diisopropylamine (**110**) (1.5 equiv., 2.8 ml, 20.2 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords *α,β*-unsaturated amide **114c** in 87% yield (2.56 g), 98% conversion from the starting material.



114c

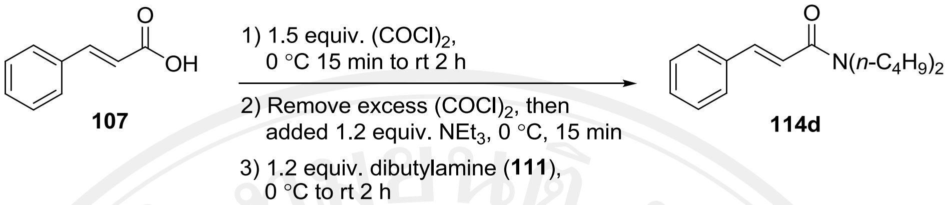
Table 2.12 Data of *α,β*-unsaturated amide **114c**

Physical properties	
Colorless liquid R_f = 0.58 (EtOAc/hexane, 2.0:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	ν_{max} (cm^{-1})
1208	C–N stretching of amide
1454, 1606	C=C stretching of aromatic
1650	C=O stretching of amide
2872, 2958	C–H stretching

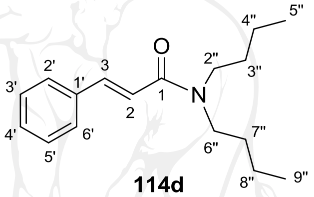
Table 2.12 Data of *α*,*β*-unsaturated amide **114c** (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
1.33	brs, 6H, CH_3-3″, 4″, 6″ or 7″
1.39	brs, 6H, CH_3-3″, 4″, 6″ or 7″
3.86	brs, 1H, CH-2″ or 5″
4.11	brs, 1H, CH-2″ or 5″
6.84	d (*J* = 15.4 Hz), 1H, CH-2
7.29–7.40	m, 3H, CH-3′, 4′, 5′
7.50	dt (*J* = 3.8, 2.1 Hz), 2H, CH-2′, 6′
7.95	d (*J* = 15.5 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
20.60(2), 21.58(2) (CH_3-3″, 4″, 6″, 7″), 45.83, 47.91 (CH_2-2″ or 5″), 120.65 (CH-2), 127.50(2), 128.66(2), 129.14 (CH-2′, 3′, 4′, 5′, 6′), 135.66 (C_q-1′), 140.77 (CH-3), 166.10 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{15}H_{22}NO$	232.1701 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{15}H_{21}NONa$	254.1521 $[M+Na]^+$
Found for $C_{15}H_{21}NONa$	254.1523 $[M+Na]^+$

2.4.4 Preparation of 3-phenyl-1-(1-*N*,*N*-dibutyl)-2*E*-propen-1-one (114d)



According to the *general procedure I* in **2.2.1**, cinnamic acid (**107**) (2.15 g, 14.5 mmol), oxalyl chloride ($(COCl)_2$) (1.5 equiv., 1.9 ml, 21.7 mmol), NEt_3 (1.5 equiv., 3.0 ml, 21.7 mmol), dibutylamine (**111**) (1.5 equiv., 3.7 ml, 21.7 mmol). Purification of the crude product by column chromatography (silica gel) using EtOAc/hexane (2.0:8.0) as eluent, affords *α*,*β*-unsaturated amide **114d** in 91% yield (3.19 g), 93% conversion from the starting material.



114d

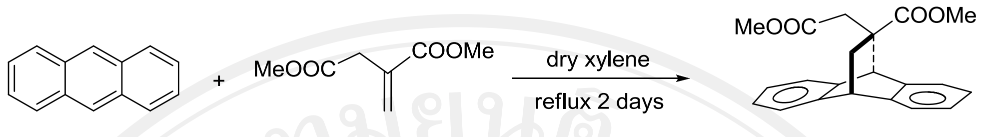
Table 2.13 Data of *α*,*β*-unsaturated amide **114d**

Physical properties	
Colorless liquid R_f = 0.58 (EtOAc/hexane, 2.0:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1127	C–N stretching of amide
1440, 1599	C=C stretching of aromatic
1642	C=O stretching of amide
2929, 2965	C–H stretching

Table 2.13 Data of *α*,*β*-unsaturated amide **114d** (continued)

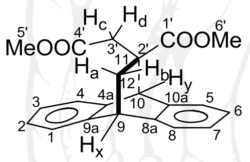
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
0.96	dt (*J* = 9.5, 7.4 Hz), 6H, CH_3-5″, 9″
1.30-1.43	m, 4H, CH_2-4″, 8″
1.53-1.67	m, 4H, CH_2-3″, 7″
3.36–3.47	m, 4H, CH_2-2″, 6″
6.84	d (*J* = 15.4 Hz), 1H, CH-2
7.30–7.40	m, 3H, CH-3′, 4′, 5′
7.51	d (*J* = 7.9, 1.5 Hz), 2H, CH-2′, 6′
7.70	d (*J* = 15.4 Hz), 1H, CH-3
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
13.72, 13.79 (CH_3-5″ or 9″), 19.98, 20.19 (CH_2-4″ or 8″), 29.98, 31.85 (CH_2-3″ or 7″), 46.56, 47.82 (CH_2-2″ or 6″), 117.75 (CH-2), 127.59(2), 128.64(2), 129.28 (CH-2′, 3′, 4′, 5′, 6′), 135.45 (C_q-1′), 142.03 (CH-3), 165.88 (C_q-1)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{17}H_{26}NO$	260. 2014 $[M+H]^+$
Lock mass of $C_{12}H_{14}N_4O_4SNa$	333.0633 $[M+Na]^+$
Calc. for $C_{17}H_{25}NONa$	282.1834 $[M+Na]^+$
Found for $C_{17}H_{25}NONa$	282.1835 $[M+Na]^+$

2.5 Preparation of 11-methoxyacetyl-11-methoxycarbonyl-9,10-dihydro-9,10-ethanoanthracene ((±)-74)[64]



77 **78** (±)-**74**

A mixture of anthracene (**77**) (205.10 g, 1.1508 mol) and dimethyl itaconate (**78**) (140.00 g, 0.8852 mol) in dried xylene (1500 ml) was heated to reflux for 48 h. The crude reaction mixture was evaporated to dryness and purified on a silica gel column. The column was eluted with hexane until no anthracene was detected. Then, it was stripped with 30% dichloromethane in hexane. Solvent was removed under reduced pressure and the almost pure product was crystallized from a mixture of CH_2Cl_2/hexane to give dimethyl itaconate–anthracene adduct ((±)-**74**) in 98% yield (290.85 g), 100% conversion from the starting material.



(±)-**74**

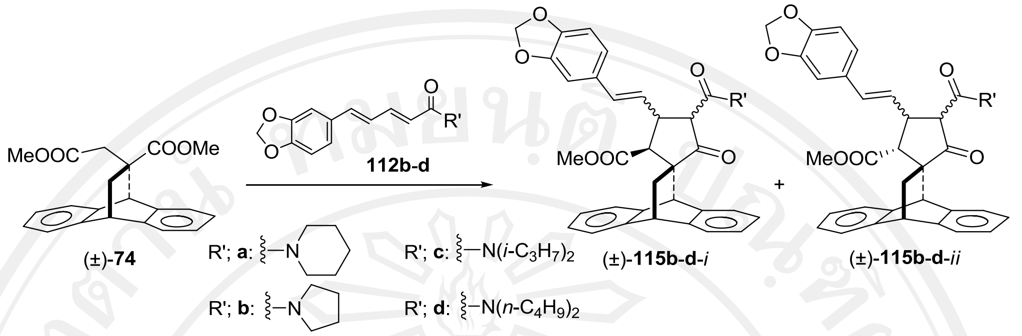
Table 2.14 Data of dimethyl itaconate–anthracene adduct ((±)-**74**)

Physical properties	
White crystals Melting point (m.p.) 154.0–155.0 °C (CH_2Cl_2/hexane) R_f = 0.61 (EtOAc/hexane, 2.0:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1060, 1170, 1255	C–O stretching of ester
1360	C–H bending of CH_3
1438	C–H bending of CH_2, CH_3
1740, 1718	C=O stretching of carbonyl

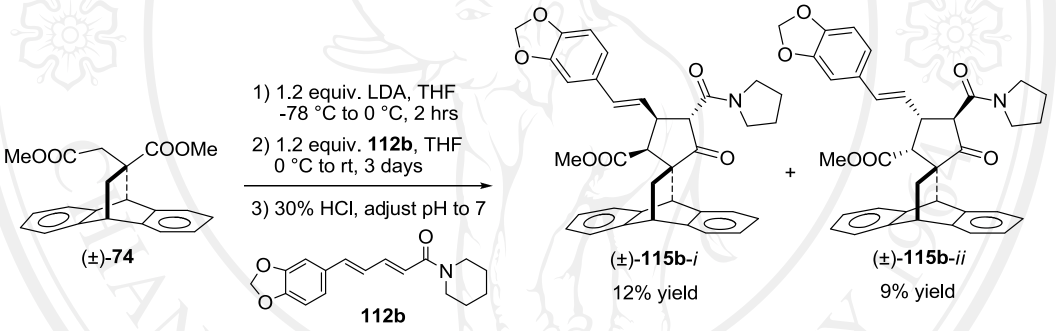
Table 2.14 Data of dimethyl itaconate–anthracene adduct ((±)-**74**) (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in CDCl$_3$	
Chemical shift (δ, ppm)	Type of proton
1.50, 2.85, 4.35	ABX system (J = 13.1, 3.0, 2.4 Hz), 3H, H$_a$, H$_b$, H$_x$
2.01	d (J = 16.1 Hz), 1H, H$_c$
2.96	d (J = 16.1 Hz), 1H, H$_d$
3.51	s, 3H, COOMe-6′
3.60	s, 3H, COOMe-5′
4.41	s, 1H, H$_y$
7.05–7.08	m, 8H, Ar-H
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)	
37.2 (CH$_2$-12), 44.5 (CH-9), 44.8 (CH$_2$-3′), 50.8 (C$_q$-11), 52.0 (CH$_3$-6′), 52.6 (CH$_3$-5′), 53.2 (CH-10), 123.7, 124.0, 126.09, 126.12, 126.2, 126.9, 127.1, 140.1, 140.6, 143.3, 144.1 (CH, C$_q$-aromatic), 171.9 (C$_q$-1′), 175.3 (C$_q$-4′)	
Mass spectrometry (EI-MS)	
Molecular weight	*m/z*
Calc. for $C_{21}H_{20}O_4$	336 [M]$^+$
Found for $C_{21}H_{20}O_4$	336 [M]$^+$

2.6 Syntheses of racemic spirocyclopentanone–anthracene adduct derivatives (±)-115b-*i*, -*ii* – (±)-115d-*i*, -*ii*



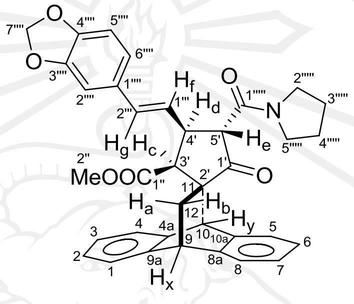
2.6.1 Syntheses of 3′-methoxycarbonyl-4′-(2-(3,4-methylenedioxy)phenyl) vinyl-5′-pyrrolidinecarbonyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-115b-*i* and (±)-115b-*ii*)



General procedure II

A 100 ml round-bottomed flask equipped with a magnetic stirrer was fitted with a three-way stopcock with a septum cap and nitrogen inlet. THF (5.0 ml) and anhydrous diisopropylamine (1.9 equiv., 0.4 ml, 2.8 mmol) were added *via* syringes. The mixture was cooled down to –78 °C, *n*-butyllithium (1.6 equiv., 1.7 ml, 1.4 N in hexane, 2.4 mmol) was added. Then, the reaction mixture was left stirring at 0 °C for 1 h. A solution of dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 0.50 g, 1.5 mmol) in THF (10 ml) was introduced to the LDA solution at –78 °C and the reaction mixture was left stirring at 0 °C for 2 h. The reaction mixture was then cooled down to –78 °C and a solution of pentadiene amide **112b** (1.2 equiv., 0.48 g, 1.8 mmol) in THF (10 ml) was added. The reaction mixture was stirred at 0 °C for 15 minute and left stirring at room temperature for 3 days. The reaction mixture was quenched with 30% hydrochloric acid solution at 0 °C followed by extraction three times with CH_2Cl_2. The combined organic extracts were washed with H_2O, dried over $MgSO_4$, filtered and evaporated to dryness.

The crude product was purified by flash column chromatography on silica gel using EtOAc/CH_2Cl_2/hexane (1.5:0.5:8.0) as eluent, to afford diastereomeric spirocyclopentanone–anthracene adducts (±)-**115b**-*i* in 12% yield (0.056 g) and (±)-**115b**-*ii* in 9% yield (0.074 g), 70% conversion from the starting material.



(±)-**115b**-*i*

Table 2.15 Data of spirocyclopentanone–anthracene adduct (±)-**115b**-*i*

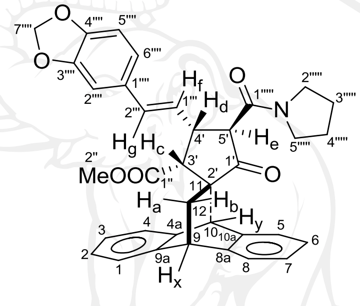
Physical properties	
White crystals Melting point (m.p.) 121.1–125.4 °C (CH_2Cl_2/hexane) R_f = 0.29 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1109, 1253	C–O stretching of ester
1491, 1504	C=C aromatic of benzene
1635, 1745	C=O stretching of carbonyl
2882, 2954	C–H stretching
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.76–1.99	m, 4H, CH_2-3′′′′′, 4′′′′′
1.30, 2.21, 4.30	ABX system (J = 12.7, 2.8, 2.5 Hz), 3H, H_a, H_b, H_x

Table 2.15 Data of spirocyclopentanone–anthracene adduct (±)-**115b**-*i* (continued)

^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
2.78	d (*J* = 7.0 Hz), 1H, H_c
3.38–3.47, 3.88–4.00	m, 2H, CH_2-2′′′′′ or 5′′′′′
3.48–3.61	m, 2H, CH_2-2′′′′′ or 5′′′′′
3.53	s, 3H, COOMe-2′′
3.72	d (*J* = 10.1 Hz), 1H, H_e
4.33–4.41	m, 1H, H_d
4.92	s, 1H, H_y
5.79	dd (*J* = 15.7, 8.1 Hz), 1H, H_f
5.93	s, 2H, CH_2-7′′′′
6.53	d (*J* = 15.6 Hz), 1H, H_g
6.74	d (*J* = 1.6 Hz), 2H, ArH-5′′′′, 6′′′′
6.83	s, 1H, ArH-2′′′′
6.99–7.42	m, 8H, ArH–anthracene
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.38, 25.76 (CH_2-3′′′′′ or 4′′′′′), 36.10 (CH_2-12), 41.89 (CH-4′), 44.19 (CH-9), 46.31, 47.10 (CH_2-2′′′′′ or 5′′′′′), 46.58 (CH-10), 51.49 (CH_3-2′′), 55.87 (CH-5′), 56.03 (CH-3′), 60.36 (C_q-2′), 101.09 (CH_2-7′′′′), 105.47, 108.28, 121.12 (CH-2′′′′, 5′′′′ or 6′′′′), 122.69, 123.71, 125.53, 125.59, 125.78, 125.98, 126.45, 126.70 (CH-aromatic–anthracene), 125.04 (CH-1′′′), 132.79 (CH-2′′′), 131.06, 138.61, 139.49, 143.51, 144.09, 147.34, 148.02 (C_q-aromatic), 165.99 (C_q-1′′), 173.75 (C_q-1′′′′′), 208.13 (C_q-1′)	

Table 2.15 Data of spirocyclopentanone–anthracene adduct (±)-**115b**-*i* (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{36}H_{34}NO_6$	576.2386 $[M+H]^+$
Lock mass of $C_{28}H_{37}N_5O_7$	578.2591 $[M+H]^+$
Calc. for $C_{36}H_{33}NO_6Na$	598.2206 $[M+Na]^+$
Found for $C_{36}H_{33}NO_6Na$	598.2202 $[M+Na]^+$



(±)-**115b**-*ii*

Table 2.16 Data of spirocyclopentanone–anthracene adduct (±)-**115b**-*ii*

Physical properties	
White crystals Melting point (m.p.) 226.5–230.1 °C (CH_2Cl_2/hexane) R_f = 0.17 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1101, 1253	C–O stretching of ester
1491, 1504	C=C aromatic of benzene
1638, 1746	C=O stretching of carbonyl
2881, 2953	C–H stretching

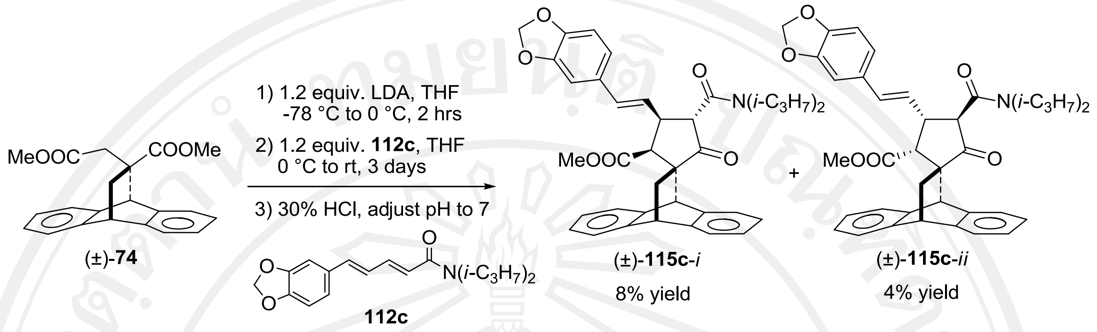
Table 2.16 Data of spirocyclopentanone–anthracene adduct (±)-**115b**-*ii* (continued)

NMR spectroscopy	
1H-NMR (400 MHz) in CDCl3	
Chemical shift (*δ*, ppm)	Type of proton
1.68–1.85	m, 4H, CH$_2$-3′′′′′, 4′′′′′
1.90, 2.10, 4.36	ABX system (*J* = 12.8, 3.3, 2.4 Hz), 3H, H$_a$, H$_b$, H$_x$
2.31	d (*J* = 6.6 Hz), 1H, H$_c$
3.27–3.46	m, 2H, CH$_2$-2′′′′′ or 5′′′′′
3.92–4.00	m, 2H, CH$_2$-2′′′′′ or 5′′′′′
3.77	s, 3H, COOMe-2′′
3.80	d (*J* = 11.3 Hz), 1H, H$_e$
3.86–3.92	m, 1H, H$_d$
4.41	s, 1H, H$_y$
5.69	dd (*J* = 15.7, 7.8 Hz), 1H, H$_f$
5.91	s, 2H, CH$_2$-7′′′′
6.34	d (*J* = 15.7 Hz), 1H, H$_g$
6.62–6.74	m, 2H, ArH-5′′′′, 6′′′′
6.77	d (*J* = 1.4 Hz), 1H, ArH-2′′′′
6.99–7.45	m, 8H, ArH–anthracene
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)	
24.23, 25.69 (CH$_2$-3′′′′′ or 4′′′′′), 40.90 (CH$_2$-12), 41.25 (CH-4′), 44.09 (CH-9), 46.02, 46.81 (CH$_2$-2′′′′′ or 5′′′′′), 47.69 (CH-10), 51.38 (CH$_3$-2′′), 56.51 (CH-5′), 57.89 (C$_q$-2′), 57.95 (CH-3′), 101.00 (CH$_2$-7′′′′), 105.35, 108.18, 120.99 (CH-2′′′′, 5′′′′ or 6′′′′), 122.56, 123.72, 124.04, 125.41, 125.53, 125.81, 126.37, 126.66 (CH-aromatic–anthracene), 124.23 (CH-1′′′), 132.52 (CH-2′′′), 130.97, 140.51, 141.22, 142.95, 143.34, 147.21, 147.90 (C$_q$-aromatic), 165.32 (C$_q$-1′′), 173.87 (C$_q$-1′′′′′), 210.88 (C$_q$-1′)	

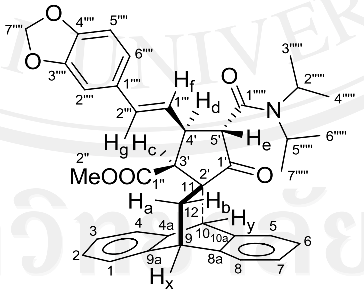
Table 2.16 Data of spirocyclopentanone–anthracene adduct (±)-**115b**-*ii* (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{36}H_{34}NO_6$	576.2386 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{36}H_{33}NO_6Na$	598.2206 $[M+Na]^+$
Found for $C_{36}H_{33}NO_6Na$	598.2204 $[M+Na]^+$

2.6.2 Syntheses 5′-(*N*,*N*-diisopropylcarboxamid-1-yl)-3′-methoxycarbonyl-4′-(2-(3,4-methylenedioxy)phenyl)vinyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-115c-*i* and (±)-115c-*ii*)



According to *general procedure II* in **2.6.1**, anhydrous diisopropylamine (1.68 equiv., 0.95 ml, 6.74 mmol), *n*-butyllithium (1.4 equiv., 4.19 ml, 1.34 N in hexane, 5.62 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.35 g, 4.01 mmol), pentadiene amide **112c** (1.2 equiv., 1.45 g, 4.82 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/ hexane (1.5:0.5:8.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**115c**-*i* in 8% yield (0.056 g) and (±)-**115c**-*ii* in 4% yield (0.074 g), 56% conversion from the starting material.



(±)-**115c**-*i*

Table 2.17 Data of spirocyclopentanone–anthracene adduct (±)-**115c**-*i*

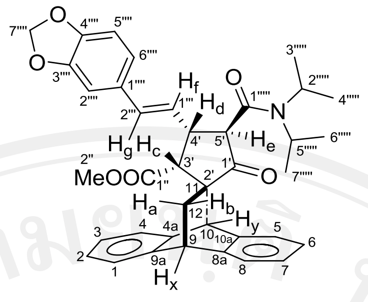
Physical properties
White crystals Melting point (m.p.) 118.5–121.5 °C (CH_2Cl_2/hexane) R_f = 0.32 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)

Table 2.17 Data of spirocyclopentanone–anthracene adduct (±)-**115c**-*i* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1040, 1252	C–O stretching of ester
1443, 1490	C=C aromatic of benzene
1631, 1744	C=O stretching of carbonyl
2932, 2966	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.13	d (*J* = 6.7 Hz), 3H, CH_3-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′
1.20	d (*J* = 6.5 Hz), 3H, CH_3-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′
1.44	d (*J* = 6.7 Hz), 3H, CH_3-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′
1.50	d (*J* = 6.7 Hz), 3H, CH_3-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′
1.29, 2.22, 4.30	ABX system (*J* = 12.7, 2.8, 2.6 Hz), 3H, H_a, H_b, H_x
2.81	d (*J* = 7.1 Hz), 1H, H_c
3.37–3.60	m, 1H, CH-2′′′′′ or 5′′′′′
4.38–4.47	m, 1H, CH-2′′′′′ or 5′′′′′
3.53	s, 3H, COOMe-2′′
3.81	d (*J* = 9.9 Hz), 1H, H_e
4.49–4.55	m, 1H, H_d
4.87	s, 1H, H_y
5.83	dd (*J* = 15.7, 7.5 Hz), 1H, H_f
5.93	s, 2H, CH_2-7′′′′
6.48	d (*J* = 15.6 Hz), 1H, H_g
6.72	d (*J* = 1.4 Hz), 2H, ArH-5′′′′, 6′′′′
6.81	s, 1H, ArH-2′′′′

Table 2.17 Data of spirocyclopentanone–anthracene adduct (±)-**115c**-*i* (continued)

<table>
<tr><th colspan="2">NMR spectroscopy</th></tr>
<tr><td colspan="2">^{1}H-NMR (400 MHz) in $CDCl_3$</td></tr>
<tr><td>Chemical shift (δ, ppm)</td><td>Type of proton</td></tr>
<tr><td>6.96–7.45</td><td>m, 8H, ArH–anthracene</td></tr>
<tr><td colspan="2">^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)</td></tr>
<tr><td colspan="2">20.38, 20.77, 20.89, 21.10 (CH_3-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′), 35.90 (CH_2-12), 41.63 (CH-4′), 44.19 (CH-9), 46.44 (CH-10), 46.57, 49.23 (CH-2′′′′′ or 5′′′′′), 51.49 (CH_3-2′′), 54.62 (CH-5′), 55.55 (CH-3′), 60.45 (C_q-2′), 101.07 (CH_2-7′′′′), 105.41, 108.28, 120.95 (CH-2′′′′, 5′′′′ or 6′′′′), 122.83, 123.62, 125.40, 125.55, 125.62, 125.97, 126.49, 126.67 (CH-aromatic–anthracene), 125.36 (CH-1′′′), 132.24 (CH-2′′′), 131.24, 138.67, 139.53, 143.40, 144.17, 147.25, 147.99 (C_q-aromatic), 165.62 (C_q-1′′), 173.93 (C_q-1′′′′′), 207.42 (C_q-1′)</td></tr>
<tr><td colspan="2">Mass spectrometry (ESI-MS)</td></tr>
<tr><td>Molecular weight</td><td><i>m/z</i></td></tr>
<tr><td>Calc. for $C_{38}H_{40}NO_6$</td><td>606.2856 $[M+H]^+$</td></tr>
<tr><td>Lock mass of $C_{33}H_{40}N_2O_9$</td><td>609.2812 $[M+H]^+$</td></tr>
<tr><td>Calc. for $C_{38}H_{39}NO_6Na$</td><td>628.2675 $[M+Na]^+$</td></tr>
<tr><td>Found for $C_{38}H_{39}NO_6Na$</td><td>628.2677 $[M+Na]^+$</td></tr>
</table>



(±)-**115c**-*ii*

Table 2.18 Data of spirocyclopentanone–anthracene adduct (±)-**115c**-*ii*

Physical properties	
White crystals Melting point (m.p.) 145.4–148.5 °C (CH_2Cl_2/hexane) $R_f = 0.20$ (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1038, 1250	C–O stretching of ester
1442, 1489	C=C aromatic of benzene
1633, 1743	C=O stretching of carbonyl
2931, 2964	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.11	d (J = 6.7 Hz), 3H, CH_3-3′′′′′ or 4′′′′′ or 6′′′′′ or 7′′′′′
1.20–1.30	m, 9H, CH_3-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′
1.88, 2.12, 4.35	ABX system (J = 12.8, 3.1, 2.4 Hz), 3H, H_a, H_b, H_x
2.30	d (J = 6.2 Hz), 1H, H_c
3.33–3.48	m, 1H, CH-2′′′′′ or 5′′′′′
4.16–4.30	m, 1H, CH-2′′′′′ or 5′′′′′
3.74	s, 3H, COOMe-2′′

Table 2.18 Data of spirocyclopentanone–anthracene adduct (±)-**115c**-*ii* (continued)

NMR spectroscopy

^{1}H-NMR (400 MHz) in $\mathrm{CDCl_3}$

Chemical shift (δ, ppm)	Type of proton
3.91	d (*J* = 11.4 Hz), 1H, $\mathrm{H_e}$
3.80–3.91	m, 1H, $\mathrm{H_d}$
4.43	s, 1H, $\mathrm{H_y}$
5.72	dd (*J* = 15.7, 7.0 Hz), 1H, $\mathrm{H_f}$
5.91	s, 2H, $\mathrm{CH_2}$-7′′′′
6.29	d (*J* = 15.7 Hz), 1H, $\mathrm{H_g}$
6.62	dd (*J* = 8.0, 1.5 Hz), 1H, ArH-5′′′′ or 6′′′′
6.69	d (*J* = 8.0 Hz), 1H, ArH-5′′′′ or 6′′′′
6.71–6.76	m, 1H, ArH-2′′′′
6.95–7.45	m, 8H, ArH–anthracene

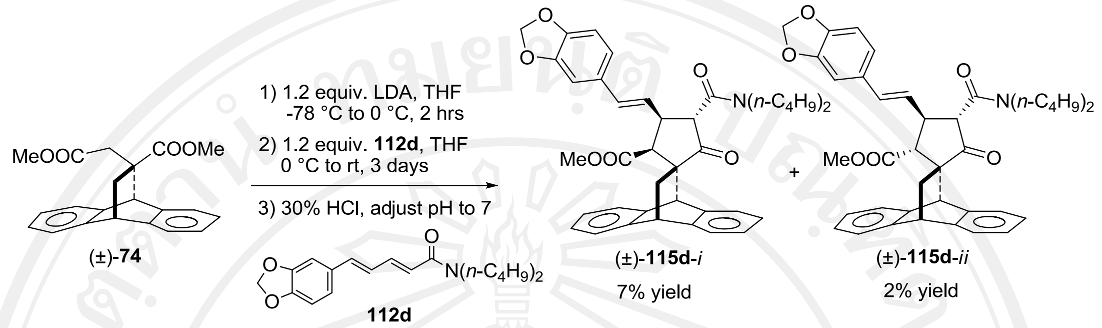
^{13}C-NMR (100 MHz) in $\mathrm{CDCl_3}$ (ppm)

20.49, 20.53, 21.21, 21.27 ($\mathrm{CH_3}$-3′′′′′, 4′′′′′, 6′′′′′ or 7′′′′′), 41.17 ($\mathrm{CH_2}$-12), 42.28 (CH-4′), 44.16 (CH-9), 46.14 (CH-10), 47.82, 48.89 (CH-2′′′′′ or 5′′′′′), 51.32 ($\mathrm{CH_3}$-2′′), 55.70 (CH-5′), 57.69 ($\mathrm{C_q}$-2′), 57.95 (CH-3′), 101.03 ($\mathrm{CH_2}$-7′′′′), 105.24, 108.24, 120.79 (CH-2′′′′, 5′′′′ or 6′′′′), 122.48, 123.80, 124.01, 125.45, 125.48, 125.73, 126.34, 126.76 (CH-aromatic–anthracene), 124.36 (CH-1′′′), 132.06 (CH-2′′′), 131.13, 140.52, 141.56, 143.00, 143.63, 147.21, 147.94 ($\mathrm{C_q}$-aromatic), 166.39 ($\mathrm{C_q}$-1′′), 173.92 ($\mathrm{C_q}$-1′′′′′), 210.74 ($\mathrm{C_q}$-1′)

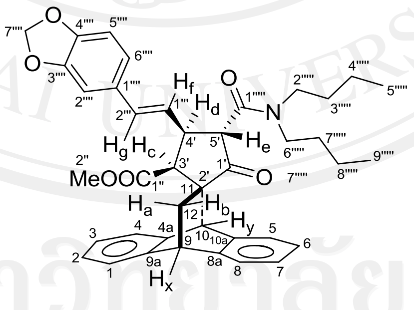
Mass spectrometry (ESI-MS)

Molecular weight	*m/z*
Calc. for $\mathrm{C_{38}H_{40}NO_6}$	606.2856 $[\mathrm{M+H}]^+$
Lock mass of $\mathrm{C_{33}H_{40}N_2O_9}$	609.2812 $[\mathrm{M+H}]^+$
Calc. for $\mathrm{C_{38}H_{39}NO_6Na}$	628.2675 $[\mathrm{M+Na}]^+$
Found for $\mathrm{C_{38}H_{39}NO_6Na}$	628.2675 $[\mathrm{M+Na}]^+$

2.6.3 Syntheses of 5′-(*N*,*N*-dibutylcarboxamid-1-yl)-3′-methoxycarbonyl-4′-(2-(3,4-methylenedioxy)phenyl)vinyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-115d-*i* and (±)-115d-*ii*)



According to *general procedure II* in **2.6.1**, anhydrous diisopropylamine (1.68 equiv., 0.71 ml, 4.99 mmol), *n*-butyllithium (1.4 equiv., 3.16 ml, 1.32 N in hexane, 4.16 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.00 g, 2.97 mmol), pentadiene amide **112d** (1.2 equiv., 1.18 g, 3.57 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/ hexane (1.0:0.5:8.5) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**115d**-*i* in 7% yield (0.078 g) and (±)-**115d**-*ii* in 2% yield (0.018 g), 62% conversion from the starting material.



(±)-**115d**-*i*

Table 2.19 Data of spirocyclopentanone–anthracene adduct (±)-**115d**-*i*

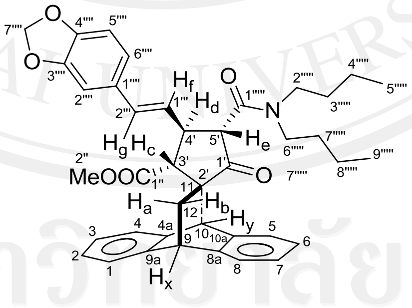
Physical properties
White crystals Melting point (m.p.) 79.5–81.4 °C (CH_2Cl_2/hexane) R_f = 0.38 (EtOAc/CH_2Cl_2/hexane, 1.0:0.5:8.5)

Table 2.19 Data of spirocyclopentanone–anthracene adduct (±)-**115d**-*i* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1038, 1251	C–O stretching of ester
1490, 1502	C=C aromatic of benzene
1634, 1744	C=O stretching of carbonyl
2872, 2956	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.86	t (*J* = 7.3 Hz), 3H, CH_3-5′′′′′ or 9′′′′′
0.96	t (*J* = 7.3 Hz), 3H, CH_3-5′′′′′ or 9′′′′′
1.20–1.59	m, 8H, CH_2-3′′′′′, 4′′′′′, 7′′′′′, 8′′′′′
1.30, 2.20, 4.30	ABX system (*J* = 12.7, 2.6, 2.5 Hz), 3H, H_a, H_b, H_x
2.80	d (*J* = 6.9 Hz), 1H, H_c
3.03–3.16	m, 2H, CH_2-2′′′′′ or 6′′′′′
3.65–3.79	m, 2H, CH_2-2′′′′′ or 6′′′′′
3.54	s, 3H, COOMe-2′′
3.82	d (*J* = 10.1 Hz), 1H, H_e
4.35–4.44	m, 1H, H_d
4.90	s, 1H, H_y
5.76	dd (*J* = 15.7, 8.2 Hz), 1H, H_f
5.94	s, 2H, CH_2-7′′′′
6.54	d (*J* = 15.6 Hz), 1H, H_g
6.73	d (*J* = 0.9 Hz), 2H, ArH-5′′′′, 6′′′′
6.81	s, 1H, ArH-2′′′′
6.97–7.45	m, 8H, ArH–anthracene

Table 2.19 Data of spirocyclopentanone–anthracene adduct (±)-**115d**-*i* (continued)

^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
13.78, 14.02 (CH_3-5′′′′′ or 9′′′′′), 19.97, 20.07 (CH_2-4′′′′′ or 8′′′′′), 29.89, 31.38 (CH_2-3′′′′′ or 7′′′′′), 36.11 (CH_2-12), 42.37 (CH-4′), 44.17 (CH-9), 46.42, 47.59 (CH_2-2′′′′′ or 6′′′′′), 46.69 (CH-10), 51.50 (CH_3-2′′), 53.91 (CH-5′), 55.84 (CH-3′), 60.35 (C_q-2′), 101.07 (CH_2-7′′′′), 105.39, 108.26, 121.04 (CH-2′′′′, 5′′′′ or 6′′′′), 122.72, 123.69, 125.58(3), 125.97, 126.48, 126.69 (CH-aromatic–anthracene), 124.86 (CH-1′′′), 132.95 (CH-2′′′), 131.08, 138.56, 139.45, 143.45, 144.08, 147.30, 147.99 (C_q-aromatic), 167.16 (C_q-1′′), 173.79 (C_q-1′′′′′), 207.79 (C_q-1′)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{40}H_{44}NO_6$	634.3169 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{40}H_{43}NO_6Na$	656.2988 $[M+Na]^+$
Found for $C_{40}H_{43}NO_6Na$	656.2990 $[M+Na]^+$



(±)-**115d**-*ii*

Table 2.20 Data of spirocyclopentanone–anthracene adduct (±)-**115d**-*ii*

Physical properties
White crystals
Melting point (m.p.) 69.8–72.1 °C (CH_2Cl_2/hexane)
R_f = 0.33 (EtOAc/CH_2Cl_2/hexane, 1.0:0.5:8.5)

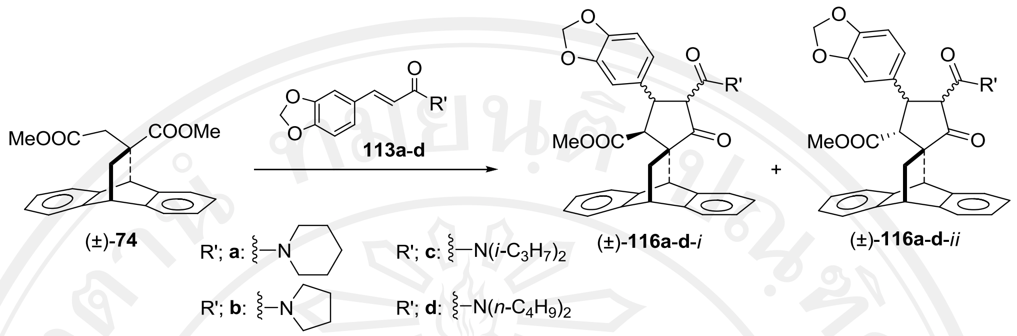
Table 2.20 Data of spirocyclopentanone–anthracene adduct (±)-**115d**-*ii* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1037, 1250	C–O stretching of ester
1489, 1503	C=C aromatic of benzene
1635, 1739	C=O stretching of carbonyl
2855, 2926	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in CDCl$_3$	
Chemical shift (δ, ppm)	Type of proton
0.82	t (*J* = 7.3 Hz), 3H, CH$_3$-5′′′′′ or 9′′′′′
0.97	t (*J* = 7.3 Hz), 3H, CH$_3$-5′′′′′ or 9′′′′′
1.17–1.58	m, 8H, CH$_2$-3′′′′′, 4′′′′′, 7′′′′′, 8′′′′′
2.12, 2.29, 4.30	ABX system (*J* = 12.2, 3.0, 2.4 Hz), 3H, H$_a$, H$_b$, H$_x$
2.65	d (*J* = 12.2 Hz), 1H, H$_c$
2.94	s, 3H, COOMe-2′′
2.99–3.13	m, 2H, CH$_2$-2′′′′′ or 6′′′′′
3.50–3.77	m, 2H, CH$_2$-2′′′′′ or 6′′′′′
3.36	d (*J* = 9.6 Hz), 1H, H$_e$
4.51–4.59	m, 1H, H$_d$
5.03	s, 1H, H$_y$
5.77	dd (*J* = 15.6, 8.2 Hz), 1H, H$_f$
5.92	d (*J* = 0.8 Hz), 2H, CH$_2$-7′′′′
6.57	d (*J* = 15.6 Hz), 1H, H$_g$
6.69–6.78	m, 2H, ArH-5′′′′, 6′′′′
6.83	d (*J* = 0.9 Hz), 1H, ArH-2′′′′
6.90–7.33	m, 8H, ArH

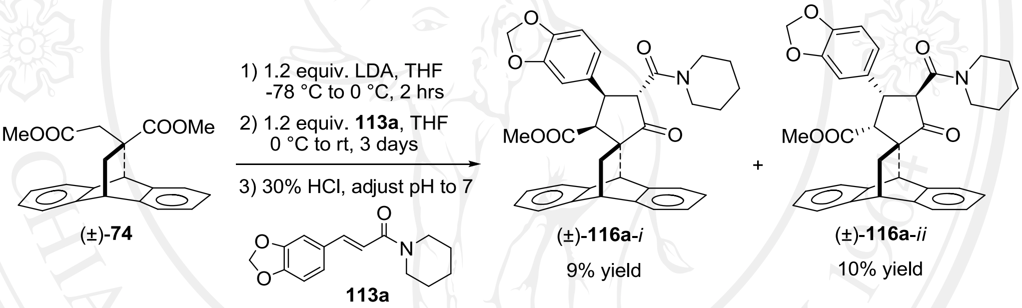
Table 2.20 Data of spirocyclopentanone–anthracene adduct (±)-**115d**-*ii* (continued)

<table>
<tr><th colspan="2">NMR spectroscopy</th></tr>
<tr><td colspan="2">^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)</td></tr>
<tr><td colspan="2">13.83, 14.05 (CH$_3$-5′′′′′ or 9′′′′′), 20.07, 20.12 (CH$_2$-4′′′′′ or 8′′′′′), 29.94, 31.52 (CH$_2$-3′′′′′ or 7′′′′′), 35.86 (CH$_2$-12), 41.86 (CH-4′), 44.29 (CH-9), 44.86 (CH-10), 46.53, 47.83 (CH$_2$-2′′′′′ or 6′′′′′), 51.38 (CH$_3$-2′′), 54.30 (CH-3′), 56.02 (CH-5′), 58.57 (C$_q$-2′), 101.04 (CH$_2$-7′′′′), 105.43, 108.26, 120.99 (CH-2′′′′, 5′′′′ or 6′′′′), 122.75, 122.94, 124.90, 125.04, 125.38, 126.13, 126.24, 128.44 (CH-aromatic–anthracene), 127.00 (CH-1′′′), 132.66 (CH-2′′′), 131.30, 137.89, 140.58, 143.85, 145.93, 147.16, 147.96 (C$_q$-aromatic), 166.49 (C$_q$-1′′), 169.49 (C$_q$-1′′′′′), 208.87 (C$_q$-1′)</td></tr>
<tr><th colspan="2">Mass spectrometry (ESI-MS)</th></tr>
<tr><td>Molecular weight</td><td><i>m/z</i></td></tr>
<tr><td>Calc. for $C_{40}H_{44}NO_6$</td><td>634.3169 [M+H]$^+$</td></tr>
<tr><td>Lock mass of $C_{33}H_{40}N_2O_9$</td><td>609.2812 [M+H]$^+$</td></tr>
<tr><td>Calc. for $C_{40}H_{43}NO_6Na$</td><td>656.2988 [M+Na]$^+$</td></tr>
<tr><td>Found for $C_{40}H_{43}NO_6Na$</td><td>656.2986 [M+Na]$^+$</td></tr>
</table>

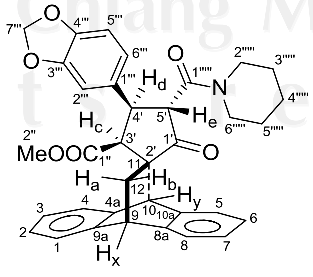
2.7 Syntheses of racemic spirocyclopentanone–anthracene adduct derivatives (±)-116a-*i*, -*ii* – (±)-116d-*i*, -*ii*



2.7.1 Syntheses of 3′-methoxycarbonyl-4′-(3,4-methylenedioxy)phenyl-5′-piperidinecarbonyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-116a-*i* and (±)-116a-*ii*)



According to *general procedure II* in **2.6.1**, anhydrous diisopropylamine (1.9 equiv., 0.8 ml, 5.7 mmol), *n*-butyllithium (1.6 equiv., 3.4 ml, 1.4 N in hexane, 4.7 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.00 g, 3.0 mmol), *α*,*β*-unsaturated amide **113a** (1.2 equiv., 0.92 g, 3.6 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.5:0.5:8.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adduct (±)-**116a**-*i* in 9% yield (0.094 g) and (±)-**116a**-*ii* in 10% yield (0.112 g), 65% conversion from starting material.



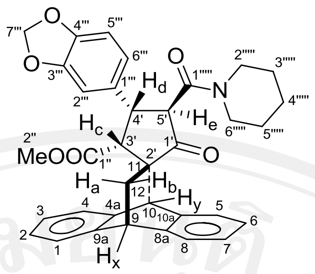
(±)-**116a**-*i*

Table 2.21 Data of spirocyclopentanone–anthracene adduct (±)-**116a**-*i*

Physical properties	
White crystals Melting point (m.p.) 95.2–98.5 °C (CH_2Cl_2/hexane) R_f = 0.48 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1110, 1243	C–O stretching of ester
1490, 1631	C=C aromatic of benzene
1744	C=O stretching of carbonyl
2854, 2927	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.38–1.72	m, 6H, CH_2-3′′′′, 4′′′′, 5′′′′
1.29, 2.25, 4.30	ABX system (J = 12.7, 2.8, 2.5 Hz), 3H, H_a, H_b, H_x
2.92	d (J = 7.0 Hz), 1H, H_c
3.37–3.51	m, 2H, CH_2-2′′′′ or 6′′′′
3.78–3.91	m, 2H, CH_2-2′′′′ or 6′′′′
3.30	s, 3H, COOMe-2′′
4.24	d (J = 10.7 Hz), 1H, H_e
4.93	dd (J =10.8, 7.1 Hz), 1H, H_d
4.90	s, 1H, H_y
5.92	s, 2H, CH_2-7′′′
6.64	dd (J = 8.1, 1.7 Hz), 1H, ArH-5′′′ or 6′′′
6.67	d (J = 1.6 Hz), 1H, ArH-2′′′
6.72	d (J = 8.0 Hz), 1H, ArH-5′′′ or 6′′′

Table 2.21 Data of spirocyclopentanone–anthracene adduct (±)-**116a**-*i* (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
7.00–7.49	m, 8H, ArH–anthracene
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.59, 25.82, 26.55 (CH_2-3⁗, 4⁗ or 5⁗), 36.23 (CH_2-12), 43.61 (CH-4'), 44.08, 47.52 (CH_2-2⁗ or 6⁗), 44.20 (CH-9), 46.92 (CH-10), 51.38 (CH_3-2″), 52.40 (CH-5′), 57.39 (CH-3′), 60.89 (C_q-2′), 101.06 (CH_2-7‴), 107.82, 108.33, 120.23 (CH-2‴, 5‴ or 6‴), 122.83, 123.76, 125.38, 125.46, 125.72, 126.07, 126.55, 126.77 (CH-aromatic–anthracene), 131.97, 138.57, 139.42, 143.46, 144.08, 146.72, 147.92 (C_q-aromatic), 165.38 (C_q-1″), 173.49 (C_q-1⁗), 207.23 (C_q-1′)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{35}H_{34}NO_6$	564.2386 $[M+H]^+$
Lock mass of $C_{28}H_{37}N_5O_7$	556.2771 $[M+H]^+$
Found for $C_{35}H_{34}NO_6$	564.2386 $[M+H]^+$



(±)-**116a**-*ii*

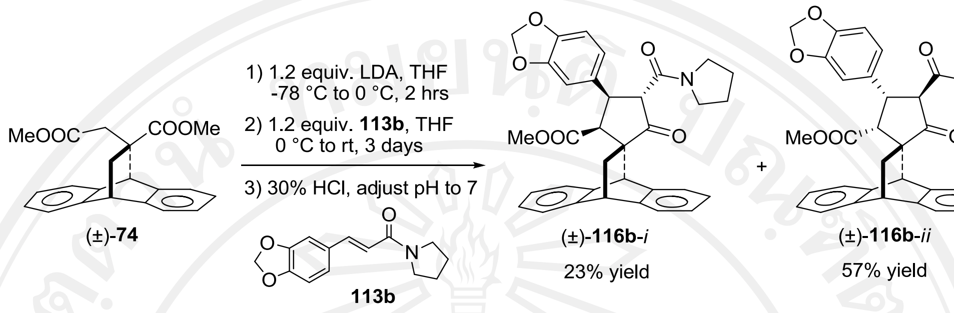
Table 2.22 Data of spirocyclopentanone–anthracene adduct (±)-**116a**-*ii*

Physical properties	
White crystals Melting point (m.p.) 264.5–266.1 °C (CH_2Cl_2/hexane) R_f = 0.35 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1106, 1238	C–O stretching of ester
1490, 1631	C=C aromatic of benzene
1721, 1745	C=O stretching of carbonyl
2855, 2941	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.31–1.74	m, 6H, CH_2-3′′′′, 4′′′′, 5′′′′
1.95, 2.10, 4.35	ABX system (J = 12.8, 3.0, 2.3 Hz), 3H, H_a, H_b, H_x
2.38	d (J = 6.2 Hz), 1H, H_c
3.23–3.33, 3.63–3.71	m, 2H, CH_2-2′′′′ or 6′′′′
3.51–3.62	m, 2H, CH_2-2′′′′ or 6′′′′
3.47	s, 3H, COOMe-2″
4.28–4.41	m, 2H, H_d, H_e

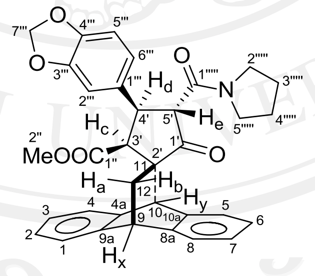
Table 2.22 Data of spirocyclopentanone–anthracene adduct (±)-**116a**-*ii* (continued)

NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
4.44	s, 1H, H_y
5.87	s, 2H, CH_2-7‴
6.53	dd (*J* = 8.1, 1.6 Hz), 1H, ArH-5‴ or 6‴
6.57	d (*J* = 1.6 Hz), 1H, ArH-2‴
6.66	d (*J* = 8.0 Hz), 1H, ArH-5‴ or 6‴
6.93–7.44	m, 8H, ArH–anthracene
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.47, 25.43, 26.61 (CH_2-3⁗, 4⁗ or 5⁗), 41.44 (CH_2-12), 43.36 (CH-4′), 43.51, 47.41 (CH_2-2⁗ or 6⁗), 44.15 (CH-9), 47.82 (CH-10), 51.22 (CH_3-2″), 53.06 (CH-5′), 58.30 (C_q-2′), 59.78 (CH-3′), 100.97 (CH_2-7‴), 107.72, 108.19, 119.94 (CH-2‴, 5‴ or 6‴), 122.50, 123.78, 124.10, 125.50, 125.53, 125.58, 126.40, 126.76 (CH-aromatic–anthracene), 131.05, 140.52, 141.22, 142.93, 143.37, 146.71, 147.79 (C_q-aromatic), 164.98 (C_q-1″), 173.61 (C_q-1⁗), 210.33 (C_q-1′)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{35}H_{34}NO_6$	564.2386 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{35}H_{33}NO_6Na$	586.2206 $[M+Na]^+$
Found for $C_{35}H_{33}NO_6Na$	586.2203 $[M+Na]^+$

2.7.2 Syntheses 3′-methoxycarbonyl-4′-(3,4-methylenedioxy)phenyl-5′-pyrrolidinecarbonyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethano-anthracenes ((±)-116b-*i* and (±)-116b-*ii*)



According to *general procedure II* in **2.6.1** anhydrous diisopropylamine (1.92 equiv., 0.42 ml, 2.97 mmol), *n*-butyllithium (1.6 equiv., 1.77 ml, 1.40 N in hexane, 2.47 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 0.52 g, 1.55 mmol), *α*,*β*-unsaturated amide **113b** (1.2 equiv., 0.46 g, 1.86 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.5:0.5:8.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**116b**-*i* in 23% yield (0.094 g) and (±)-**116b**-*ii* in 57% yield (0.231 g), 47% conversion from the starting material.



(±)-**116b**-*i*

Table 2.23 Data of spirocyclopentanone–anthracene adduct (±)-**116b**-*i*

Physical properties
White crystals Melting point (m.p.) 203.8–205.2 °C (CH_2Cl_2/hexane) R_f = 0.26 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)

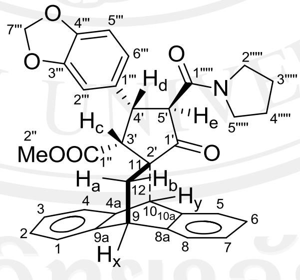
Table 2.23 Data of spirocyclopentanone–anthracene adduct (±)-**116b**-*i* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1037, 1244	C–O stretching of ester
1489, 1504	C=C aromatic of benzene
1635, 1743	C=O stretching of carbonyl
2880, 2952	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.72–2.00	m, 4H, CH_2-3′′′′, 4′′′′
1.30, 2.25, 4.30	ABX system (J = 12.7, 2.8, 2.6 Hz), 3H, H_a, H_b, H_x
2.90	d (J = 7.0 Hz), 1H, H_c
3.29	s, 3H, COOMe-2″
3.38–3.48, 3.96–4.06	m, 2H, CH_2-2′′′′ or 5′′′′
3.48–3.58	m, 2H, CH_2-2′′′′ or 5′′′′
4.10	d (J = 10.9 Hz), 1H, H_e
4.84	dd (J = 10.2, 7.1 Hz), 1H, H_d
4.99	s, 1H, H_y
5.92	s, 2H, CH_2-7‴
6.66	d (J = 8.1 Hz), 1H, ArH-5‴ or 6‴
6.68	s, 1H, ArH-2‴
6.73	d (J = 7.9 Hz), 1H, ArH-5‴ or 6‴
7.00–7.50	m, 8H, ArH–anthracene

Table 2.23 Data of spirocyclopentanone–anthracene adduct (±)-**116b**-*i* (continued)

NMR spectroscopy
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)
24.35, 25.75 (CH$_2$-3⁗ or 4⁗), 36.46 (CH$_2$-12), 43.56 (CH-4′), 44.16 (CH-9), 46.31, 47.07 (CH$_2$-2⁗ or 5⁗), 46.69 (CH-10), 51.36 (CH$_3$-2″), 54.85 (CH-5′), 57.76 (CH-3′), 60.77 (C$_q$-2′), 101.07 (CH$_2$-7‴), 107.82, 108.33, 120.28 (CH-2‴, 5‴ or 6‴), 122.67, 123.79, 125.40, 125.59, 125.79, 126.05, 126.47, 126.72 (CH-aromatic–anthracene), 131.73, 138.50, 139.51, 143.53, 144.02, 146.76, 147.90 (C$_q$-aromatic), 166.03 (C$_q$-1″), 173.41 (C$_q$-1⁗), 208.00 (C$_q$-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{34}H_{32}NO_6$	550.2229 $[M+H]^+$
Lock mass of $C_{28}H_{37}N_5O_7Na$	578.2591 $[M+Na]^+$
Calc. for $C_{34}H_{31}NO_6Na$	572.2049 $[M+Na]^+$
Found for $C_{34}H_{31}NO_6Na$	572.2051 $[M+Na]^+$



(±)-**116b**-*ii*

Table 2.24 Data of spirocyclopentanone–anthracene adduct (±)-**116b**-*ii*

Physical properties
White crystals Melting point (m.p.) 254.4–256.3 °C (CH$_2$Cl$_2$/hexane) R_f = 0.15 (EtOAc/CH$_2$Cl$_2$/hexane, 1.5:0.5:8.0)

Table 2.24 Data of spirocyclopentanone–anthracene adduct (±)-**116b**-*ii* (continued)

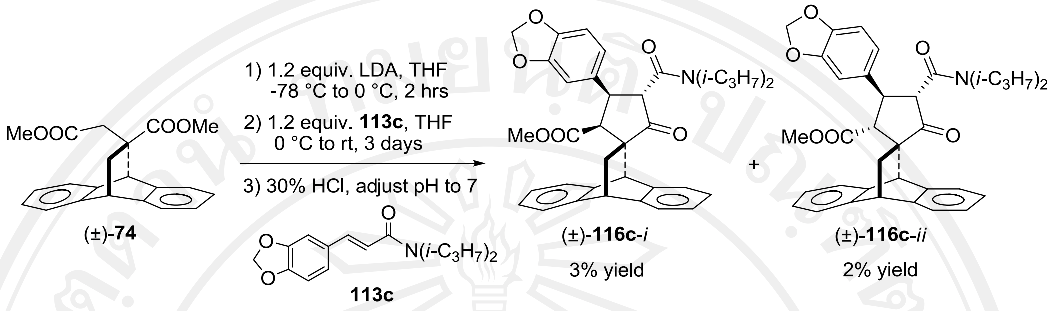
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1038, 1255	C–O stretching of ester
1435, 1490	C=C aromatic of benzene
1640, 1744	C=O stretching of carbonyl
2879, 2950	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.64–1.96	m, 4H, CH_2-3′′′′, 4′′′′
1.99, 2.19, 4.40	ABX system (*J* = 12.8, 3.0, 2.3 Hz), 3H, H_a, H_b, H_x
2.41	d (*J* = 6.7 Hz), 1H, H_c
3.25–3.39	m, 2H, CH_2-2′′′′ or 5′′′′
3.39–3.49, 3.94–4.09	m, 2H, CH_2-2′′′′ or 5′′′′
3.51	s, 3H, COOMe-2′′
4.20	d (*J* = 12.0 Hz), 1H, H_e
4.35	dd (*J* = 12.0, 6.6 Hz), 1H, H_d
4.48	s, 1H, H_y
5.88	s, 2H, CH_2-7′′′
6.58	dd (*J* = 8.1, 1.6 Hz), 1H, ArH-5′′′ or 6′′′
6.62	d (*J* = 1.6 Hz), 1H, ArH-2′′′
6.69	d (*J* = 8.0 Hz), 1H, ArH-5′′′ or 6′′′
6.94–7.51	m, 8H, ArH–anthracene

Table 2.24 Data of spirocyclopentanone–anthracene adduct (±)-**116b**-*ii* (continued)

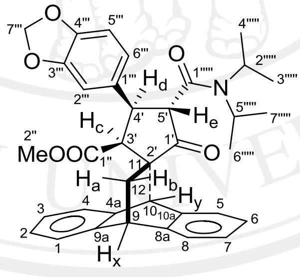
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)
24.12, 25.60 (CH_2-3′′′′ or 4′′′′), 41.19 (CH_2-12), 42.96 (CH-4′), 44.03 (CH-9), 45.95, 46.72 (CH_2-2′′′′ or 5′′′′), 47.68 (CH-10), 51.14 (CH_3-2′′), 55.64 (CH-5′), 58.38 (C_q-2′), 59.78 (CH-3′), 100.90 (CH_2-7′′′), 107.64, 108.11, 120.11 (CH-2′′′, 5′′′ or 6′′′), 122.49, 123.66, 123.99, 125.36, 125.46, 125.75, 126.30, 126.59 (CH-aromatic–anthracene), 130.87, 140.48, 141.04, 142.88, 143.25, 146.66, 147.69 (C_q-aromatic), 165.24 (C_q-1′′), 173.42 (C_q-1′′′′), 210.77 (C_q-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{34}H_{32}NO_6$	550.2229 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{34}H_{31}NO_6Na$	572.2049 $[M+Na]^+$
Found for $C_{34}H_{31}NO_6Na$	572.2048 $[M+Na]^+$

2.7.3 Syntheses of 5′-(*N*,*N*-diisopropylcarboxamid-1-yl)-3′-methoxycarbonyl-4′-(3,4-methylenedioxy)phenyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-116c-*i* and (±)-116c-*ii*)



According to *general procedure II* in **2.6.1** anhydrous diisopropyl-amine (1.68 equiv., 1.06 ml, 7.49 mmol), *n*-butyllithium (1.4 equiv., 4.66 ml, 1.34 N in hexane, 6.24 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.50 g, 4.46 mmol), *α*,*β*-unsaturated amide **113c** (1.2 equiv., 1.47 g, 5.35 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.0:0.5:8.5) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**116c**-*i* in 3% yield (0.044 g) and (±)-**116c**-*ii* in 2% yield (0.036 g), 59% conversion from the starting material.



(±)-**116c**-*i*

Table 2.25 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*i*

Physical properties
White crystals Melting point (m.p.) 112.2–115.0 °C (CH_2Cl_2/hexane) R_f = 0.33 (EtOAc/CH_2Cl_2/hexane, 1.0:0.5:8.5)

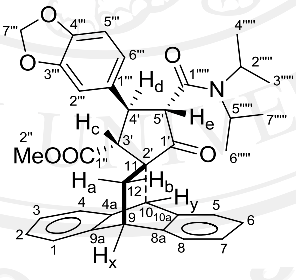
Table 2.25 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*i* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1039, 1235	C–O stretching of ester
1441, 1489	C=C aromatic of benzene
1635, 1739	C=O stretching of carbonyl
2932, 2965	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (*δ*, ppm)	Type of proton
1.14	d (J = 6.7 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.23	d (J = 6.4 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.40	d (J = 6.7 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.50	d (J = 6.7 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.29, 2.23, 4.30	ABX system (J = 12.8, 2.5, 2.4 Hz), 3H, H$_a$, H$_b$, H$_x$
2.94	d (J = 7.0 Hz), 1H, H$_c$
3.30	s, 3H, COOMe-2′′
3.49	hept (J = 6.5 Hz), 1H, CH-2′′′′ or 5′′′′
4.54	hept (J = 6.5 Hz), 1H, CH-2′′′′ or 5′′′′
4.20	d (J = 10.5 Hz), 1H, H$_e$
4.94	s, 1H, H$_y$
4.98	dd (J = 10.5, 7.0 Hz), 1H, H$_d$
5.92	s, 2H, CH$_2$-7′′′
6.63	d (J = 8.1 Hz), 1H, ArH-5′′′ or 6′′′
6.66	s, 1H, ArH-2′′′
6.72	d (J = 8.0 Hz), 1H, ArH-5′′′ or 6′′′
6.96–7.50	m, 8H, ArH–anthracene

Table 2.25 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*i* (continued)

NMR spectroscopy
^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)
20.35, 20.75, 20.81, 21.03 (CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′), 36.06 (CH$_2$-12), 43.20 (CH-4'), 44.20 (CH-9), 46.47, 46.75 (CH-2′′′′ or 5′′′′), 49.45 (CH-10), 51.37 (CH$_3$-2′′), 53.81 (CH-5′), 56.97 (CH-3′), 60.93 (C$_q$-2′), 101.03 (CH$_2$-7′′′), 107.67, 108.25, 119.82 (CH-2′′′, 5′′′ or 6′′′), 122.83, 123.72, 125.45, 125.48, 125.57, 126.06, 126.53, 126.72 (CH-aromatic–anthracene), 132.44, 138.61, 139.45, 143.45, 144.13, 146.57, 147.92 (C$_q$-aromatic), 165.66 (C$_q$-1′′), 173.69 (C$_q$-1′′′′), 207.28 (C$_q$-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{36}H_{38}NO_6$	580.2699 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{36}H_{37}NO_6Na$	602.2519 $[M+Na]^+$
Found for $C_{36}H_{37}NO_6Na$	602.2518 $[M+Na]^+$



(±)-**116c**-*ii*

Table 2.26 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*ii*

Physical properties
White crystals
Melting point (m.p.) 170.1–173.9 °C (CH$_2$Cl$_2$/hexane)
R_f = 0.30 (EtOAc/CH$_2$Cl$_2$/hexane, 1.0:0.5:8.5)

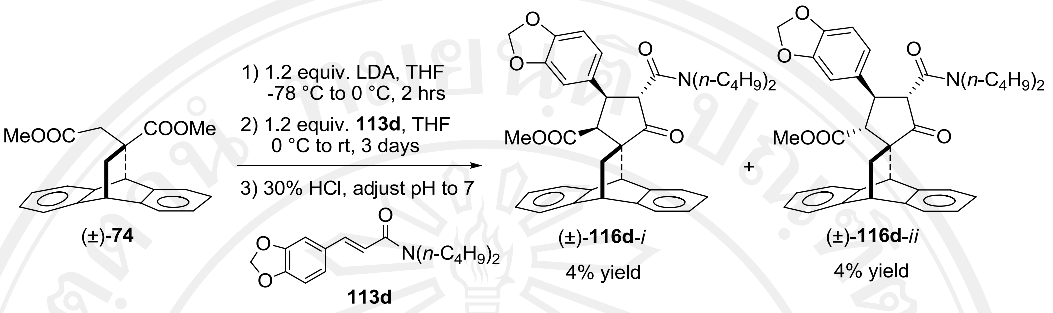
Table 2.26 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*ii* (continued)

IR spectroscopy (evaporated thin film)	
$\nu_{\max}$ (cm^{-1})	Type of vibration
1041, 1247	C–O stretching of ester
1442, 1492	C=C aromatic of benzene
1633, 1746	C=O stretching of carbonyl
2930, 2967	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.89	d (*J* = 6.8Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.05	d (*J* = 6.5 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.43	d (*J* = 6.7 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.50	d (*J* = 6.8 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
2.14, 2.35, 4.32	ABX system (*J* = 12.3, 3.1, 2.5 Hz), 3H, H_a, H_b, H_x
2.89	s, 3H, COOMe-2″
2.93	d (*J* = 12.7 Hz), 1H, H_c
3.39–3.52	m, 1H, CH-2′′′′ or 5′′′′
4.08–4.21	m, 1H, CH-2′′′′ or 5′′′′
3.43	d (*J* = 9.7 Hz), 1H, H_e
5.02–5.10	m, 1H, H_d
5.08	s, 1H, H_y
5.91	s, 2H, CH_2-7‴
6.71–6.75	m, 3H, ArH-2‴, 5‴, 6‴
6.92–7.33	m, 8H, ArH–anthracene

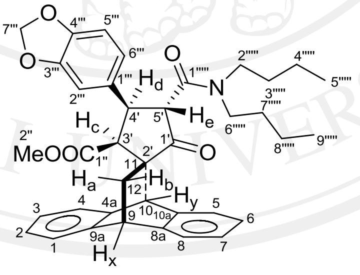
Table 2.26 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*ii* (continued)

<table>
<tr><th colspan="2">^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)</th></tr>
<tr><td colspan="2">20.56, 20.68, 20.71, 20.74 (CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′), 35.51 (CH$_2$-12), 43.09 (CH-4′), 44.30 (CH-9), 44.77 (CH-10), 46.54, 49.17 (CH-2′′′′ or 5′′′′), 51.37 (CH$_3$-2′′), 54.03 (CH-3′), 59.45 (C$_q$-2′), 59.83 (CH-5′), 100.97 (CH$_2$-7′′′), 107.58, 108.47, 120.29 (CH-2′′′, 5′′′ or 6′′′), 122.70, 123.11 124.89, 124.93, 125.34, 126.20, 126.25, 128.41 (CH-aromatic–anthracene), 135.36, 137.88, 140.68, 143.80, 145.98, 146.45, 147.89 (C$_q$-aromatic), 165.17 (C$_q$-1′′), 169.46 (C$_q$-1′′′′), 208.43 (C$_q$-1′)</td></tr>
<tr><th colspan="2">Mass spectrometry (ESI-MS)</th></tr>
<tr><th>Molecular weight</th><th><i>m/z</i></th></tr>
<tr><td>Calc. for $C_{36}H_{38}NO_6$</td><td>580.2699 [M+H]$^+$</td></tr>
<tr><td>Lock mass of $C_{33}H_{40}N_2O_9$</td><td>609.2812 [M+H]$^+$</td></tr>
<tr><td>Calc. for $C_{36}H_{37}NO_6Na$</td><td>602.2519 [M+Na]$^+$</td></tr>
<tr><td>Found for $C_{36}H_{37}NO_6Na$</td><td>602.2519 [M+Na]$^+$</td></tr>
</table>

2.7.4 Syntheses of 5′-(*N*,*N*-dibutylcarboxamid-1-yl)-3′-methoxycarbonyl-4′-(3,4-methylenedioxy)phenyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-116d-*i* and (±)-116d-*ii*)



According to *general procedure II* in **2.6.1**, anhydrous diisopropylamine (1.68 equiv., 1.06 ml, 7.49 mmol), *n*-butyllithium (1.4 equiv., 4.74 ml, 1.32 N in hexane, 6.24 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.50 g, 4.46 mmol), *α*,*β*-unsaturated amide **113d** (1.2 equiv., 1.62 g, 5.35 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (0.5:0.5:9.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**116d**-*i* in 4% yield (0.061 g) and (±)-**116d**-*ii* in 4% yield (0.056 g), 55% conversion from the starting material.



(±)-**116d**-*i*

Table 2.27 Data of spirocyclopentanone–anthracene adduct (±)-**116d**-*i*

Physical properties
White crystals Melting point (m.p.) 82.5–85.1 °C (CH_2Cl_2/hexane) R_f = 0.41 (EtOAc/CH_2Cl_2/hexane, 0.5:0.5:9.0)

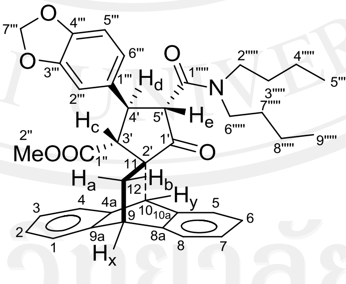
Table 2.27 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*i* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1038, 1244	C–O stretching of ester
1489	C=C aromatic of benzene
1634, 1744	C=O stretching of carbonyl
2872, 2956	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.89	t (J = 7.3 Hz), 3H, CH_3-5′′′′ or 9′′′′
0.96	t (J = 7.3 Hz), 3H, CH_3-5′′′′ or 9′′′′
1.18–1.65	m, 8H, CH_2-3′′′′, 4′′′′, 7′′′′, 8′′′′
1.31, 2.25, 4.30	ABX system (J = 12.7, 2.5, 2.4 Hz), 3H, H_a, H_b, H_x
2.90	d (J = 6.9 Hz), 1H, H_c
3.32	s, 3H, COOMe-2′′
2.93–3.03, 3.69–3.80	m, 2H, CH_2-2′′′′ or 6′′′′
3.04–3.15, 3.79–3.90	m, 2H, CH_2-2′′′′ or 6′′′′
4.18	d (J = 10.8 Hz), 1H, H_e
4.87	dd (J = 10.8, 6.9 Hz), 1H, H_d
4.96	s, 1H, H_y
5.91	d (J = 1.6 Hz), 2H, CH_2-7′′′
6.67	dd (J = 8.1, 1.2 Hz), 1H, ArH-5′′′ or 6′′′
6.70	d (J = 1.6 Hz), 1H, ArH-2′′′
6.72	d (J = 8.0 Hz), 1H, ArH-5′′′ or 6′′′
6.96–7.49	m, 8H, ArH–anthracene

Table 2.27 Data of spirocyclopentanone–anthracene adduct (±)-**116c**-*i* (continued)

^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)
13.80, 14.05 (CH$_3$-5′′′′ or 9′′′′), 20.09, 20.13 (CH$_2$-4′′′′ or 8′′′′), 29.87, 31.40 (CH$_2$-3′′′′ or 7′′′′), 36.56 (CH$_2$-12), 44.05 (CH-4′), 44.21 (CH-9), 46.52, 47.64 (CH$_2$-2′′′′ or 6′′′′), 46.90 (CH-10), 51.42 (CH$_3$-2′′), 53.14 (CH-5′), 57.69 (CH-3′), 60.83 (C$_q$-2′), 101.11 (CH$_2$-7′′′), 108.02, 108.30, 120.45 (CH-2′′′, 5′′′ or 6′′′), 122.77, 123.81, 125.44, 125.61(2), 126.09, 126.58, 126.76 (CH-aromatic–anthracene), 131.86, 138.52, 139.52, 143.55, 144.08, 146.84, 147.96 (C$_q$-aromatic), 167.05 (C$_q$-1′′), 173.66 (C$_q$-1′′′′), 207.66 (C$_q$-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{38}H_{42}NO_6$	608.3012 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{38}H_{41}NO_6Na$	630.2832 $[M+Na]^+$
Found for $C_{38}H_{41}NO_6Na$	630.2832 $[M+Na]^+$



(±)-**116d**-*ii*

Table 2.28 Data of spirocyclopentanone–anthracene adduct (±)-**116d**-*ii*

Physical properties
White crystals Melting point (m.p.) 172.3–173.7 °C (CH_2Cl_2/hexane) R_f = 0.35 (EtOAc/CH_2Cl_2/hexane, 0.5:0.5:9.0)

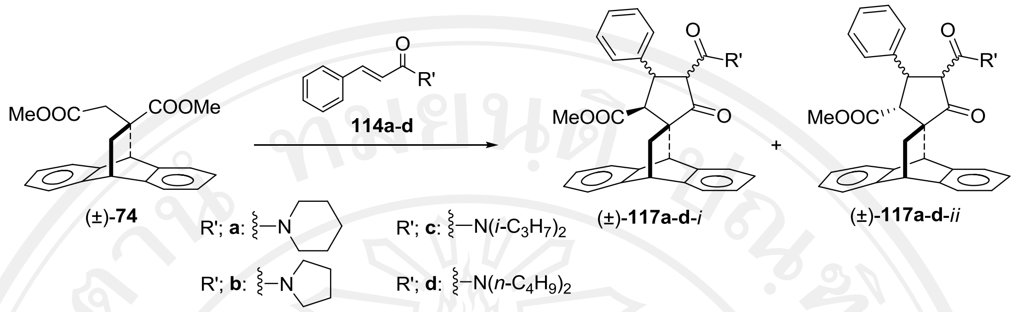
Table 2.28 Data of spirocyclopentanone–anthracene adduct (±)-**116d**-*ii* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1037, 1251	C–O stretching of ester
1443, 1489	C=C aromatic of benzene
1637, 1739	C=O stretching of carbonyl
2872, 2956	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.71	t (J = 7.1 Hz), 3H, CH_3-5′′′′ or 9′′′′
0.96	t (J = 7.3 Hz), 3H, CH_3-5′′′′ or 9′′′′
0.92–1.51	m, 8H, CH_2-3′′′′, 4′′′′, 7′′′′, 8′′′′
2.16, 2.35, 4.32	ABX system (J = 12.2, 3.0, 2.5 Hz), 3H, H_a, H_b, H_x
2.86	s, 3H, COOMe-2′′
2.95	d (J = 12.6 Hz), 1H, H_c
2.79–2.91, 3.34–3.49	m, 2H, CH_2-2′′′′ or 6′′′′
2.98–3.08, 3.57–3.71	m, 2H, CH_2-2′′′′ or 6′′′′
3.44	d (J = 10.1 Hz), 1H, H_e
4.88	dd (J = 12.6, 10.1 Hz), 1H, H_d
5.12	s, 1H, H_y
5.90	s, 2H, CH_2-7′′′
6.71	d (J = 8.4 Hz), 1H, ArH-5′′′ or 6′′′
6.73–6.79	m, 2H, ArH-2′′′, 5′′′ or 6′′′
6.92–7.35	m, 8H, ArH–anthracene

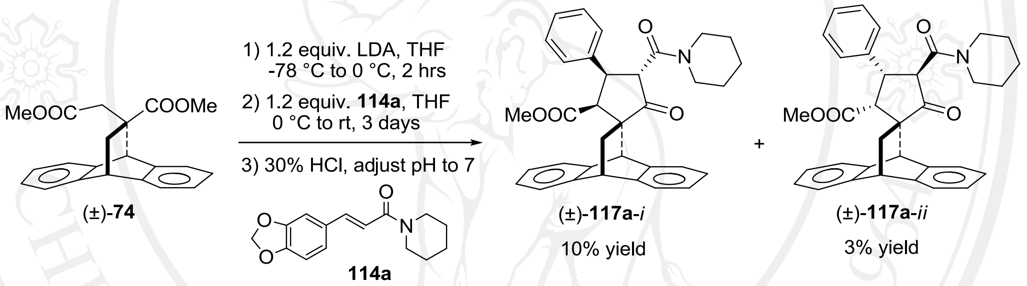
Table 2.28 Data of spirocyclopentanone–anthracene adduct (±)-**116d**-*ii* (continued)

NMR spectroscopy	
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
13.70, 14.02 (CH_3-5′′′′ or 9′′′′), 19.82, 20.07 (CH_2-4′′′′ or 8′′′′), 29.95, 31.39 (CH_2-3′′′′ or 7′′′′), 35.96 (CH_2-12), 43.98 (CH-4′), 44.30 (CH-9), 44.78 (CH-10), 46.61, 47.81 (CH_2-2′′′′ or 6′′′′), 51.38 (CH_3-2′′), 54.87 (CH-3′), 58.75 (CH-5′), 59.13 (C_q-2′), 101.01 (CH_2-7′′′), 107.80, 108.46, 120.62 (CH-2′′′, 5′′′ or 6′′′), 122.77, 122.94, 124.92, 125.10, 125.39, 126.14, 126.25, 128.40 (CH-aromatic–anthracene), 134.73, 137.90, 140.56, 143.89, 145.93, 146.59, 147.88 (C_q-aromatic), 166.74 (C_q-1′′), 169.36 (C_q-1′′′′), 208.76 (C_q-1′)	
Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{38}H_{42}NO_6$	608.3012 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{38}H_{41}NO_6Na$	630.2832 $[M+Na]^+$
Found for $C_{38}H_{41}NO_6Na$	630.2832 $[M+Na]^+$

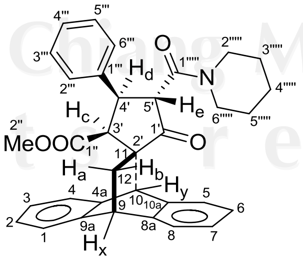
2.8 Syntheses of racemic spirocyclopentanone–anthracene adduct derivatives (±)-117a-*i*, -*ii* – (±)-117d-*i*, -*ii*



2.8.1 Syntheses of 3′-methoxycarbonyl-4′-phenyl-5′-piperidinecarbonyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-117a-*i* and (±)-117a-*ii*)



According to *general procedure II* in **2.6.1** anhydrous diisopropyl-amine (1.9 equiv., 0.8 ml, 5.7 mmol), *n*-butyllithium (1.6 equiv., 3.4 ml, 1.4 N in hexane, 4.7 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.00 g, 3.0 mmol), *α*,*β*-unsaturated amide **114a** (1.2 equiv., 0.77 g, 3.6 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.5:0.5:8.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**117a**-*i* in 10% yield (0.109 g) and (±)-**117a**-*ii* in 3% yield (0.031 g), 68% conversion from the starting material.



(±)-**117a**-*i*

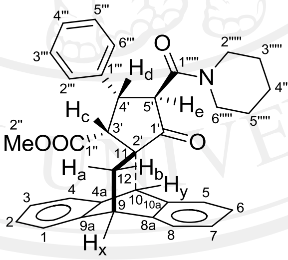
Table 2.29 Data of spirocyclopentanone–anthracene adduct (±)-**117a**-*i*

Physical properties	
White crystals Melting point (m.p.) 206.5–209.4 °C (CH_2Cl_2/hexane) R_f = 0.62 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1130, 1265	C–O stretching of ester
1439, 1631	C=C aromatic of benzene
1745	C=O stretching of carbonyl
2856, 2938	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.48–1.76	m, 6H, CH_2-3′′′′, 4′′′′, 5′′′′
1.31, 2.26, 4.31	ABX system (J = 12.8, 2.8, 2.5 Hz), 3H, H_a, H_b, H_x
2.99	d (J = 7.1 Hz), 1H, H_c
3.21	s, 3H, COOMe-2′′
3.37–3.52	m, 2H, CH_2-2′′′′ or 6′′′′
3.77–3.89	m, 2H, CH_2-2′′′′ or 6′′′′
4.35	d (J = 10.6 Hz), 1H, H_e
4.96	s, 1H, H_y
5.03	dd (J = 10.5, 7.1 Hz), 1H, H_d
6.97–7.53	m, 13H, ArH

Table 2.29 Data of spirocyclopentanone–anthracene adduct (±)-**117a**-*i* (continued)

^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)
24.53, 25.77, 26.48 (CH_2-3′′′′, 4′′′′ or 5′′′′), 36.18 (CH_2-12), 43.83 (CH-4′), 44.00, 47.47 (CH_2-2′′′′ or 6′′′′), 44.15 (CH-9), 46.83 (CH-10), 51.21 (CH_3-2′′), 51.85 (CH-5'), 57.27 (CH-3′), 60.80 (C_q-2′), 122.79, 123.72, 125.35, 125.43, 125.67, 126.01, 126.49, 126.71, 127.15(2), 127.26, 128.58(2) (CH-aromatic), 138.11, 138.56, 139.42, 143.43, 144.07 (C_q-aromatic), 165.45 (C_q-1′′), 173.43 (C_q-1′′′), 207.31 (C_q-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{34}H_{34}NO_4$	520.2488 $[M+H]^+$
Lock mass of $C_{28}H_{37}N_5O_7$	556.2771 $[M+H]^+$
Calc. for $C_{34}H_{33}NO_4Na$	542.2307 $[M+Na]^+$
Found for $C_{34}H_{33}NO_4Na$	542.2305 $[M+Na]^+$



(±)-**117a**-*ii*

Table 2.30 Data of spirocyclopentanone–anthracene adduct (±)-**117a**-*ii*

Physical properties
White crystals Melting point (m.p.) 248.5–250.4 °C (CH_2Cl_2/hexane) R_f = 0.48 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)

Table 2.30 Data of spirocyclopentanone–anthracene adduct (±)-**117a**-*ii* (continued)

IR spectroscopy (evaporated thin film)

ν_{max} (cm^{-1})	Type of vibration
1132, 1267	C–O stretching of ester
1362	C–H bending of CH_3
1441, 1633	C=C aromatic of benzene
1747	C=O stretching of carbonyl
2858, 2940	C–H stretching

NMR spectroscopy

^{1}H-NMR (400 MHz) in $CDCl_3$

Chemical shift (*δ*, ppm)	Type of proton
1.28–1.77	m, 6H, CH_2-4′′′′, 5′′′′, 6′′′′
1.99, 2.14, 4.38	ABX system (*J* = 12.8, 3.1, 2.5 Hz), 3H, H_a, H_b, H_x
2.44	d (*J* = 6.3 Hz), 1H, H_c
3.21–3.31, 3.65–3.75	m, 2H, CH_2-2′′′′ or 6′′′′
3.52–3.63	m, 2H, CH_2-2′′′′ or 6′′′′
3.38	s, 3H, COOMe-2′′
4.42	dd (*J* = 6.3, 12.0 Hz), 1H, H_d
4.46	s, 1H, H_y
4.48	d (*J* = 12.0 Hz), 1H, H_e
6.91–7.45	m, 13H, Ar-H

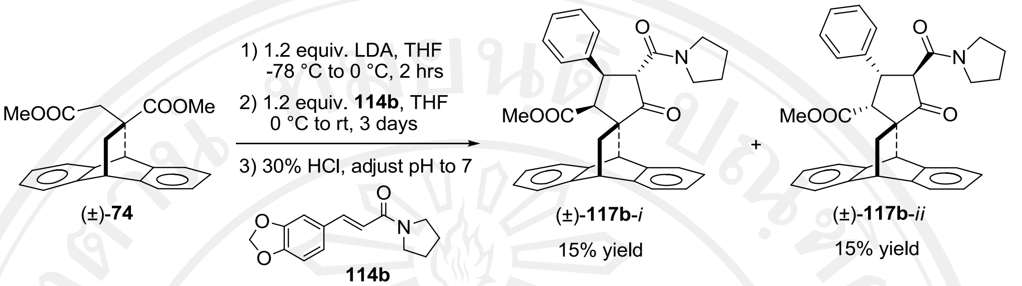
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)

24.49, 25.45, 26.62 (CH_2-4′′′′, 5′′′′ or 6′′′′), 41.43 (CH_2-12), 43.51, 47.45 (CH_2-3′′′′ or 7′′′′), 43.63 (CH-4′), 44.20 (CH-9), 47.83 (CH-10), 51.06 (CH_3-2′′), 52.61 (CH-5′), 58.32 (C_q-2′), 59.77 (CH-3′), 122.52, 123.79, 124.11, 125.51, 125.55, 125.82, 126.39, 126.79, 127.04(2), 127.32, 128.48(2) (CH-aromatic), 137.23, 140.56, 141.27, 142.99, 143.41 (C_q-aromatic), 165.13 (C_q-1′′), 173.58 (C_q-1′′′′), 210.49 (C_q-1′)

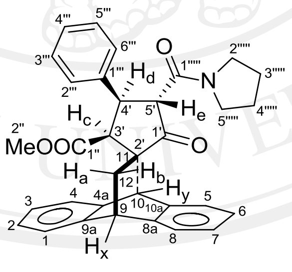
Table 2.30 Data of spirocyclopentanone–anthracene adduct (±)-**117a**-*ii* (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{34}H_{34}NO_4$	520.2488 $[M+H]^+$
Lock mass of $C_{28}H_{37}N_5O_7$	578.2591 $[M+Na]^+$
Calc. for $C_{34}H_{33}NO_4Na$	542.2307 $[M+Na]^+$
Found for $C_{34}H_{33}NO_4Na$	542.2305 $[M+Na]^+$

2.8.2 Syntheses of 3′-methoxycarbonyl-4′-phenyl-5′-pyrrolidinecarbonyl-1′-cyclo-pentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-117b-*i* and (±)-117b-*ii*)



According to *general procedure II* in **2.6.1** anhydrous diisopropylamine (1.92 equiv., 0.40 ml, 2.85 mmol), *n*-butyllithium (1.6 equiv., 1.70 ml, 1.40 N in hexane, 2.38 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 0.50 g, 1.49 mmol), *α*,*β*-unsaturated amide **114b** (1.2 equiv., 0.36 g, 1.78 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.5:0.5:8.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**117b**-*i* in 15% yield (0.090 g) and (±)-**117b**-*ii* in 15% yield (0.090 g), 79% conversion from the starting material.



(±)-**117b**-*i*

Table 2.31 Data of spirocyclopentanone–anthracene adduct (±)-**117b**-*i*

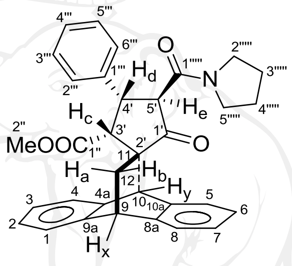
Physical properties
White crystals Melting point (m.p.) 204.4–205.7 °C (CH_2Cl_2/hexane) R_f = 0.39 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)

Table 2.31 Data of spirocyclopentanone–anthracene adduct (±)-**117b**-*i* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1176	C–O stretching of ester
1434, 1497	C=C aromatic of benzene
1636, 1744	C=O stretching of carbonyl
2878, 2952	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.65–2.06	m, 4H, CH_2-3′′′′, 4′′′′
1.31, 2.26, 4.30	ABX system (J = 12.8, 2.8, 2.3 Hz), 3H, H_a, H_b, H_x
2.96	d (J = 7.0 Hz), 1H, H_c
3.40–3.47, 3.98–4.08	m, 2H, CH_2-2′′′′ or 5′′′′
3.47–3.53	m, 2H, CH_2-2′′′′ or 5′′′′
3.20	s, 3H, COOMe-2′′
4.21	d (J = 10.8 Hz), 1H, H_e
4.93	dd (J = 10.7, 7.0 Hz), 1H, H_d
5.05	s, 1H, H_y
7.00–7.54	m, 13H, ArH
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
24.34, 25.74 (CH_2-3′′′′ or 4′′′′), 36.44 (CH_2-12), 43.80 (CH-4′), 44.17 (CH-9), 46.28, 47.05 (CH_2-2′′′′ or 5′′′′), 46.64 (CH-10), 51.20 (CH_3-2′′), 54.32 (CH-5′), 57.69 (CH-3′), 60.73 (C_q-2′), 122.65, 123.77, 125.41, 125.59, 125.77, 126.02, 126.45, 126.69, 127.23(2), 127.33, 128.61(2) (CH-aromatic), 137.96, 138.54, 139.55, 143.53, 144.05 (C_q-aromatic), 166.11 (C_q-1′′), 173.37 (C_q-1′′′′), 208.09 (C_q-1′)	

Table 2.31 Data of spirocyclopentanone–anthracene adduct (±)-**117b**-*i* (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{33}H_{32}NO_4$	506.2331 $[M+H]^+$
Lock mass of $C_{28}H_{37}N_5O_7$	556.2771 $[M+H]^+$
Calc. for $C_{33}H_{31}NO_4Na$	528.2151 $[M+Na]^+$
Found for $C_{33}H_{31}NO_4Na$	528.2154 $[M+Na]^+$



(±)-**117b**-*ii*

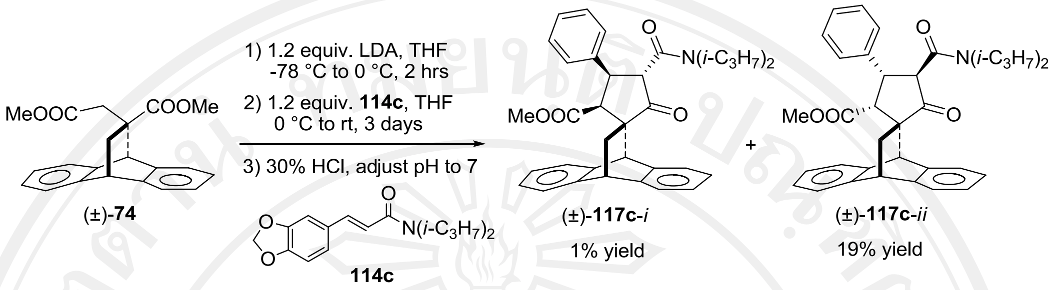
Table 2.32 Data of spirocyclopentanone–anthracene adduct (±)-**117b**-*ii*

Physical properties	
White crystals Melting point (m.p.) 263.1–267.3 °C (CH_2Cl_2/hexane) R_f = 0.26 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)	
IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1175	C–O stretching of ester
1497	C=C aromatic of benzene
1638, 1745	C=O stretching of carbonyl
2875, 2950	C–H stretching

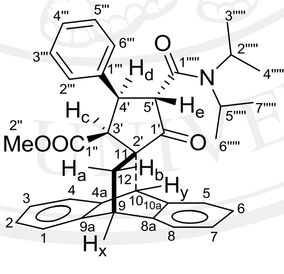
Table 2.32 Data of spirocyclopentanone–anthracene adduct (±)-**117b**-*ii* (continued)

<table>
<tr><th colspan="2">NMR spectroscopy</th></tr>
<tr><td colspan="2">^{1}H-NMR (400 MHz) in $CDCl_3$</td></tr>
<tr><td>Chemical shift (δ, ppm)</td><td>Type of proton</td></tr>
<tr><td>1.68–1.97</td><td>m, 4H, CH_2-3′′′′, 4′′′′</td></tr>
<tr><td>2.00, 2.19, 4.39</td><td>ABX system (J = 12.9, 3.0, 2.4 Hz), 3H, H_a, H_b, H_x</td></tr>
<tr><td>2.43</td><td>d (J = 6.7 Hz), 1H, H_c</td></tr>
<tr><td>3.28–3.33</td><td>m, 2H, CH_2-2′′′′ or 5′′′′</td></tr>
<tr><td>3.41–3.49, 3.97–4.08</td><td>m, 2H, CH_2-2′′′′ or 5′′′′</td></tr>
<tr><td>3.39</td><td>s, 3H, COOMe-2′′</td></tr>
<tr><td>4.27</td><td>d (J = 11.9 Hz), 1H, H_e</td></tr>
<tr><td>4.41</td><td>dd (J = 10.8, 5.5 Hz), 1H, H_d</td></tr>
<tr><td>4.45</td><td>s, 1H, H_y</td></tr>
<tr><td>6.92–7.48</td><td>m, 13H, ArH</td></tr>
<tr><td colspan="2">^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)</td></tr>
<tr><td colspan="2">24.28, 25.77 (CH_2-3′′′′ or 4′′′′), 41.31 (CH_2-12), 43.35 (CH-4′), 44.22 (CH-9), 46.05, 46.87 (CH_2-2′′′′ or 5′′′′), 47.81 (CH-10), 51.08 (CH_3-2′′), 55.29 (CH-5′), 58.51 (C_q-2′), 59.91 (CH-3′), 122.63, 123.78, 124.12, 125.49, 125.60, 125.89, 126.42, 126.74, 127.22(2), 127.38, 128.50(2) (CH-aromatic), 137.22, 140.63, 141.22, 143.05, 143.40 (C_q-aromatic), 165.48 (C_q-1′′), 173.52 (C_q-1′′′′), 211.07 (C_q-1′)</td></tr>
<tr><td colspan="2">Mass spectrometry (ESI-MS)</td></tr>
<tr><td>Molecular weight</td><td><i>m/z</i></td></tr>
<tr><td>Calc. for $C_{33}H_{32}NO_4$</td><td>506.2331 $[M+H]^+$</td></tr>
<tr><td>Lock mass of $C_{32}H_{41}NO_2$</td><td>472.3215 $[M+H]^+$</td></tr>
<tr><td>Calc. for $C_{33}H_{31}NO_4Na$</td><td>528.2151 $[M+Na]^+$</td></tr>
<tr><td>Found for $C_{33}H_{31}NO_4Na$</td><td>528.2153 $[M+Na]^+$</td></tr>
</table>

2.8.3 Syntheses of 5′-(*N*,*N*-diisopropylcarboxamid-1-yl)-3′-methoxycarbonyl-4′-phenyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-117c-*i* and (±)-117c-*ii*)



According to *general procedure II* in **2.6.1** anhydrous diisopropyl-amine (1.68 equiv., 0.71 ml, 4.99 mmol), *n*-butyllithium (1.40 equiv., 3.16 ml, 1.32 N in hexane, 4.16 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.00 g, 2.97 mmol), *α*,*β*-unsaturated amide **114c** (1.2 equiv., 0.82 g, 3.57 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.0:0.5:8.5) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**117c**-*i* in 1% yield (0.016 g) and (±)-**117c**-*ii* in 19% yield (0.228 g), 75% conversion from the starting material.



(±)-**117c**-*i*

Table 2.33 Data of spirocyclopentanone–anthracene adduct (±)-**117c**-*i*

Physical properties
White crystals
Melting point (m.p.) 98.5–101.9 °C (CH_2Cl_2/hexane)
R_f = 0.47 (EtOAc/CH_2Cl_2/hexane, 1.0:0.5:8.5)

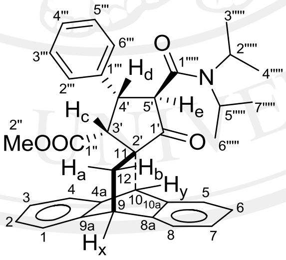
Table 2.33 Data of spirocyclopentanone–anthracene adduct (±)-**117c**-*i* (continued)

<table>
<tr><th colspan="2">IR spectroscopy (evaporated thin film)</th></tr>
<tr><th>ν_{max} (cm^{-1})</th><th>Type of vibration</th></tr>
<tr><td>1198, 1329</td><td>C–O stretching of ester</td></tr>
<tr><td>1437, 1458</td><td>C=C aromatic of benzene</td></tr>
<tr><td>1632, 1743</td><td>C=O stretching of carbonyl</td></tr>
<tr><td>2851, 2926</td><td>C–H stretching</td></tr>
<tr><th colspan="2">NMR spectroscopy</th></tr>
<tr><th colspan="2">^{1}H-NMR (400 MHz) in CDCl$_3$</th></tr>
<tr><th>Chemical shift (δ, ppm)</th><th>Type of proton</th></tr>
<tr><td>1.14</td><td>d (J = 6.7 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′</td></tr>
<tr><td>1.24</td><td>d (J = 6.4 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′</td></tr>
<tr><td>1.39</td><td>d (J = 6.7 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′</td></tr>
<tr><td>1.51</td><td>d (J = 6.7 Hz), 3H, CH$_3$-3′′′′, 4′′′′, 6′′′′ or 7′′′′</td></tr>
<tr><td>1.31, 2.25, 4.30</td><td>ABX system (J = 12.7, 2.7, 2.6 Hz), 3H, H$_a$, H$_b$, H$_x$</td></tr>
<tr><td>3.02</td><td>d (J = 7.0 Hz), 1H, H$_c$</td></tr>
<tr><td>3.22</td><td>s, 3H, COOMe-2′′</td></tr>
<tr><td>3.48</td><td>hept (J = 6.7 Hz), 1H, CH-2′′′′ or 5′′′′</td></tr>
<tr><td>4.57</td><td>hept (J = 6.7 Hz), 1H, CH-2′′′′ or 5′′′′</td></tr>
<tr><td>4.31</td><td>d (J = 10.3 Hz), 1H, H$_e$</td></tr>
<tr><td>4.93</td><td>s, 1H, H$_y$</td></tr>
<tr><td>5.08</td><td>dd (J = 10.4, 7.1 Hz), 1H, H$_d$</td></tr>
<tr><td>6.95–7.52</td><td>m, 13H, Ar-H</td></tr>
</table>

Table 2.33 Data of spirocyclopentanone–anthracene adduct (±)-**117c**-*i* (continued)

NMR spectroscopy
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)
20.36, 20.74, 20.82, 21.00 (CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′), 36.05 (CH_2-12), 43.42 (CH-4′), 44.21 (CH-9), 46.48, 49.49 (CH-2′′′′ or 5′′′′), 46.72 (CH-10), 51.28 (CH_3-2′′), 53.32 (CH-5′), 56.86 (CH-3′), 60.90 (C_q-2′), 122.86, 123.74, 125.48, 125.53, 125.59, 126.07, 126.55, 126.73, 126.97(2), 127.11, 128.58(2) (CH-aromatic), 138.63, 138.66, 139.50, 143.48, 144.18 (C_q-aromatic), 165.77 (C_q-1′′), 173.73 (C_q-1′′′′), 207.49 (C_q-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{35}H_{38}NO_4$	536.2801 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{35}H_{37}NO_4Na$	558.2620 $[M+Na]^+$
Found for $C_{35}H_{37}NO_4Na$	558.2620 $[M+Na]^+$



(±)-**117c**-*ii*

Table 2.34 Data of spirocyclopentanone–anthracene adduct (±)-**117c**-*ii*

Physical properties
White crystals Melting point (m.p.) 238.2–242.1 °C (CH_2Cl_2/hexane) R_f = 0.42 (EtOAc/CH_2Cl_2/hexane, 1.0:0.5:8.5)

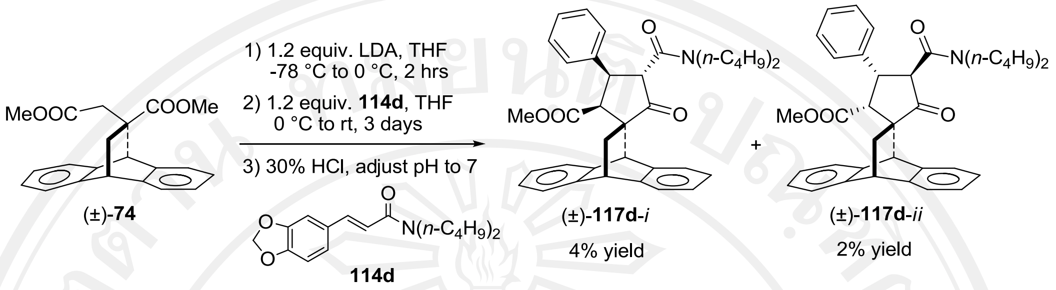
Table 2.34 Data of spirocyclopentanone–anthracene adduct (±)-**117c**-*ii* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1174, 1207	C–O stretching of ester
1439	C=C aromatic of benzene
1635, 1744	C=O stretching of carbonyl
2874, 2967	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
1.03	d (J = 6.7 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.11	d (J = 6.7 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.25	d (J = 6.4 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.26	d (J = 6.7 Hz), 3H, CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′
1.98, 2.19, 4.38	ABX system (J = 12.8, 3.1, 2.2 Hz), 3H, H_a, H_b, H_x
2.42	d (J = 5.6 Hz), 1H, H_c
3.23–3.36	m, 1H, CH-2′′′′ or 5′′′′
3.39	s, 3H, COOMe-2′′
4.31–4.43	m, 3H, H_d, H_e, CH-2′′′′ or 5′′′′
4.47	s, 1H, H_y
6.91–7.47	m, 13H, Ar-H
^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)	
20.39, 20.54, 20.90, 21.14 (CH_3-3′′′′, 4′′′′, 6′′′′ or 7′′′′), 41.60 (CH_2-12), 44.27(2) (CH-9, 4′), 46.18, 49.36 (CH-2′′′′ or 5′′′′), 47.93 (CH-10), 51.02 (CH_3-2′′), 54.68 (CH-5′), 58.23 (C_q-2′), 59.77 (CH-3′), 122.53, 123.85, 124.15, 125.49, 125.55, 125.79, 126.38, 126.85, 127.14(2), 127.28, 128.38(2) (CH-aromatic), 137.45, 140.66, 141.54, 143.08, 143.72 (C_q-aromatic), 166.10 (C_q-1′′), 173.74 (C_q-1′′′′), 210.82 (C_q-1′)	

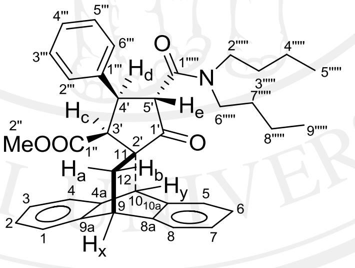
Table 2.34 Data of spirocyclopentanone–anthracene adduct (±)-**117c**-*ii* (continued)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{35}H_{38}NO_4$	536.2801 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{35}H_{37}NO_4Na$	558.2620 $[M+Na]^+$
Found for $C_{35}H_{37}NO_4Na$	558.2618 $[M+Na]^+$

2.8.4 Syntheses of 5′-(*N*,*N*-dibutylcarboxamid-1-yl)-3′-methoxycarbonyl-4′-phenyl-1′-cyclopentanone-2′-spiro-11-9,10-dihydro-9,10-ethanoanthracenes ((±)-117d-*i* and (±)-117d-*ii*)



According to *general procedure II* in **2.6.1** anhydrous diisopropyl-amine (1.68 equiv., 1.06 ml, 7.49 mmol), *n*-butyllithium (1.4 equiv., 4.74 ml, 1.32 N in hexane, 6.24 mmol), dimethyl itaconate–anthracene adduct ((±)-**74**) (1.0 equiv., 1.50 g, 4.46 mmol), *α*,*β*-unsaturated amide **114d** (1.2 equiv., 1.39 g, 5.35 mmol). Purification by preparative thin layer chromatography (PLC) using EtOAc/CH_2Cl_2/hexane (1.5:0.5:8.0) as eluent, affords diastereomeric spirocyclopentanone–anthracene adducts (±)-**117d**-*i* in 4% yield (0.084 g) and (±)-**117d**-*ii* in 2% yield (0.048 g), 90% conversion from the starting material.



(±)-**117d**-*i*

Table 2.35 Data of spirocyclopentanone–anthracene adduct (±)-**117d**-*i*

Physical properties
White crystals Melting point (m.p.) 168.2–170.1 °C (CH_2Cl_2/hexane) R_f = 0.42 (EtOAc/CH_2Cl_2/hexane, 1.5:0.5:8.0)

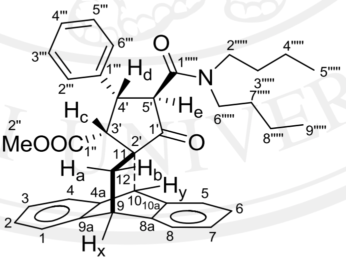
Table 2.35 Data of spirocyclopentanone–anthracene adduct (±)-**117d**-*ii* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1124, 1175	C–O stretching of ester
1434, 1458	C=C aromatic of benzene
1636, 1745	C=O stretching of carbonyl
2872, 2956	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.89	t (*J* = 7.3 Hz), 3H, CH_3-5′′′′ or 9′′′′
0.95	t (*J* = 7.3 Hz), 3H, CH_3-5′′′′ or 9′′′′
1.22–1.41, 1.47–1.62	m, 8H, CH_2-3′′′′, 4′′′′, 7′′′′, 8′′′′
1.27, 2.26, 4.30	ABX system (*J* = 12.7, 2.4, 2.2 Hz), 3H, H_a, H_b, H_x
2.96	d (*J* = 7.0 Hz), 1H, H_c
2.93–3.04, 3.67–3.79	m, 2H, CH_2-2′′′′ or 6′′′′
3.05–3.16, 3.79–3.91	m, 2H, CH_2-2′′′′ or 6′′′′
3.25	s, 3H, COOMe-2′′
4.28	d (*J* = 11.0 Hz), 1H, H_e
4.97	dd (*J* = 10.7, 7.0 Hz), 1H, H_d
5.01	s, 1H, H_y
6.97–7.52	m, 13H, ArH

Table 2.35 Data of spirocyclopentanone–anthracene adduct (±)-**117d**-*ii* (continued)

^{13}C-NMR (100 MHz) in CDCl$_3$ (ppm)
13.79, 14.04 (CH$_3$-5′′′′ or 9′′′′), 20.08, 20.12 (CH$_2$-4′′′′ or 8′′′′), 29.85, 31.35 (CH$_2$-3′′′′ or 7′′′′), 36.54 (CH$_2$-12), 44.22 (CH-9), 44.26 (CH-4′), 46.53, 47.65 (CH$_2$-2′′′′ or 6′′′′), 46.87 (CH-10), 51.30 (CH$_3$-2′′), 52.66 (CH-5′), 57.60 (CH-3′), 60.79 (C$_q$-2′), 122.77, 123.80, 125.46, 125.60(2), 126.07, 126.57, 126.74, 127.42(3), 128.62(2) (CH-aromatic), 138.08, 138.54, 139.55, 143.55, 144.10 (C$_q$-aromatic), 167.11 (C$_q$-1′′), 173.64 (C$_q$-1′′′′), 207.79 (C$_q$-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{37}H_{42}NO_4$	564.3114 [M+H]$^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 [M+H]$^+$
Calc. for $C_{37}H_{41}NO_6Na$	586.2933 [M+Na]$^+$
Found for $C_{37}H_{41}NO_4Na$	586.2929 [M+Na]$^+$



(±)-**117d**-*ii*

Table 2.36 Data of spirocyclopentanone–anthracene adduct (±)-**117d**-*ii*

Physical properties
White crystals Melting point (m.p.) 192.4–195.3 °C (CH$_2$Cl$_2$/hexane) R_f = 0.48 (EtOAc/CH$_2$Cl$_2$/hexane, 1.5:0.5:8.0)

Table 2.36 Data of spirocyclopentanone–anthracene adduct (±)-**117d**-*ii* (continued)

IR spectroscopy (evaporated thin film)	
ν_{max} (cm^{-1})	Type of vibration
1175, 1195	C–O stretching of ester
1435, 1458	C=C aromatic of benzene
1638, 1745	C=O stretching of carbonyl
2871, 2956	C–H stretching
NMR spectroscopy	
^{1}H-NMR (400 MHz) in $CDCl_3$	
Chemical shift (δ, ppm)	Type of proton
0.79	t (J = 7.3 Hz), 3H, CH_3-5′′′′ or 9′′′′
0.95	t (J = 7.2 Hz), 3H, CH_3-5′′′′ or 9′′′′
1.22–1.41, 1.47–1.62	m, 8H, CH_2-3′′′′, 4′′′′, 7′′′′, 8′′′′
1.99, 2.17, 4.38	ABX system (J = 12.8, 3.0, 2.5 Hz), 3H, H_a, H_b, H_x
2.40	dd (J = 4.8, 0.9 Hz), 1H, H_c
2.93–3.04, 3.22–3.35	m, 2H, CH_2-2′′′′ or 6′′′′
3.04–3.13, 3.66–3.78	m, 2H, CH_2-2′′′′ or 6′′′′
3.43	s, 3H, COOMe-2′′
4.35–4.39	m, 2H, H_d, H_e
4.47	s, 1H, H_y
6.93–7.47	m, 13H, ArH

Table 2.36 Data of spirocyclopentanone–anthracene adduct (±)-**117d**-*ii* (continued)

^{13}C-NMR (100 MHz) in $CDCl_3$ (ppm)
13.71, 13.83 (CH_3-5‴ or 9‴), 20.11, 20.13 (CH_2-4‴ or 8‴), 29.71, 31.47 (CH_2-3‴ or 7‴), 41.58 (CH_2-12), 44.23 (CH-4′), 44.26 (CH-9), 46.62, 47.80 (CH_2-2‴ or 6‴), 47.83 (CH-10), 51.10 (CH_3-2″), 53.71 (CH-5′), 58.42 (C_q-2′), 59.95 (CH-3′), 122.58, 123.79, 124.10, 125.51, 125.57, 125.80, 126.37, 126.71, 127.32(2), 127.44, 128.44(2) (CH-aromatic), 137.25, 140.57, 141.34, 143.04, 143.50 (C_q-aromatic), 166.85 (C_q-1″), 173.67 (C_q-1‴), 210.94 (C_q-1′)

Mass spectrometry (ESI-MS)	
Molecular weight	*m/z*
Calc. for $C_{37}H_{42}NO_4$	564.3114 $[M+H]^+$
Lock mass of $C_{33}H_{40}N_2O_9$	609.2812 $[M+H]^+$
Calc. for $C_{37}H_{41}NO_6Na$	586.2933 $[M+Na]^+$
Found for $C_{37}H_{41}NO_4Na$	586.2936 $[M+Na]^+$