Asymmetric Total Synthesis of (+)-Swainsonine

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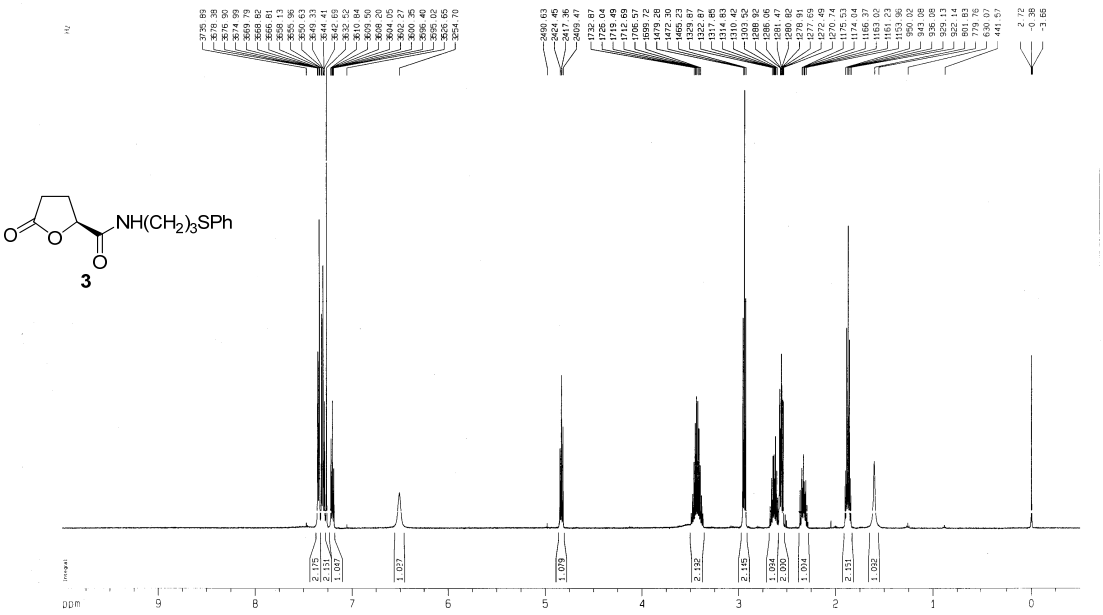
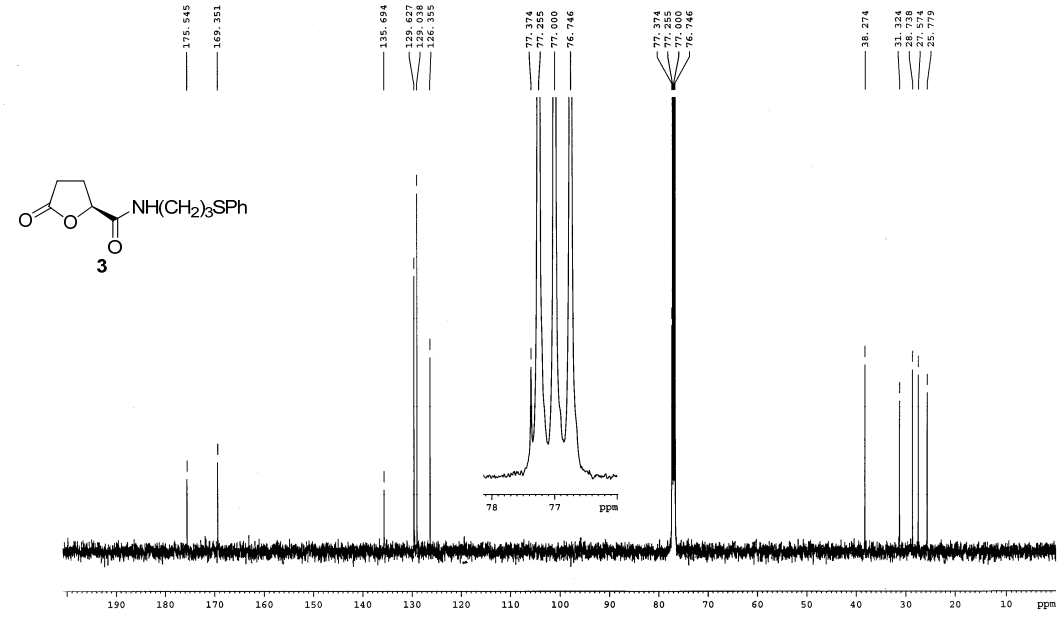
1. ^{1}H and ^{13}C spectra

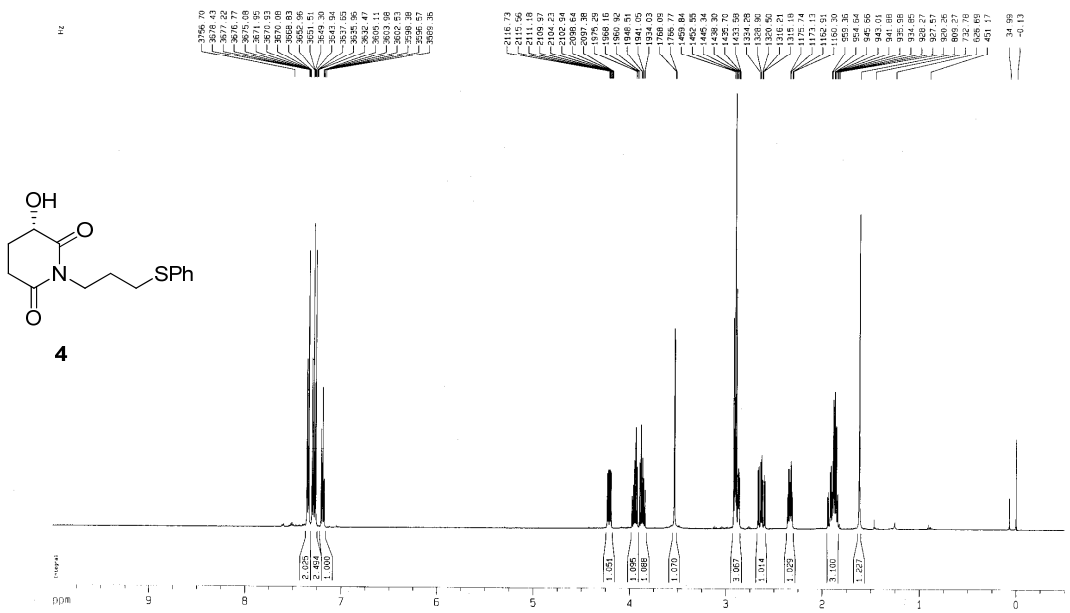
^{1}H-NMR spectrum of **3** (500 MHz, $CDCl_3$)



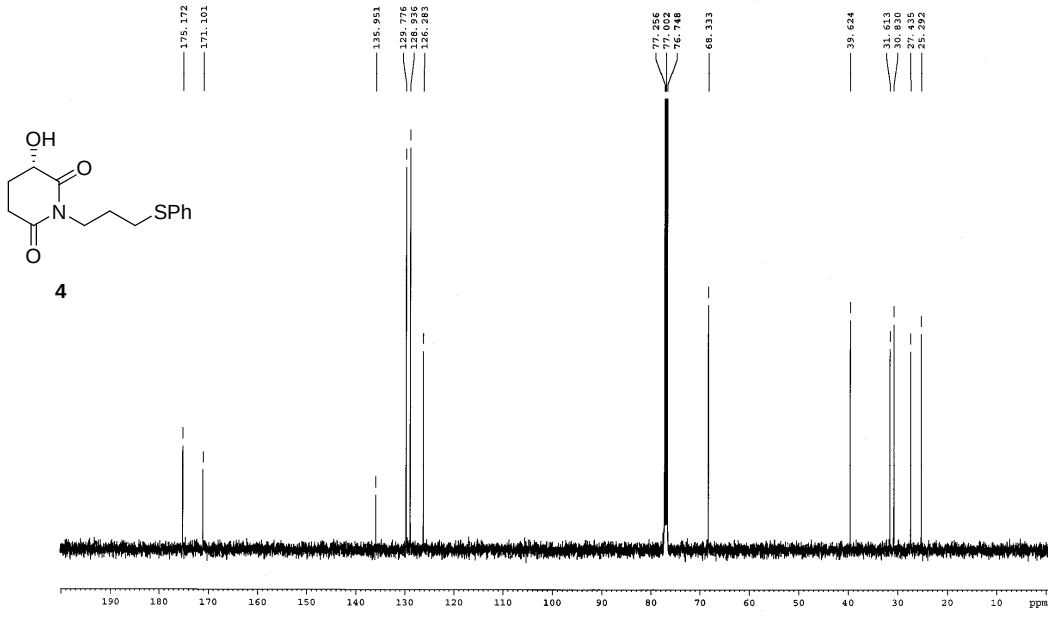
^{13}C-NMR spectrum of **3** (125 MHz, $CDCl_3$)



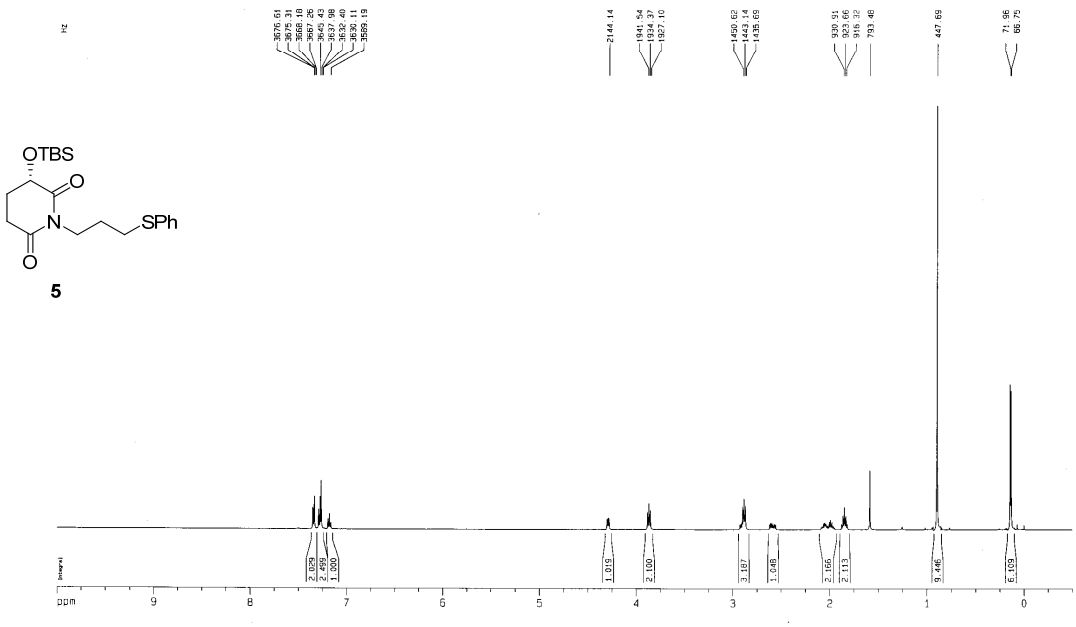
^{1}H-NMR spectrum of **4** (500 MHz, $CDCl_3$)



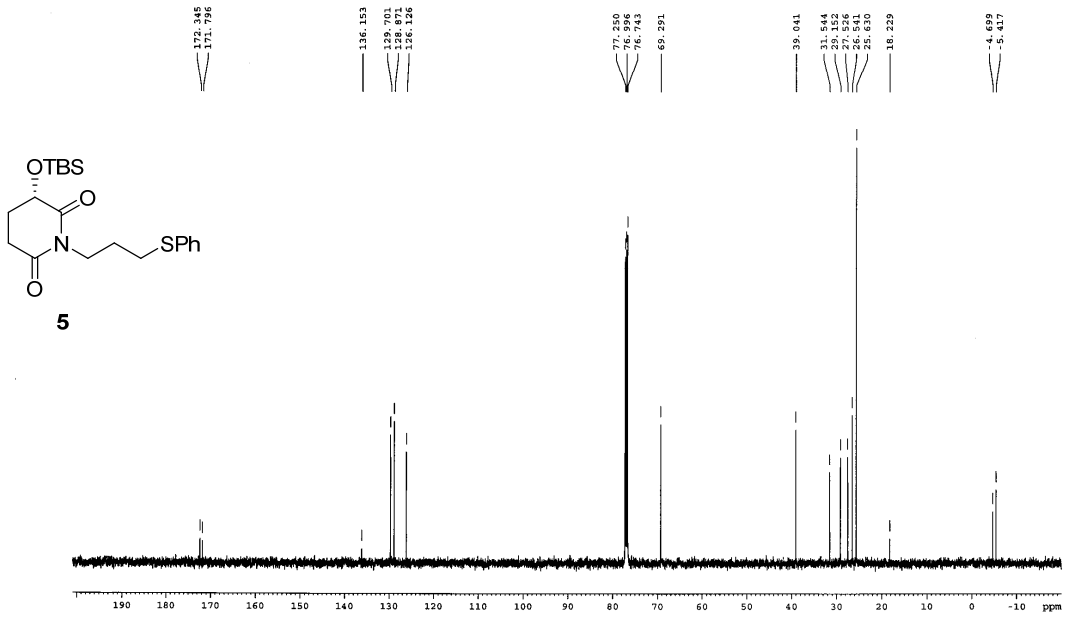
^{13}C-NMR spectrum of **4** (125 MHz, $CDCl_3$)



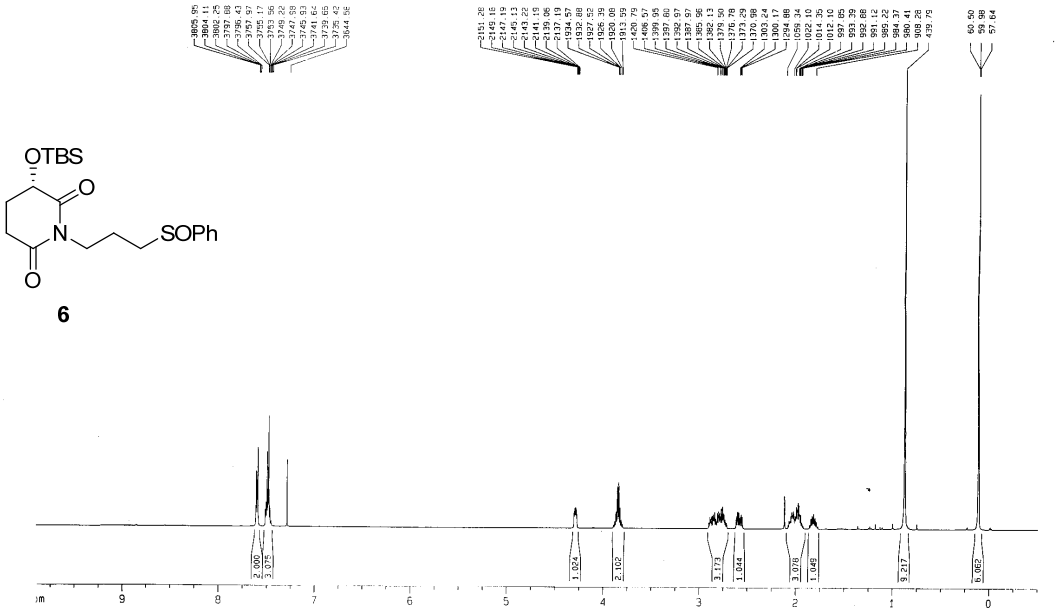
^{1}H-NMR spectrum of **5** (500 MHz, $CDCl_3$)



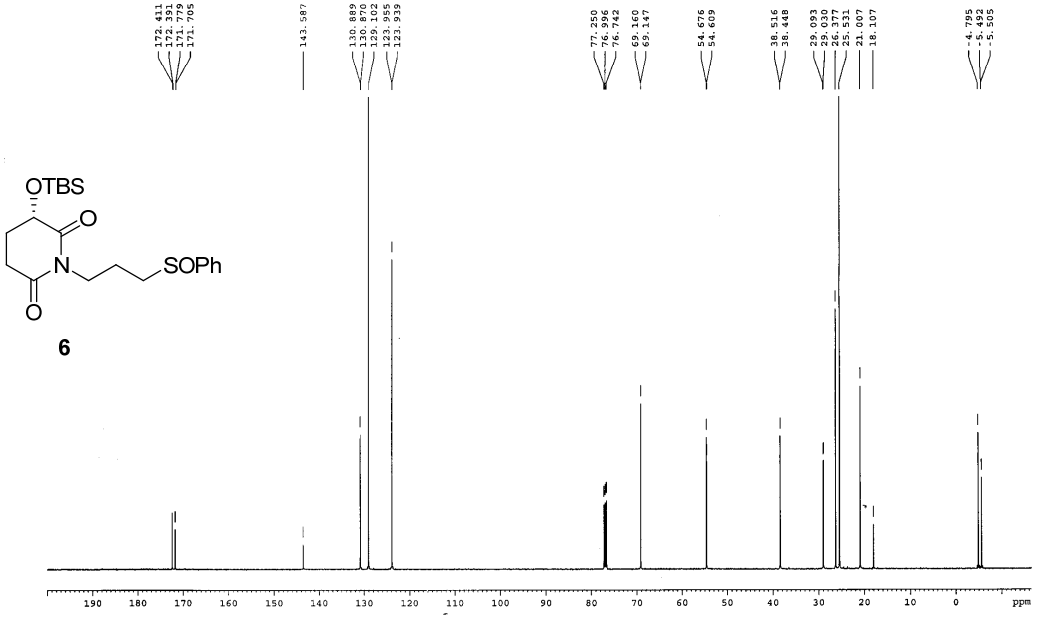
^{13}C-NMR spectrum of **5** (125 MHz, $CDCl_3$)



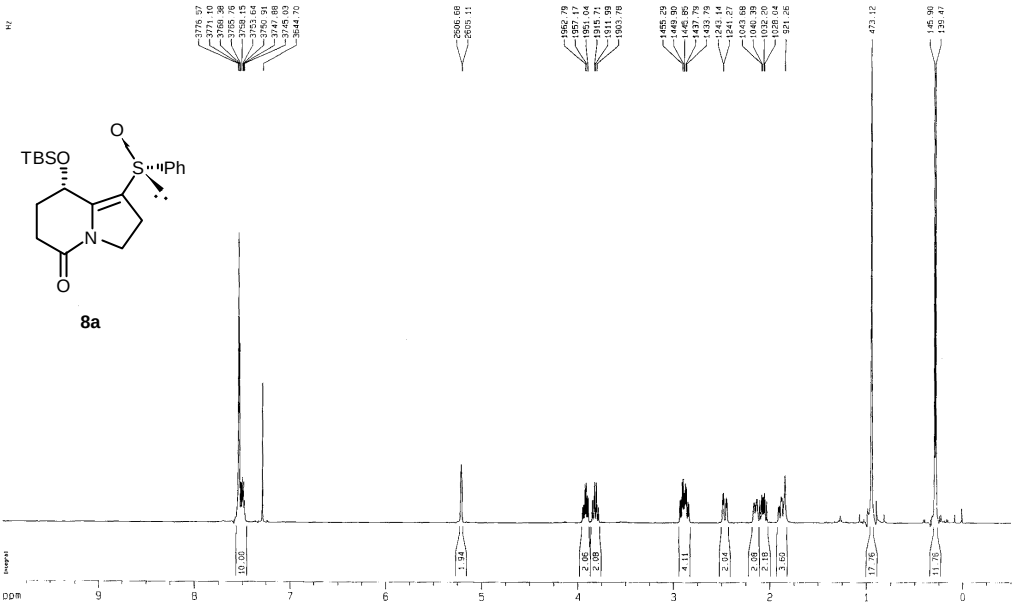
^{1}H-NMR spectrum of **6** (500 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **6** (125 MHz, $CDCl_3$)



^{1}H-NMR spectrum of **8a** (125 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **8a** (500 MHz, $CDCl_3$)

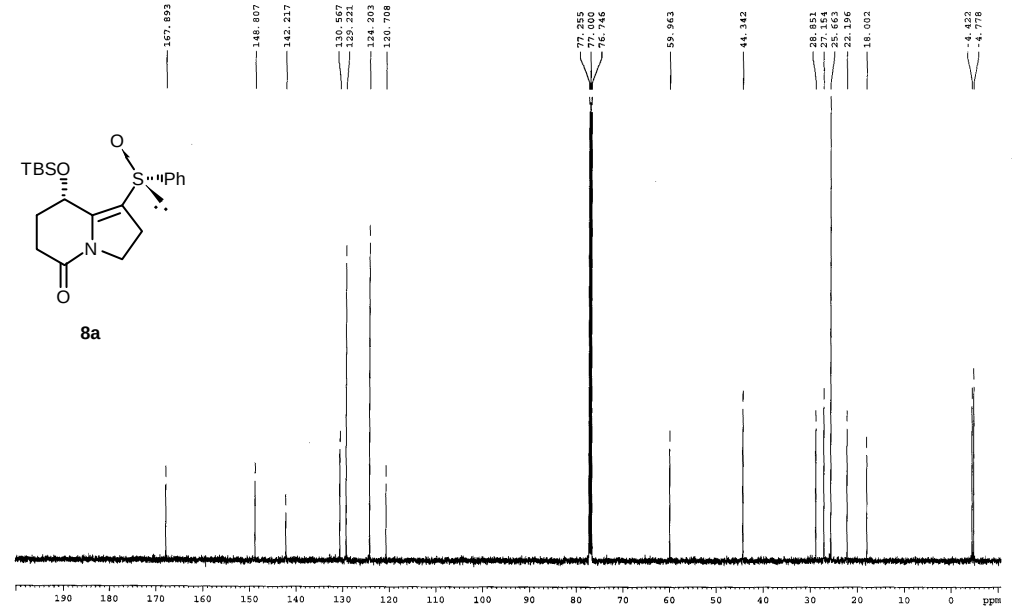
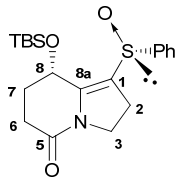


Table 1. 500 MHz COSY-45 correlations of some protons of compound **8a**.



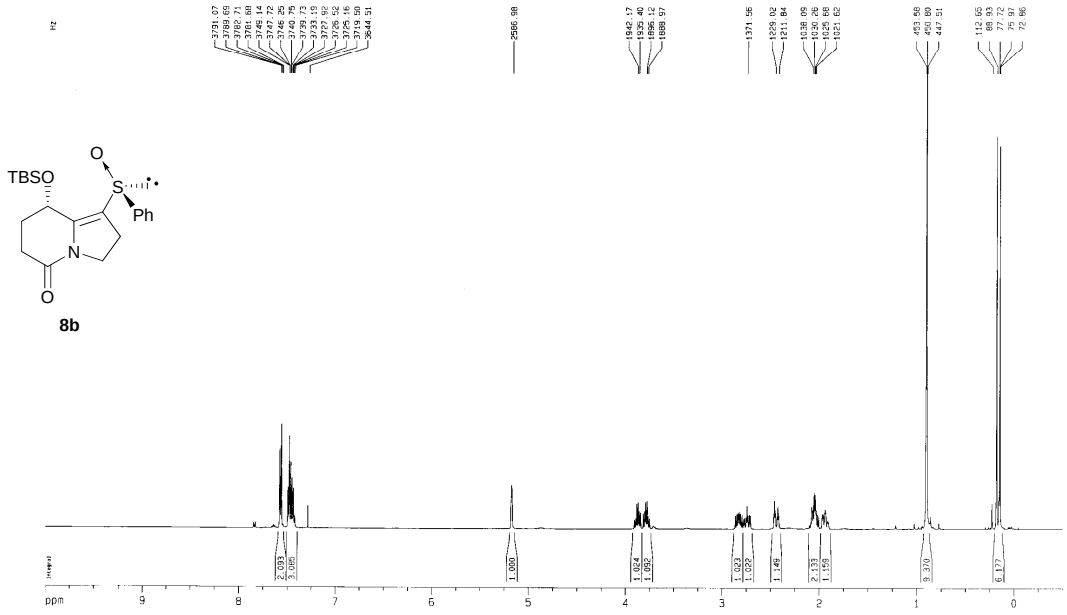
8a

δ_H (ppm)	δ_H (ppm) of correlated protons
5.20 (C_8-*H*)	2.17-2.12 (C_6-*H*), 1.88-1.84 (C_7-*H*)
2.94-2.85 (C_6-*H*)	1.88-1.84 (C_7-*H*), 2.47 (C_7-*H*)
2.47 (C_7-*H*)	1.88-1.84 (C_7-*H*)
2.17-2.12 (C_6-*H*)	1.88-1.84 (C_7-*H*)
3.91 (C_3-*H*)	2.94-2.85 (C_2-*H*), 2.07 (C_2-*H*)
3.76 (C_3-*H*)	2.94-2.85 (C_2-*H*), 2.07 (C_2-*H*)

Table 2. Observed C-H correlations from HMQC spectrum of **8a**.

δ_C (ppm)	δ_H (ppm)	Assignment
167.9	-	C_5
148.8	-	C_{8a}
120.8	-	C_2
60.0	5.20 (dd, *J* = 4.0, 2.2 Hz, 1H)	C_8
44.3	3.91 (ddd, *J* = 12.0, 12.0, 5.6 Hz, 1H) and 3.76 (ddd, *J* = 12.0, 12.0, 8.2 Hz, 1H)	C_3
28.8	2.47 (ddd, *J* = 17.3, 4.8, 2.8 Hz, 1H) and 1.88-1.84 (m, 1H)	C_7
27.1	2.94-2.85 (m, 1H) and 2.17-2.12 (m, 1H)	C_6
22.2	2.94-2.85 (m, 1H) and 2.07 (ddd, *J* = 15.7, 11.5, 8.2 Hz, 1H)	C_2

^{1}H-NMR spectrum of **8b** (500 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **8b** (125 MHz, $CDCl_3$)

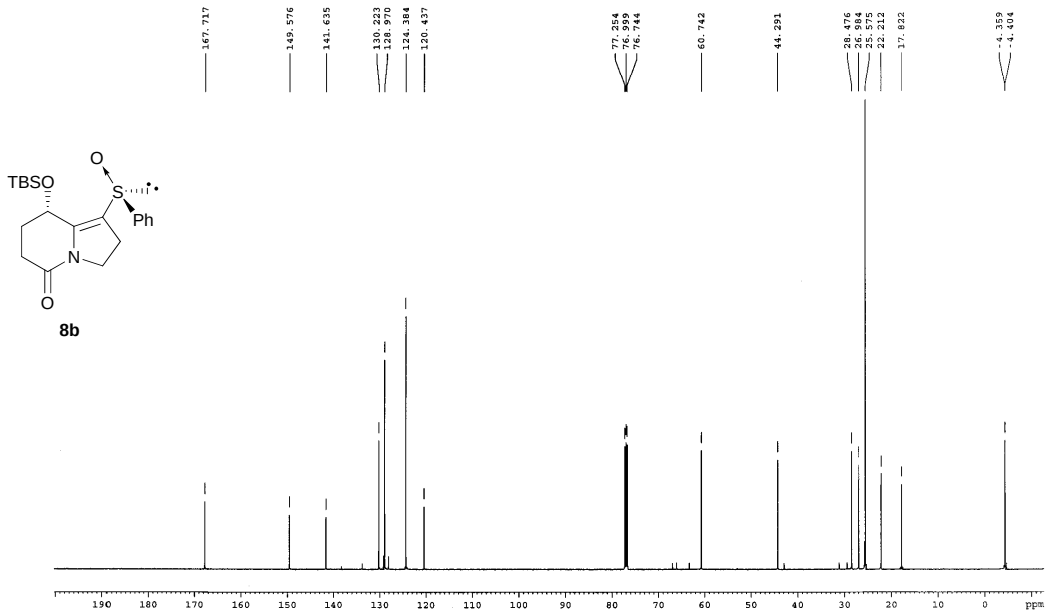
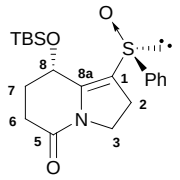


Table 3. 500 MHz COSY-45 correlations of some protons of compound **8b**.



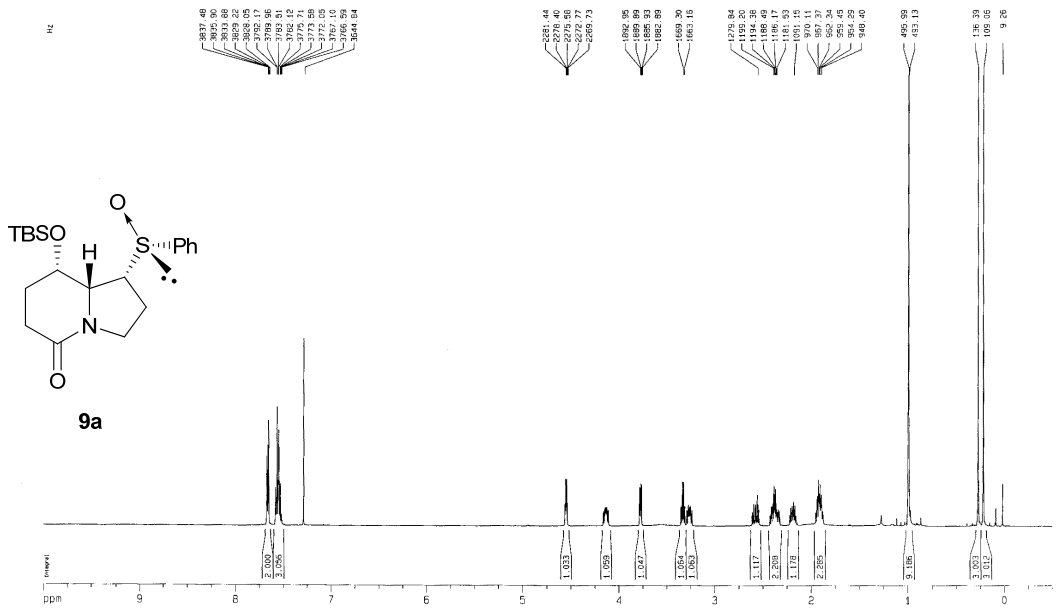
8b

δ_H (ppm)	δ_H (ppm) of correlated protons
5.18-5.17 (C_8-*H*)	1.97-1.90 (C_7-*H*)
3.87 (C_3-*H*)	2.08-2.00 (C_2-*H*), 2.83 (C_2-*H*)
3.78 (C_3-*H*)	2.08-2.00 (C_2-*H*), 2.83 (C_2-*H*)
2.83 (C_2-*H*)	2.08-2.00 (C_2-*H*)
2.74 (C_6-*H*)	1.97-1.90 (C_7-*H*)
2.44 (C_6-*H*)	1.97-1.90 (C_7-*H*)

Table 4. Observed C-H correlations from HMQC spectrum of **8b**.

δ_C (ppm)	δ_H (ppm)	Assignment
167.7	-	C_5
149.5	-	C_{8a}
141.6	-	C_1
60.7	5.18-5.17 (m, 1H)	C_8
44.3	3.87 (ddd, *J* = 12.0, 12.0, 6.7 Hz, 1H) and 3.78 (ddd, *J* = 12.0, 12.0, 7.1 Hz, 1H)	C_3
28.5	2.08-2.00 (m, 2H) and 1.97-1.90 (m, 1H)	C_7
27.0	2.74 (ddd, *J* = 17.0, 12.5, 4.9 Hz, 1H) and 2.44 (dt, *J* = 17.2, 3.8 Hz, 1H)	C_6
22.2	2.83 (ddd, *J* = 16.1, 11.8, 7.1 Hz, 1H) and 2.08-2.00 (m, 2H)	C_2

^{1}H-NMR spectrum of **9a** (500 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **9a** (125 MHz, $CDCl_3$)

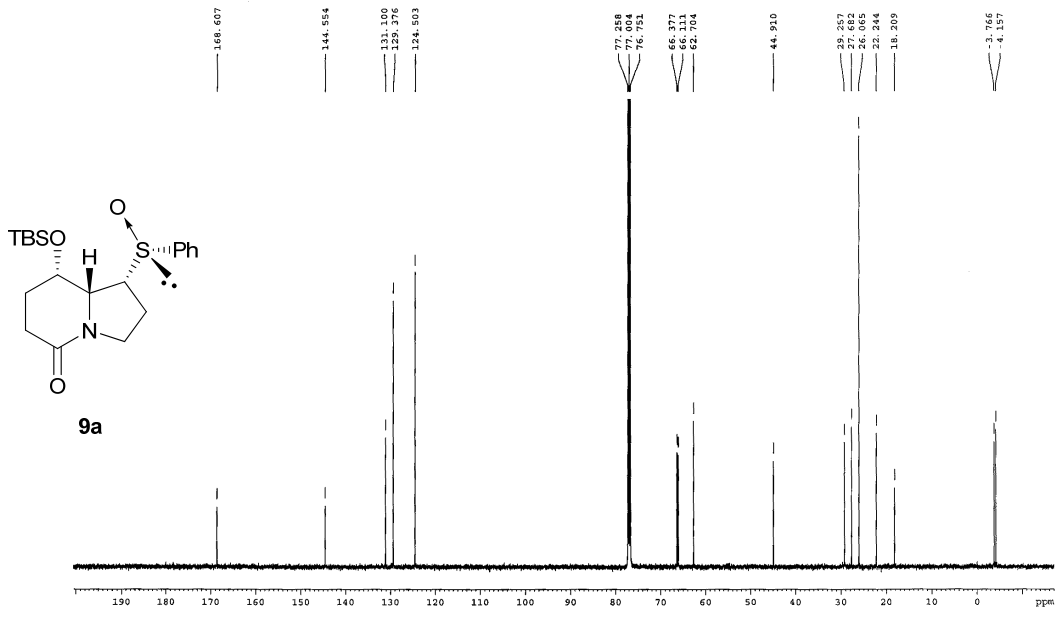
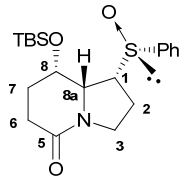


Table 5. 500 MHz COSY-45 correlations of some protons of compound **9a**.



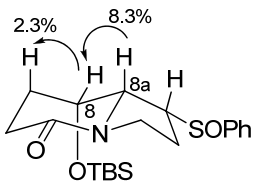
9a

δ_H (ppm)	δ_H (ppm) of correlated protons
4.55 (C_8-*H*)	1.95-1.87 (C_7-*H*), 2.22-2.15 (C_7-*H*), 3.77 (C_{8a}-*H*)
4.14 (C_3-*H*)	1.95-1.87 (C_2-*H*), 2.43-2.33 (C_2-*H*), 3.26 (C_3-*H*)
3.77 (C_{8a}-*H*)	3.33 (C_1-*H*)
3.33 (C_1-*H*)	1.95-1.87 (C_2-*H*), 2.43-2.33 (C_2-*H*)
3.26 (C_3-*H*)	1.95-1.87 (C_2-*H*), 2.43-2.33 (C_2-*H*)
2.58 (C_6-*H*)	1.95-1.87 (C_7-*H*), 2.22-2.15 (C_7-*H*), 2.43-2.33 (C_6-*H*)
2.22-2.15 (C_7-*H*)	1.95-1.87 (C_7-*H*)

Table 6. Observed C-H correlations from HMQC spectrum of **9a**.

δ_C (ppm)	δ_H (ppm)	Assignment
168.6	-	C_5
66.4	4.55 (dt, *J* = 5.6, 3.0 Hz, 1H)	C_8
66.1	3.33 (app. q, *J* = 7.1 Hz, 1H)	C_1
62.7	3.77 (dd, *J* = 7.0, 3.1 Hz, 1H)	C_{8a}
44.9	4.14 (ddd, *J* = 11.5, 8.6, 5.6 Hz, 1H) and 3.26 (ddd, *J* = 11.5, 8.2, 6.7 Hz, 1H)	C_3
29.3	2.22-2.15 (m, 1H) and 1.95-1.87 (m, 2H)	C_7
27.7	2.58 (dt, *J* = 17.7, 7.8 Hz, 1H) and 2.43-2.33 (m, 2H)	C_6
22.2	2.43-2.33 (m, 2H) and 1.95-1.87 (m, 2H)	C_2

Table 7. NOE enhancements observed in compound **9a**.

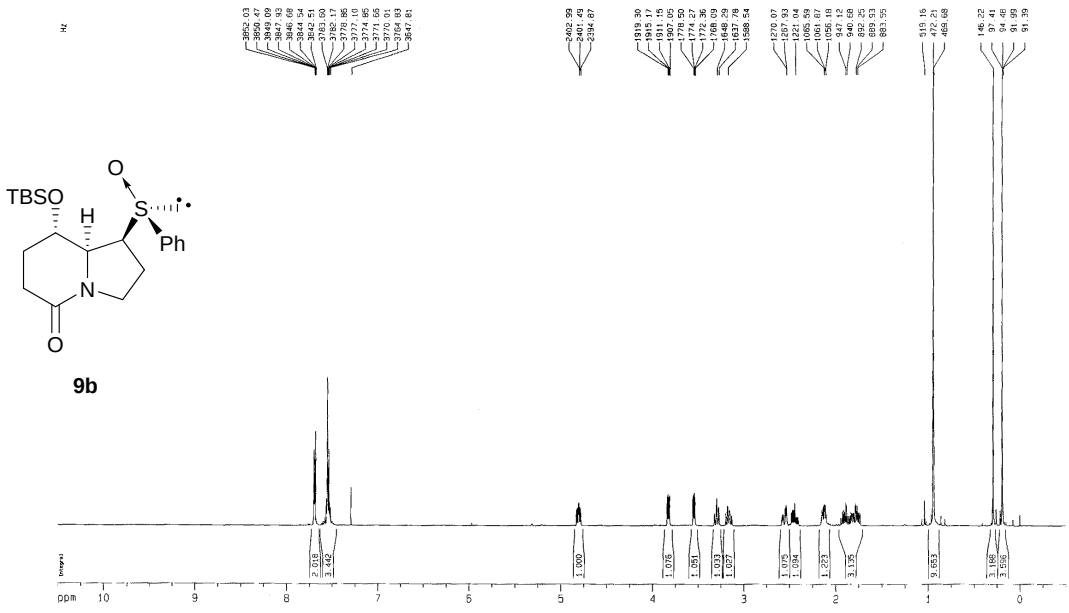


9a

$^{3}J_{H8\text{-}H8a}$ = 3 Hz

Irradiation	Results
C_1-*H*	2.7% enhancement of C_3-H_a 8.9% enhancement of C_{8a}-*H* 3.7% enhancement of C_2-H_a
C_{8a}-*H*	8.3% enhancement of C_8-*H* 8.7% enhancement of C_1-*H* 3.9% enhancement of C_2-H_a
C_8-*H*	8.1% enhancement of C_{8a}-*H* 2.3% enhancement of C_7-H_a 3.0% enhancement of C_2-H_a

^{1}H-NMR spectrum of **9b** (500 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **9b** (125 MHz, $CDCl_3$)

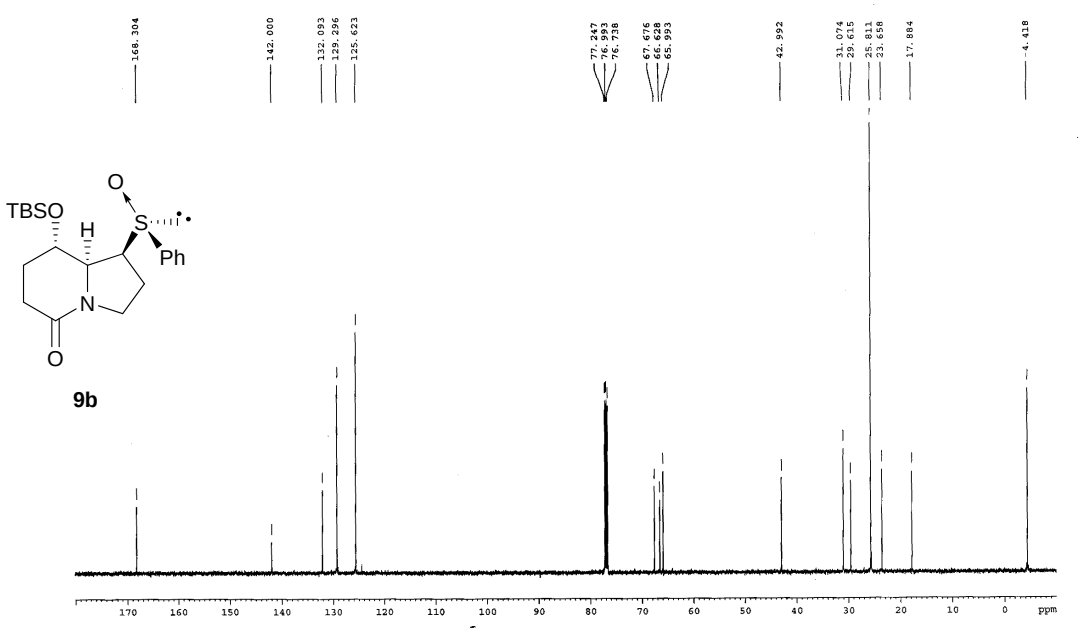
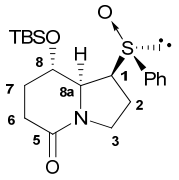


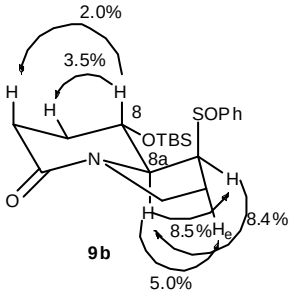
Table 8. 500 MHz COSY-45 correlations of some protons of compound **9b**.



9b

δ_H (ppm)	δ_H (ppm) of correlated protons
4.80 (C_8-*H*)	1.94-1.73 (C_7-*H*), 3.82 (C_{8a}-*H*)
3.82 (C_{8a}-*H*)	3.54 (C_1-*H*)
3.54 (C_1-*H*)	1.94-1.73 (C_2-*H*)
3.29 (C_3-*H*)	1.94-1.73 (C_2-*H*), 3.16 (C_3-*H*)
3.16 (C_3-*H*)	1.94-1.73 (C_2-*H*)
2.55 (C_6-*H*)	1.94-1.73 (C_7-*H*), 2.16-2.10 (C_7-*H*), 2.44 (C_6-*H*)
2.44(C_6-*H*)	1.94-1.73 (C_7-*H*), 2.16-2.10 (C_7-*H*)
2.16-2.10 (C_7-*H*)	1.94-1.73 (C_7-*H*)

Table 9. NOE enhancements observed in compound **9b**.

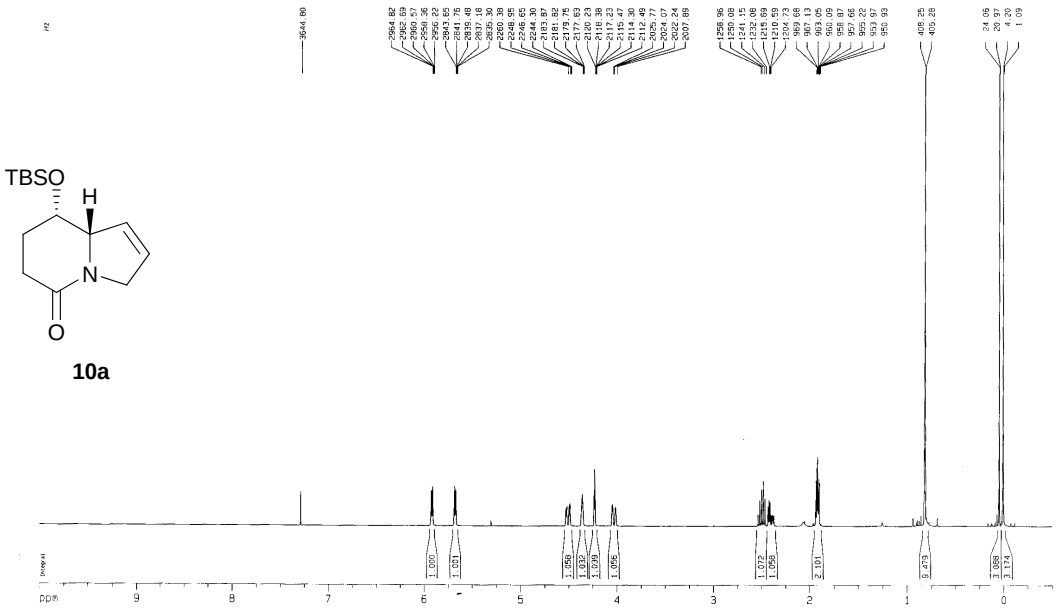


9b

$^3J_{H8\text{-}H8a}$ = 8.0 Hz

Irradiation	Results
C_1-*H*	3.5% enhancement of C_2-H_e 8.4% enhancement of C_{8a}-*H*
C_{8a}-*H*	5.0% enhancement of C_2-H_e 8.5% enhancement of C_1-*H*
C_8-*H*	2.0% enhancement of C_6-H_a 3.5% enhancement of C_7-H_e

^{1}H-NMR spectrum of **10a** (500 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **10a** (125 MHz, $CDCl_3$)

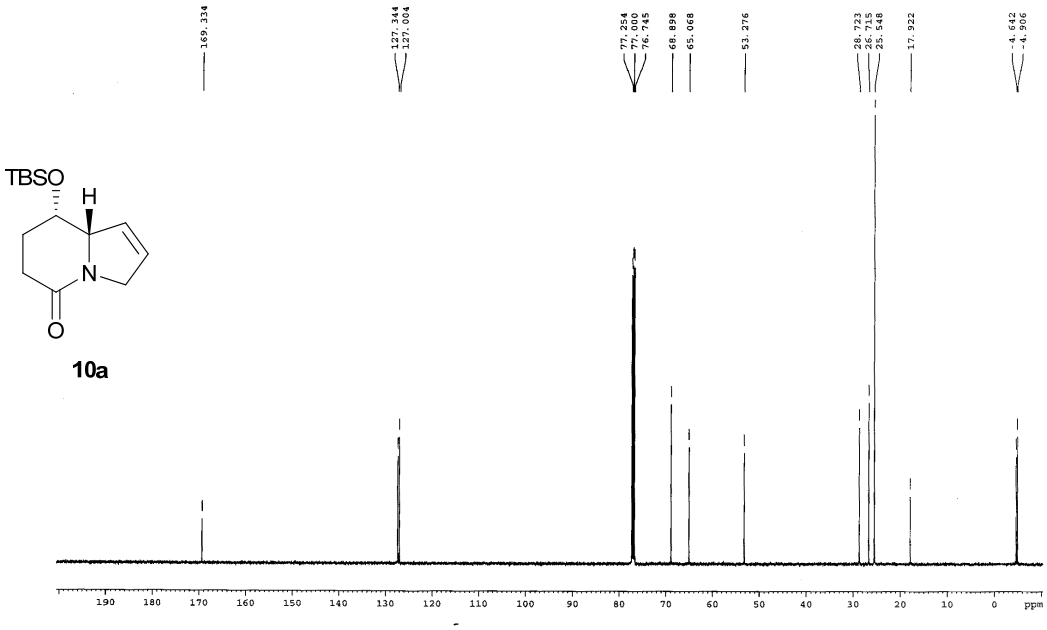
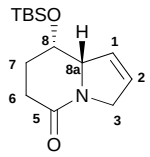


Table 10. 500 MHz COSY-45 correlations of some protons of compound **10a**.



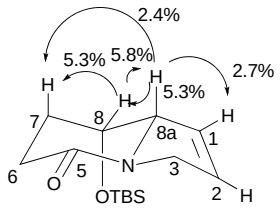
10a

δ_H (ppm)	δ_H (ppm) of correlated protons
5.93-5.90 (C_2-*H*)	4.05-4.01 (C_3-*H*), 4.37-4.35 (C_{8a}-*H*), 4.53-4.48 (C_3-*H*), 5.69-5.66 (C_1-*H*)
5.69-5.66 (C_1-*H*)	4.05-4.01 (C_3-*H*), 4.37-4.35 (C_{8a}-*H*), 4.53-4.48 (C_3-*H*)
4.53-4.48 (C_3-*H*)	4.05-4.01 (C_3-*H*)
4.24-4.22 (C_8-*H*)	1.94-1.90 (C_7-*H*)
2.49 (C_6-*H*)	1.94-1.90 (C_7-*H*)
2.40 (C_6-*H*)	1.94-1.90 (C_7-*H*)

Table 11. Observed C-H correlations from HMQC spectrum of **10a**.

δ_C (ppm)	δ_H (ppm)	Assignment
169.3	-	C_5
127.3	5.69-5.66 (m, 1H)	C_1
127.0	5.93-5.90 (m, 1H)	C_2
68.9	4.37-4.35 (m, 1H)	C_{8a}
65.1	4.24-4.22 (m, 1H)	C_8
53.3	4.53-4.48 (m, 1H) and 4.05-4.01 (m, 1H)	C_3
28.7	1.94-1.90 (m, 2H)	C_7
26.7	2.49 (dt, *J* = 17.8, 9.1 Hz, 1H) and 2.40 (ddd, *J* = 17.8, 6.7, 4.3 Hz, 1H)	C_6

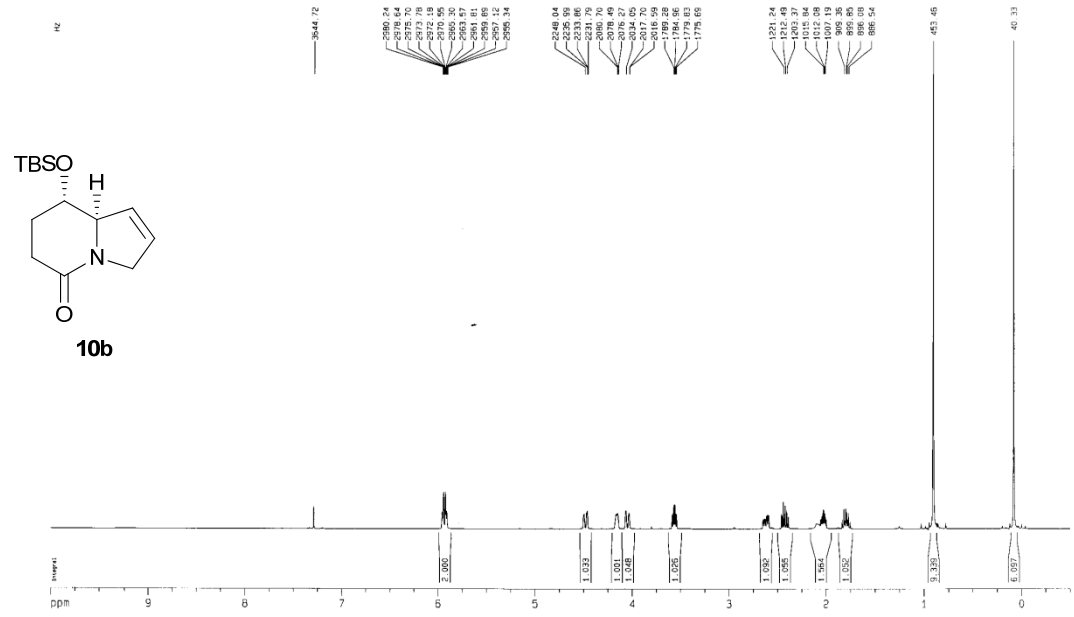
Table 12. NOE enhancements observed in compound **10a**.



10a

Irradiation	Results
C_8-*H*	5.8% enhancement of C_{8a}-*H* 5.3% enhancement of C_7-H_a
C_{8a}-*H*	5.3% enhancement of C_8-*H* 2.7% enhancement of C_1-*H* 2.4% enhancement of C_7-H_a

^{1}H-NMR spectrum of **10b** (500 MHz, $CDCl_3$)



^{13}C-NMR spectrum of **10b** (125 MHz, $CDCl_3$)

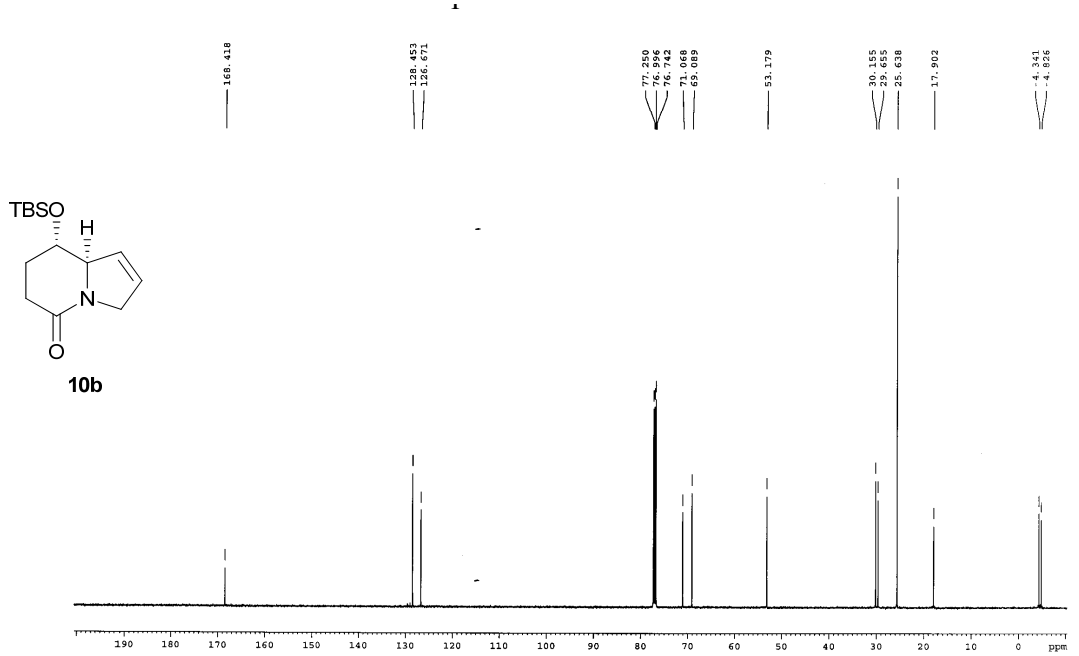
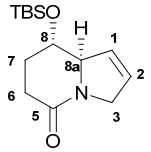


Table 13. 500 MHz COSY-45 correlations of some protons of compound **10b**.



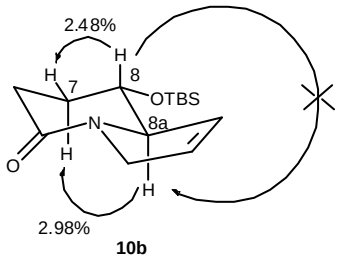
10b

δ_H (ppm)	δ_H (ppm) of correlated protons
5.96-5.90 (C_2-*H*)	4.50-4.46 (C_3-*H*), 4.06-4.03 (C_3-*H*),
4.50-4.46 (C_3-*H*)	4.06-4.03 (C_3-*H*)
4.17-4.14 (C_{8a}-*H*)	3.57 (C_8-*H*)
3.57 (C_8-*H*)	1.84-1.75 (C_7-*H*), 2.05-1.99 (C_7-*H*)
2.63 (C_6-*H*)	1.84-1.75 (C_7-*H*), 2.05-1.99 (C_7-*H*), 2.42 (C_6-*H*)
2.42 (C_6-*H*)	1.84-1.75 (C_7-*H*), 2.05-1.99 (C_7-*H*)
2.05-1.99 (C_7-*H*)	1.84-1.75 (C_7-*H*)

Table 14. Observed C-H correlations from HMQC spectrum of **10b**.

δ_C (ppm)	δ_H (ppm)	Assignment
168.4	-	C_5
128.5	5.96-5.90 (m, 2H)	C_2
126.7	5.96-5.90 (m, 2H)	C_1
71.1	3.57 (td, *J* = 9.5, 5.2 Hz, 1H)	C_8
69.1	4.17-4.14 (m, 1H)	C_{8a}
53.3	4.50-4.46 (m, 1H) and 4.06-4.03 (m, 1H)	C_3
30.2	2.05-1.99 (m, 1H) and 1.84-1.75 (m, 1H)	C_7
29.7	2.63 (ddd, *J* = 17.8, 8.5, 3.6 Hz, 1H) and 2.42 (dt, *J* = 17.9, 8.5 Hz, 1H)	C_6

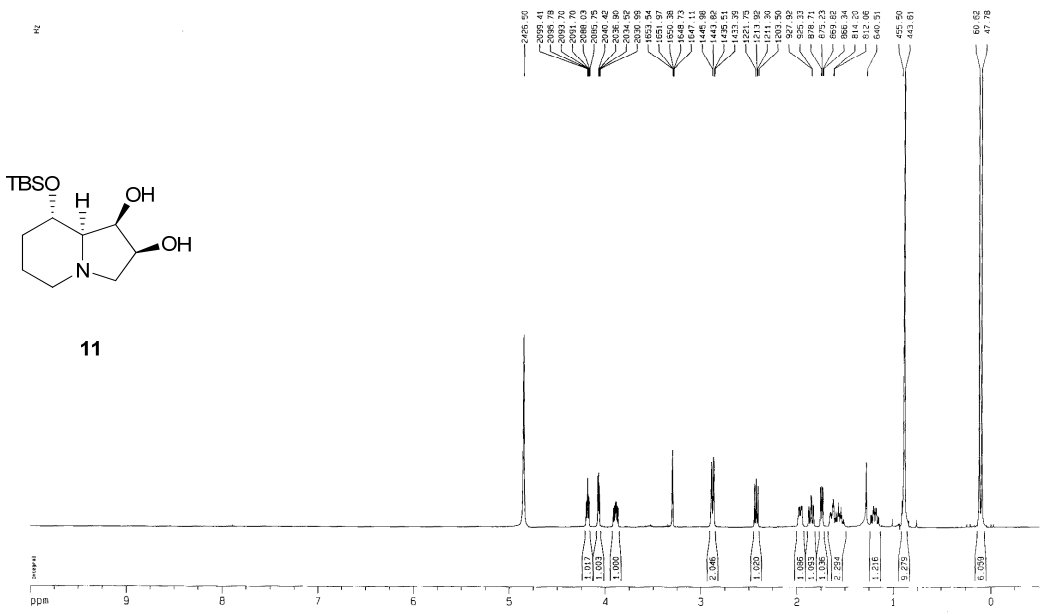
Table 15. NOE enhancements observed in compound **10a**.



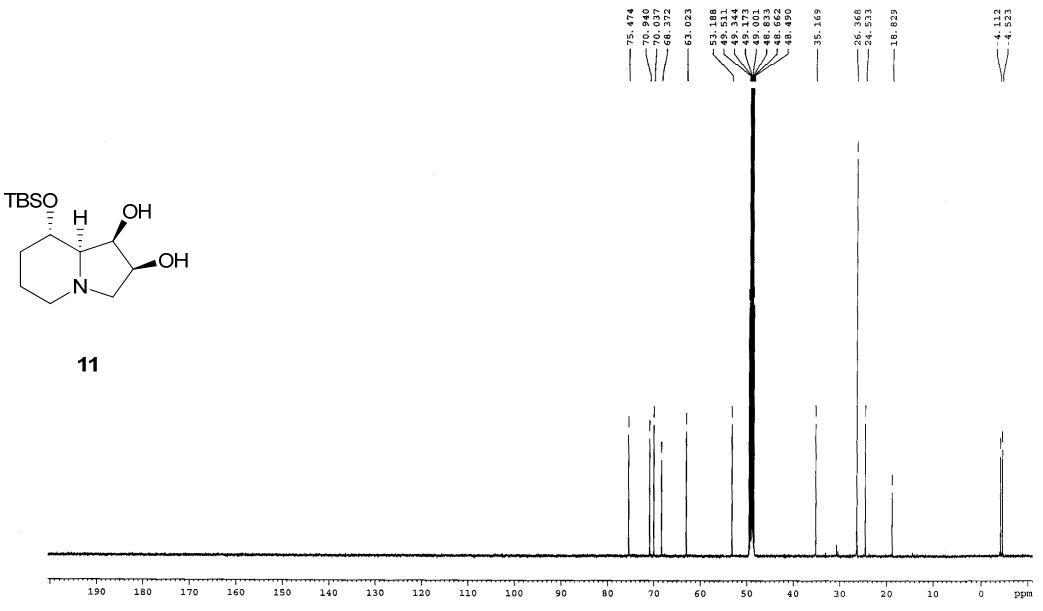
10b

Irradiation	Results
C_8-*H*	2.48% enhancement of C_7-H_e
C_{8a}-*H*	2.98% enhancement of C_7-H_a

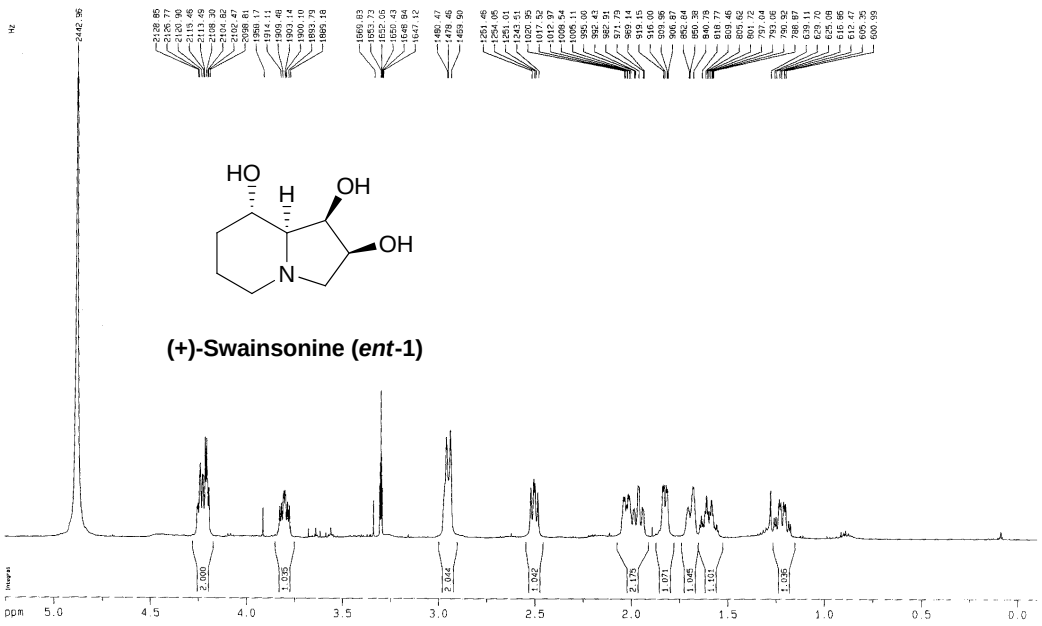
^{1}H-NMR spectrum of **11** (500 MHz, CD_3OD)



^{13}C-NMR spectrum of **11** (125 MHz, CD_3OD)



^{1}H-NMR spectrum of (+)-swainsonine (***ent*-1**) (500 MHz, CD_3OD)



^{13}C-NMR spectrum of (+)-swainsonine (***ent*-1**) (125 MHz, CD_3OD)