HETEROCYCLES, Vol. 57, No. 10, 2002, pp. 1841 - 1850, Received, 5th July, 2002

REGIOSELECTIVE PREPARATION OF PTERIN 6-TRIFLATE AND ITS APPLICATION TO 6-SUBSTITUTED PTERIN SYNTHESIS

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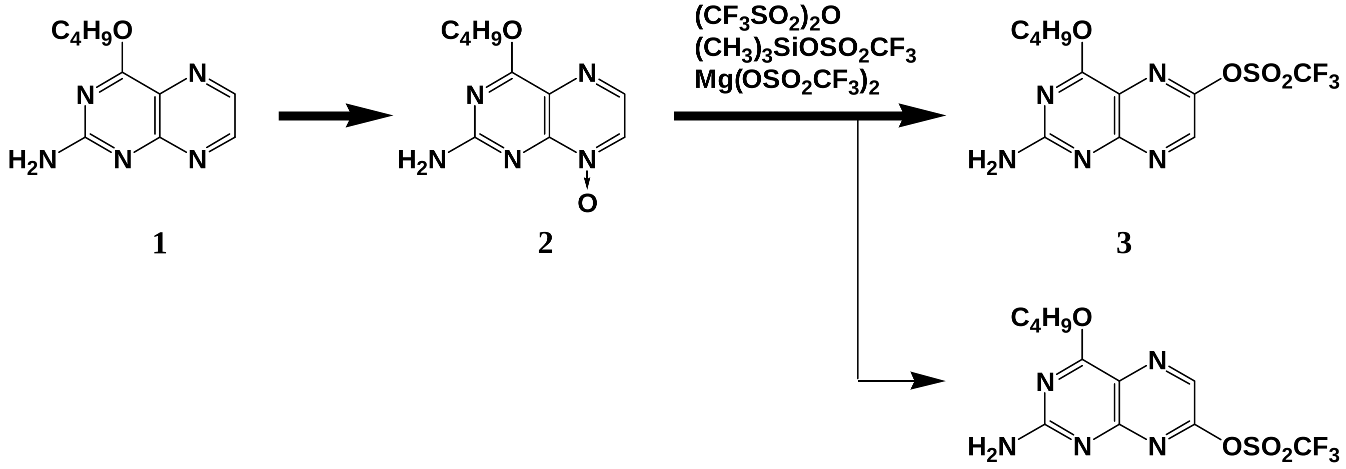
Abstract – 4-Butoxypteridine 6-triflate is prepared selectively from 4-butoxypteridine 8-oxide by a reaction with trifluoromethanesulfonic anhydride, and the triflate group can be replaced by various nucleophiles with functional groups.

6-Substituted pterins (2-aminopteridin-4(3*H*)-one), such as biopterin, neopterin and folic acid, are found out from almost all kinds of living organisms, and tetrahydro derivatives of these pterins are known to play important rolls as cofactors in various metabolic systems.[1] For example, (6*R*)-tetrahydrobiopterin is a cofactor for aromatic amino acid hydroxylases which oxidize phenylalanine and tyrosine to tyrosine and L-DOPA, respectively.[2] (6*R*)-Tetrahydrobiopterin is also known to be a cofactor for nitric oxide (NO) synthases.[3] On the other side, (6*S*)-tetrahydrofolate is a very important cofactor for C1 transfer processes in nucleic acid biosyntheses and an indispensable nutrient for cell growth.[4] In addition, since some 6-substituted pteridine derivatives can inhibit the actions of dihydrofolate reductase activating folic acid, these compounds can be used as strong anticancer agents like methotrexate which is one of the most staple chemotherapeuticals.[5] These biochemical and pharmaceutical interests have encouraged the investigations on efficient synthetic methodologies for 6-substituted pteridines. Practical procedures of those pterins mainly employed the regioselective preparation of the pteridine ring (the pyrazine or pyrimidine part) using precursors with completely constructed sidecomphain units.[6] On the contrary, we have previously reported a regioselective pteridine synthesis based on nucleophilic substitution of 1,3-dimethyllumazine (pteridin-2,4-(1*H*,3*H*)-dione) 6-triflate (trifluoromethanesulfonate).[7—9] Although the reaction could be employed as a general and versatile method for various 6-substituted lumazines, some difficulties have been pointed out to expand to pterin synthesis. The largest one is that the key reaction for the preparation of triflate starting material, oxidation of pterin to its *N*-oxide, proceeded with the opposite regioselectivity. In this paper, we would like to describe the regioselective preparation of pterin 6-triflate and its application to 6-substituted pterin synthesis.

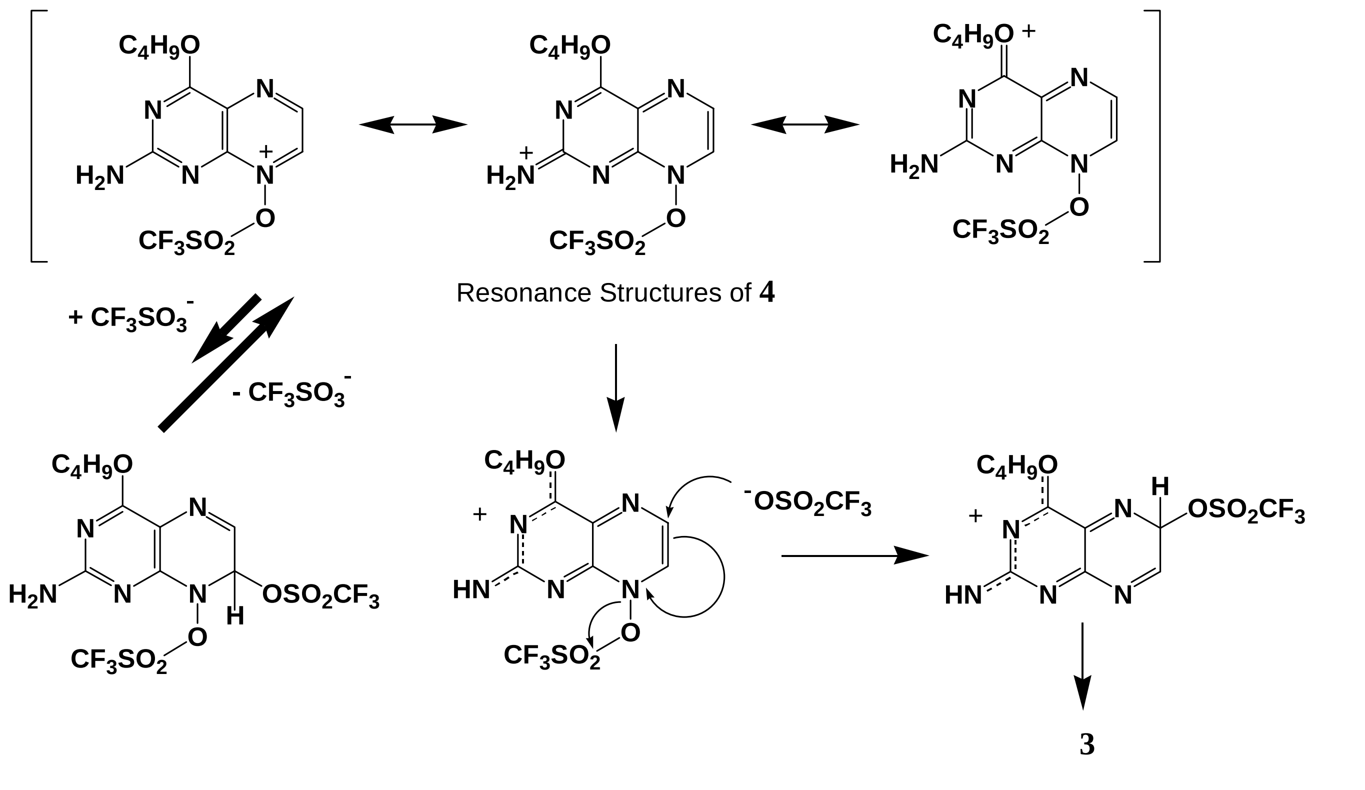
RESULTS AND DISCUSSION

1,3-Dimethyllumazine 6-triflate is selectively prepared from 1,3-dimethyllumazine by the treatments with hydrogen peroxide in trifluoroacetic acid followed by trifluoromethanesulfonic anhydride in high yields.[7] However, the oxidation of 4-butoxypteridine (**1**) to its *N*-oxide by hydrogen peroxide in trifluoroacetic acid or *m*CPBA in dichloromethane affords not 5-oxide but 8-oxide (**2**) in moderate yields.[10] Although treatment of **2** with trifluoromethanesulfonic anhydride gave 4-butoxypteridine 6-triflate (**3**) selectively, the yield was quite low (< 10%) and the significant amount of **2** remained (at low temperature) as intact or decompomposed (under forcing conditions). The reaction was improved up to 38% yield by addition of magnesium triflate and trimethylsilyl triflate (0.5 and 2 equivalent, respectively) in the reaction mixture, and under the conditions a trace amount (less than 1% yield) of the 7-triflate isomer was obtained as a by-product. The C(6) selective nucleophilic substitution with triflate anion contrasts with the C(7) selective reaction of **2** with Grignard reagents. The predominance of



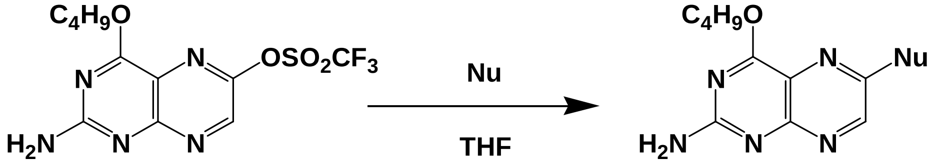
nucleophilic attack at the neighboring position of *N*-oxide in the presence of Lewis acid or RSO_2^+ could be rationalized by molecular orbital studies. *Ab-initio* MO calculations showed that electron density on C(6) of cationic complex (**2**$(CH_3O)–SO_2F)^+$ increased from +0.046 (**2**) to –0.033 while that on C(7) decompreased from –0.005 to +0.219.[12] In addition, lager LUMO distributed over C(7) than C(6).[12] Thus, the C(7) position of pterin 8-oxide became more electrophilic when cationic species bound to the oxygen atom.

N-Oxide (**2**) reacted with trifluoromethanesulfonic anhydride to give cationic intermediate (**4**: (**2**$–SO_2CF_3)^+$) stabilized by strongly electron donating 2-amino and 4-alkoxy groups. Nucleophilic attack on **4** by weakly coordinating triflate anion might occur predominantly at the most positive neighboring C(7) position. However the resulting 7-triflate adduct is destabilized by existence of the electron donating substituents (NH_2 and C_4H_9O), and the reverse reaction affords the most stable cationic intermediate (**4**) again. Thus, the triflate addition on the C(7) position seems to be reversible, and this is the reason why the conversion of **2** is poor without metal triflate additives. On the other side, S_N2' attack of triflate to C(6), although it is a minor pathway because of the lower electrophilicity of C(6), is an irreversible process since those electron donating groups do not effect to push out triflate. The selective formation of 6-triflate (**3**) can be explained by the kinetically less favored but irreversible process.



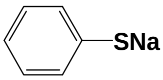
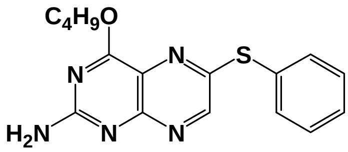
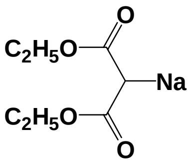
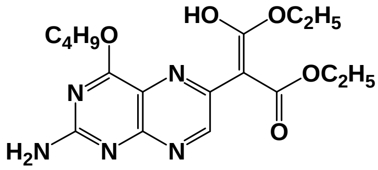
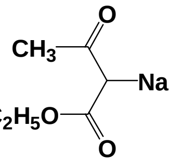
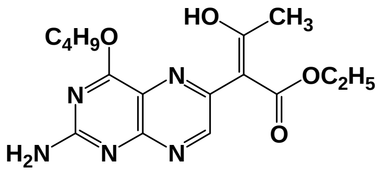
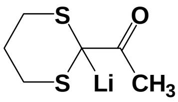
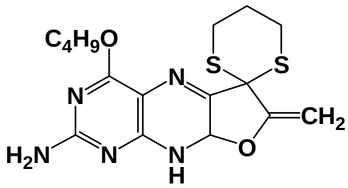
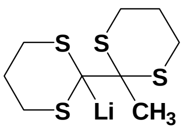
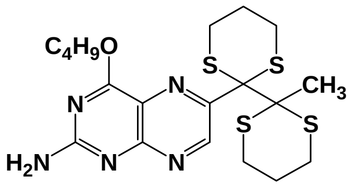
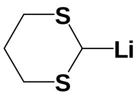
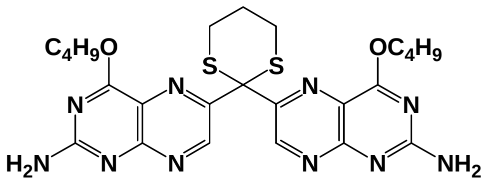
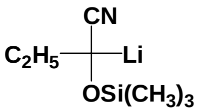
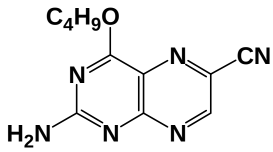
Reactions of **3** with anionic nucleophiles, such as sodium thiophenoxide and carbanions of active methylene compounds and 1,3-dithiane derivatives, proceeded in THF at 20 °C to give 6-substituted 4-butoxypteridines (**5a** – **5e**) in high to moderate yields (entries 1 – 5). The enol forms (**5b** and **5c**) are stabilized by the intramolecular hydrogen bonds with N(5). Compound (**5d**) was produced by nucleophilic addition of the initially obtained enol intermediate to C(7)=N(8) bond.[13] On the other sidecomparbanions of 1,3-dithian and cyanhydrine silyl ether did not afford the desired products. The 2:1 adduct of **3** and 1,3-dithiane (**5f**) and 6-cyano derivative (**5g**) were obtained as only one product after purification by silica-gel column chromatography in low yields, respectively (entries 6 and 7). Since pteridine is a strongly electron withdrawing group, the initially produced 1:1 product of **3** and 1,3-dithiane seems to be more acidic than unsubstantiated 1,3-dithiane itself. Thence, the carbanion of the initial product can be produced by hydrogen abstraction with unreacted 2-lithio-1,3-dithiane, and its reaction with **3** gives the 1:2 adduct (**5f**). Although the mechanism of the unexpected cyanation is unclear, existing acidic hydrogen (C(2)–NH_2) may carry out O–Si bond cleavage and generation of cyanide ion which can replace the triflate group of **3**. These results are summarized in Table 1.

The butyl group on the O–C(4) position can be removed by alkaline hydrolysis,[14] and treatment of **5e**, which is a synthetic equivalent to the biologically important pterin with α-diketone substituents,[15] by aq. sodium hydroxide in methanol gave 6-substituted pterin (**6**) in 98% yield. However, dithioacetal groups of **6** could not be removed any more by usual deprotection treatments, such as HgO, $Hg(OCOCF_3)_2$, NBS, and so on, and the starting material remained as intact. Under forcing conditions, at > 90 ºC or in the presence of sulfuric acid, treatments of **6** with Hg^{2+} reagent decompomposed the pteridine structures. Although it is unsuccessful for this substitution method to synthesize 6-acylpterin derivatives by using common masked acyl carbanion (Umpolung) reagents, pterin triflate (**3**) is employable as a highly reactive substrate for synthesis of numerous 6-substituted pterins with various functional groups on the sidecomphain using regiospecific nucleophilic substitution.[16]

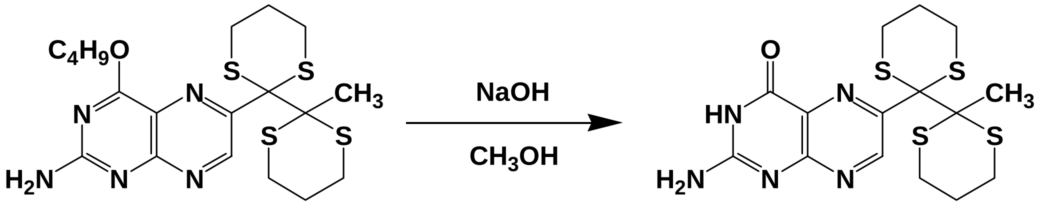


3 **5**

Table 1. Reaction of 3 with Nucleophiles.

entry	nucleophile	product		
		structure	No.	yield/%[a)]
1			**5a**	80
2			**5b**	41
3			**5c**	41
4			**5d**	38
5			**5e**	89
6			**5f**	15
7			**5g**	34

[a)]Isolated yield after column chromatography on silica gel.



5e **6**

EXPERIMENTAL

*2-Amino-4-butoxypteridine 8-oxide (**2**):* To a solution of 2-amino-4-butoxypteridine[10] (**1**, 9.15 g, 42 mmol) in trifluoroacetic acid (40 mL) was added 30% hydrogen peroxide (5.0 mL, 44 mmol) at 25 ºC, and the mixture was stirred for 2 h. To this was added 1 M $Na_2S_2O_3$ solution, and the mixture was concentrated *in vacuo*. The residue (*ca.* 10 mL) was diluted with water (50 mL) and neutralized by a saturated solution of $NaHCO_3$. This was extracted with CH_2Cl_2 (100 mL x 3), and the combined extracts were dried over $MgSO_4$. The solvent was removed *in vacuo*, and the residue was subjected to column chromatography on silica gel eluting with ethyl acetate. After concentration of the combined fractions, pure **2** (3.0 g, 31%) was obtained as yellow crystals (mp (toluene) 191–193 ºC (decomp)).[10]

*2-Amino-4-butoxy-6-trifluoromethanesulfonyloxypteridine (**3**):* Under Ar atmosphere, a mixture of **2** (1.00 g, 4.26 mmol), trimethylsilyl triflate (1.60 mL, 8.84 mmol), and anhydrous magnesium triflate (0.68 g, 2.12 mmol) in dry acetonitrile (50 mL) was stirred at 0 ºC for 1 h, then to this was added trifluoromethanesulfonic anhydride (0.80 mL, 4.76 mmol). After 1-h stirring, the mixture was neutralized by addition of a sat. $NaHCO_3$ solution, and the resulting mixture was concentrated to 1/2 volume and extracted with CH_2Cl_2 (50 mL x 3). The combined organic solutions were dried over $MgSO_4$ and concentrated, and the residue was subjected to column chromatography on silica gel eluting with a 1:1 (v/v) mixture of hexane and ethyl acetate. Pure **3** (0.605 g, 38%) was obtained as yellow crystals. mp (methanol) 125–127 ºC (decomp); TLC R_f = 0.32 (toluene:ethyl acetate = 1:1); IR (KBr disk): ν/cm^{-1} = 3329, 3179, 2967, 1644, 1599, 1543, 1431, 1225, 1177, 1136, 889, 819, 611; UV (CH_3OH): λ_{max}/nm (ε) = 371 (7000), 270 (12000), 244 (19000); ^1H NMR (400 MHz, $CDCl_3$): δ/ppm = 1.01 (3H, t, J = 7.4 Hz, CH_3), 1.53 (2H, m, CH_2), 1.89(2H, m, CH_2), 4.55 (2H, t, J = 6.8 Hz, CH_2O), 5.69 (1H, br, NH_2), 6.91 (1H, br, NH_2), 8.75 (1H, s, HC(7)); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.64, 18.99, 30.33, 68.60, 117.05 (q), 120.09, 144.29, 146.51, 156.83, 162.31, 167.32; EI-MS: m/z = 367.2 (M^+); ESI-MS: m/z = 368.15 ($[M + H]^+$). Anal. Calcd for $C_{11}H_{12}N_5O_4F_3S$: C, 35.97; H, 3.29; N, 19.07. Found. C, 35.97; H, 3.20; N, 18.77.

2-Amino-4-butoxy-7-trifluoromethanesulfonyloxypteridine: Yellow crystals. mp (methanol) 135–137 ºC (decomp); TLC R_f = 0.66 (hexane:ethyl acetate = 1:1); IR (KBr disk): ν/cm^{-1} = 3474, 3115, 2967, 1595, 1537, 1433, 1372, 1202, 1134, 1090, 1032, 951, 864, 820, 762, 646; UV (CH_3OH): λ_{max}/nm (ε) = 362 (8400), 272 (8700), 239 (16000); ^1H NMR (400 MHz, $CDCl_3$): δ/ppm = 1.01 (3H, t, J = 7.4 Hz, CH_3), 1.53 (2H, m, CH_2), 1.93(2H, m, CH_2), 4.61 (2H, t, J = 6.8 Hz, CH_2O), 6.60 (2H, br, NH_2), 8.38 (1H, s, HC(6)); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.70, 19.07, 30.41, 68.86, 116.84 (q), 123.85, 131.53, 154.41, 155.52, 162.73, 167.29; EI-MS: m/z = 367.2 (M^+).

*Reaction of **3** with Sodium Benzenethioate; a Typical Example:* A mixture of 60% NaH (0.08 g, 0.2 mmol) and thiophenol (0.03 mL, 0.3 mmol) in THF (5 mL) was stirred at 25 ºC for 1 min. To this was added **3** (0.054 g, 0.15 mmol), and the mixture was stirred for additional 10 min. The mixture was neutralized by addition of 1 M HCl and extracted by CH_2Cl_2 (20 mL x 5). The combined organic layer was dried over $MgSO_4$, and the residue was subjected to column chromatography on silica gel eluting with a 1:1 mixture of hexane and ethyl acetate. Pure **5a** (0.039 g, 80%) was obtained as yellow crystals: mp (methanol) 141–144 ºC (decomp); TLC R_f = 0.25 (hexane:ethyl acetate = 1:1); IR (KBr disk): ν/cm^{-1} = 3306, 2924, 2855, 1640, 1591, 1520, 1431, 1377, 1211, 1132, 739; UV (CH_3OH): λ_{max}/nm (ε) = 400 (5400), 290 (12000), 246 (11000), 222 (12000); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 0.99 (3H, t, J = 7.6 Hz, CH_3), 1.49 (2H, m, CH_2), 1.86 (2H, m, CH_2), 4.52 (2H, t, J = 6.8 Hz, CH_2O), 5.30 (2H, br, NH_2), 7.43 (3H, m, Ar), 7.62 (2H, m, Ar), 8.45 (1H, s, HC(7)); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 18.81, 19.08, 30.48, 68.10, 129.34, 129.78, 134.38, 150.07, 152.36, 154.71, 160.72, 167.03. Anal. Calcd for $C_{16}H_{17}N_5OS$: C, 58.70; H, 5.23; N, 21.39. Found. C, 58.71; H, 5.20; N, 21.23.

*Compound (**5b**) (keto/enol mixture):* Yellow solids: mp (methanol) 116–118 ºC (decomp); TLC R_f = 0.50 (hexane:ethyl acetate = 1:1); IR (KBr disk): ν/cm^{-1} = 3511, 3283, 3460, 2959, 1678, 1597, 1561, 1499, 1368, 1262, 1165, 1084, 1042, 980, 802, 696; UV (CH_3OH): λ_{max}/nm (ε) = 420 (24000), 311 (12000), 237 (35400); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 0.98 (3H, t, J = 7.3 Hz, CH_3), 1.32 (3H, t, J = 7.0 Hz, CH_3), 1.34 (3H, t, J = 7.0 Hz, CH_3), 1.48 (2H, m, CH_2), 1.85 (2H, m, CH_2), 4.26 (2H, dd, J = 6.8, 7.3 Hz, CH_2O), 4.31 (2H, dd, J = 6.8, 7.3 Hz, CH_2O), 4.46 (2H, t, J = 6.8 Hz, CH_2O), 5.18 (2H, br, NH_2), 8.44 (1H, s, HC(7)), 12.66 (1H, br, OH); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.78, 14.18, 14.23, 19.11, 30.73, 60.69, 61.06, 67.06, 67.63, 92.41, 111.18, 142.11, 145.79, 148.49, 161.67, 165.71, 166.10, 168.90. Anal. Calcd for $C_{17}H_{23}N_5O_5$: C, 54.10; H, 6.14; N, 18.56. Found. C, 54.36; H, 6.25; N, 18.23.

*Compound (**5c**) (keto/enol mixture):* Yellow solids: mp (methanol) 154–156 ºC (decomp); TLC R_f = 0.35 (hexane:ethyl acetate = 1:1); IR (KBr disk): ν/cm^{-1} = 3368, 2961, 1692, 1616, 1497, 1456, 1362, 1211, 1152, 1065, 997, 880, 806, 775, 611; UV (CH_3OH): λ_{max}/nm (ε) = 405 (9700), 304 (6100), 262 (6200), 229 (16000); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 0.97 (3H, t, J = 7.8 Hz, CH_3), 1.37 (3H, t, J = 7.0 Hz,

CH_3), 1.43 (2H, m, CH_2), 1.74 (2H, m, CH_2), 2.32 (3H, s, CH_3), 4.36 (4H, m, $2CH_2O$), 4.86 (2H, br, NH_2), 8.09 (1H, s, HC(7)), 13.16 (1H, br, OH); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.71, 13.89, 19.06, 28.21, 30.75, 61.79, 67.31, 98.19, 108.75, 141.42, 143.57, 153.54, 157.10, 158.37, 168.58, 196.88. Anal. Calcd for $C_{16}H_{21}N_5O_4$: C, 55.32; H, 6.09; N, 20.16. Found. C, 55.04; H, 6.00; N, 20.02.

*Compound (**5d**):* Yellow solids: mp (methanol) 107–110 ºC (decomp); TLC R_f = 0.42 (ethyl acetate); IR (KBr disk): ν/cm^{-1} = 3339, 2957, 2361, 1599, 1445, 1348, 1310, 1236, 1148, 1034, 984, 907, 786, 669; UV (CH_3OH): λ_{max}/nm (ε) = 291 (19000), 223 (21000); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 0.94 (3H, t, *J* = 7.3 Hz, CH_3), 1.44 (2H, m, CH_2), 1.75 (2H, m, CH_2), 2.17 (2H, m, CH_2), 2.88 (5H, m), 3.58 (1H, dd, *J* =16.0 and 8.5 Hz, CH), 4.27 (1H, d, *J* = 6.0 Hz, CH=), 4.36 (1H, d, *J* = 6.0 Hz, CH=), 4.51 (1H, dd, *J* = 8.8 Hz, CH), 4.67 (2H, br s), 5.21 (1H, br s); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.81, 19.08, 25.44, 29.72, 30.34, 30.99, 35.34, 48.50, 66.35, 101.83, 102.48, 148.72, 155.09, 158.10, 159.18, 163.46; EI-MS: *m*/*z* = 379.1 (M^+). Anal. Calcd for $C_{16}H_{21}N_5O_2S_2$: C, 50.64; H, 5.58; N, 18.45. Found. C, 50.55; H, 5.71; N, 18.16.

*Compound (**5e**):* Yellow solids: mp (methanol) 101–107 ºC (decomp); TLC R_f = 0.48 (ethyl acetate); IR (KBr disk): ν/cm^{-1} = 3146, 2915, 2363, 1688, 1526, 1472, 1416, 1341, 1285, 1109, 841, 660; UV (CH_3OH): λ_{max}/nm (ε) = 392 (5200), 294 (27000); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 1.02 (3H, t, *J* = 7.4 Hz, CH_3), 1.54 (2H, m, CH_2), 1.88 (2H, m, CH_2), 2.03, (2H, m, CH_2), 2.11 (2H, m, CH_2), 2.16 (3H, s, CH_3), 2.91 (6H, m), 3.38 (2H, t, *J* = 7.0 Hz, CH_2), 4.51 (2H, t, *J* = 5.8 Hz, CH_2), 5.28 (2H, br, NH_2), 8.62 (1H, s, HC(7)); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.87, 19.24, 20.68, 24.09, 29.04, 29.12, 29.79, 29.84, 30.57, 31.35, 67.80, 123.44, 150.56, 151.34, 154.81, 160.24, 166.81; EI-MS: *m*/*z* = 469.2 (M^+); ESI-MS: *m*/*z* = 508.22 ($[M + K]^+$), 492.26 ($[M + Na]^+$), 470.25 ($[M + H]^+$). Anal. Calcd for $C_{19}H_{27}N_5OS_4$: C, 48.58; H, 5.79; N, 14.91. Found. C, 48.57; H, 5.81; N, 14.67.

*Compound (**5f**):* Yellow solids: mp (methanol) 171–173 ºC (decomp); TLC R_f = 0.53 (dichloromethane: methanol = 1:1); IR (KBr disk): ν/cm^{-1} = 3341, 2959, 1597, 1561, 1524, 1441, 1375, 1223, 1130, 1032, 820, 640; UV (CH_3OH): λ_{max}/nm (ε) = 398 (14000), 289 (34000), 245 (29000); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 0.99 (6H, t, *J* = 7.3 Hz, CH_3), 1.53 (4H, m, CH_2), 1.87 (4H, m, CH_2), 2.26 (2H, m, CH_2), 3.42 (4H, t, *J* = 6.8 Hz, CH_2S), 4.50 (4H, t, *J* = 6.6 Hz, CH_2), 5.46 (4H, br, NH_2), 8.61 (2H, s, HC(7)); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.82, 19.21, 21.31, 28.56, 29.04, 30.53, 67.98, 123.20, 150.47, 151.40, 154.17, 160.46, 166.80, 176.10. Anal. Calcd for $C_{24}H_{30}N_{10}O_2S_2$: C, 51.98; H, 5.45; N, 25.26. Found. C, 52.11; H, 5.20; N, 24.93.

*Compound (**5g**):* Yellow solids: mp (methanol) 195–198 ºC (decomp); TLC R_f = 0.33 (hexane:ethyl acetate = 1:1); IR (KBr disk): ν/cm^{-1} = 3496, 3293, 3096, 2961, 1644, 1595, 1534, 1472, 1395, 1346, 1198, 1092, 826, 760; UV (CH_3OH): λ_{max}/nm (ε) = 394 (5700), 251 (20000), 213 (16000); ^{1}H NMR (400 MHz, $CDCl_3$): δ/ppm = 1.01 (3H, t, *J* = 7.3 Hz, CH_3), 1.53 (2H, m, CH_2), 1.93 (2H, m, CH_2), 4.61 (2H, t, *J* = 6.8 Hz, CH_2O), 5.55 (1H, br, NH_2), 6.25 (1H, br, NH_2), 8.72 (1H, s, HC(7)); ^{13}C NMR (100 MHz, $CDCl_3$): δ/ppm = 13.73, 19.08, 30.53, 69.12, 115.05, 126.21, 135.09, 141.34, 156.07, 162.34, 167.50; EI-MS: EI-MS: *m*/*z* = 244.2 (M^+). Anal. Calcd for $C_{11}H_{12}N_6O$: C, 54.09; H, 4.95; N, 34.41. Found. C, 53.88; H, 5.24; N, 33.93.

*Compound (**6**):* Yellow crystals: mp (DMF and H_2O) 220–225 ºC (decomp); IR (KBr disk): ν/cm^{-1} = 3146, 2915, 1688, 1526, 1472, 1416, 1341, 1285, 1109, 841, 660; UV (CH_3OH): λ_{max}/nm (ε) = 392 (5200), 294 (27000); ^{1}H NMR (400 MHz, CD_3SOCD_3): δ/ppm = 1.85 (2H, m, CH_2), 1.98 (2H, m, CH_2), 2.06 (3H, s, CH_3), 2.85 (6H, m, CH_2S), 3.26 (2H, t, *J* = 6.8 Hz, CH_2S), 6.81 (2H, br, NH_2), 8.59 (1H, s, HC(7)), 11.46 (1H, br, NH); ^{13}C NMR (100 MHz, CD_3SOCD_3): δ/ppm = 19.99, 23.61, 28.60, 29.04, 29.13, 29.27, 30.22, 67.57, 126.34, 126.80, 128.44, 148.81, 153.21, 160.42. Anal. Calcd for $C_{15}H_{19}N_5OS_4$: C, 43.56; H, 4.63; N, 16.93. Found. C, 43.55; H, 4.47; N, 16.99.

ACKNOWLEDGMENTS

We thank Mr. Y. Andoh (School of Informatics and Sciences, Nagoya University) and T. Omaru (Institute for Molecular Sciences) for their technical support.

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2-D Contour Map of the LUMO of (**2**(CH_3O)–SO_2F)$^+$

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