Preparation of Pyrimidinophanes from Pyrimidine Bases

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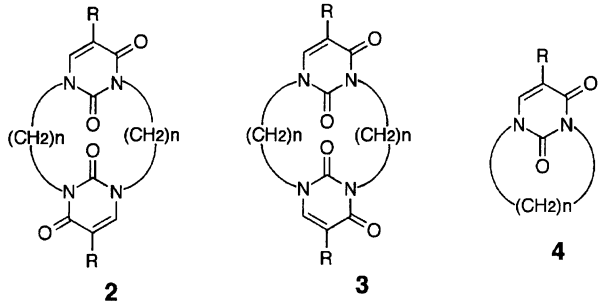
Treatment of pyrimidine bases such as uracil, thymine, and 5-fluorouracil with $X(CH_2)_nX$ (X = I or Br; n = 4—12) gave three types of pyrimidinophanes. When the numbers of carbon atoms of $X(CH_2)_nX$ are odd numbers (n = 5, 7, 9, 11), three structures of pyrimidinophanes could be differentiated on the basis of the ^{13}C NMR and mass spectra. Treatment of pyrimidinophanes with 1,4-naphthoquinone or maleimides in the presence of palladium(II) acetate gave the coupling products. Reaction of pyrimidinophanes with $NaNO_2$ in the presence of palladium(II) acetate led to the nitration.

Molecules with an aromatic ring bridged by an aliphatic chain have been called cyclophanes since Cram and Steinberg created this name.[1] These are of interest in connection with supermolecular chemistry.[2] Purinophanes and pyrimidinophanes are the cyclophanes containing nucleic acid bases such as purine and pyrimidine bases as the aromatic ring. While purinophanes have been extensively studied in connection with the stacking structures in DNA by Sakata and Misumi et al.,[3] pyrimidinophanes has not adequately been investigated except for a few compounds. The pyrimidinophanes may also be of interest in connection with the formation of pyrimidine photodimers in DNA by ultraviolet light[4] and the mechanistic studies on DNA photolyse.[5] Htay and Meth-Cohn[6] reported the formation of a pyrimidinophane (**3b-6**) by the treatment of thymine (**1b**) with $Br(CH_2)_6Br$ but the structure was equivocal: They mentioned in their report that isomers were possible. Reznik et al.[7] prepared a pyrimidinophane (**2a-4**), whose structure was not confused with that of the isomer (**3a-4**), by the treatment of 1-(4-bromobutyl)uracil with *p*-toluenesulfonamide. They also studied the reaction of uracil (**1a**) and 6-methyluracil sodium salts with $Br(CH_2)_nBr$, but the isolation of pyrimidinophanes was not reported.[8] The compounds similar to (**2b-6**) were also obtained from 1′,2′-secothymidine derivatives.[9] On the other hand, Golankiewicz et al.[10] reported that the treatment of 1,1′-trimethylenebis[thymine] with $Br(CH_2)_3Br$ gave pyrimidinophane (**3b-3**) and a cyclic tetramer of thymine. Reznik et al.[11] and Kinoshita et al.[12] reported the preparation of pyrimidinophanes containing a sulfur atom. However, little attention has been paid to a direct preparation of pyrimidinophanes from pyrimidine bases (**1**) such as **1a** and **1b**. This paper describes the direct preparation of three types of pyrimidinophanes: (**2**), (**3**), and (**4**) from **1a**, **1b**, and 5-fluorouracil (**1c**) which is of importance as the anti-cancer reagent (Chart 1).[13] The structures of the three pyrimidinophanes were distinguishable by means of ^{13}C NMR and mass spectral data. Previously we reported the alkenylation of uracils with 1,4-naphthoquinone or maleimides[14] and the nitration with $NaNO_2$[15] by palladium(II) acetate. In order to prepare pyrimidinophanes with functional groups, the alkenylation and nitration of pyrimidinophanes in the presence of palladium(II) acetate were further investigated.



	n	R
3b-3:	3	Me
2a-4; 3a-4:	4	H
2b-4; 3b-4:	4	Me
2a-5; 3a-5:	5	H
2b-5; 3b-5:	5	Me
2c-5; 3c-5:	5	F
2a-6; 3a-6:	6	H
2b-6; 3b-6:	6	Me
2a-7; 3a-7:	7	H
2b-7; 3b-7:	7	Me
2c-7; 3c-7:	7	F
2a-9; 3a-9; 4a-9:	9	H
2c-9; 3c-9; 4c-9:	9	F
4a-10:	10	H
4c-10:	10	F
2a-11; 3a-11; 4a-11:	11	H
4a-12:	12	H
4b-12:	12	Me

Chart 1.

Results and Discussion

Treatment of **1** with $X(CH_2)_nX$ (X = Br or I, n = 4—7) in *N*,*N*-dimethylformamide (DMF) containing sodium hydride

gave a mixture of **2** and **3** (ca. 1 : 1) as main products. Selective formation of either **2** or **3** was not observed in any experiment. When the numbers of n of $X(CH_2)_nX$ are more than 9, the compounds (**4**) were further obtained together with the mixture of **2** and **3**. Therefore, the important problem in the direct preparation of the pyrimidinophanes is how to elucidate the three types of structures of **2**, **3**, and **4**. The ^1H NMR and mass spectra of pyrimidinophanes **2** and **3** were similar. However, when the numbers of methylene groups in $X(CH_2)_nX$ are odd numbers ($n=5$, 7, 9, 11), the structures of **2** and **3** were differentiated on the basis of the numbers of peaks on the ^{13}C NMR spectra, e.g., the numbers of the peaks of the pentamethylene chain on the ^{13}C NMR spectra of **2a-5** were five whereas those of **3a-5** were six. On the other hand, the ^{13}C NMR spectral data did not give any evidence to distinguish structures of **2** and **3** with even numbers of methylene groups in $X(CH_2)_nX$ ($n=4$ and 6) such as **2a-4**, **3a-4**, **2b-4**, **3b-4**, **2a-6**, **3a-6**, **2b-6**, and **3b-6**. The structures of **4** were distinguishable from those of **2** and **3** on the basis of mass spectral data: e.g., both M^+ of **2a-9** and **3a-9** were 472, while that of **4a-9** was 236. Attempted isolation of the pyrimidinophanes from the treatment of **1a** or **1b** with $I(CH_2)_3I$ was not successful. The yields of **2**, **3**, and **4** are summarized in Table 1. In an effort to determine the relationship between the formation of pyrimidinophanes and the base used, treatment of **1** with $X(CH_2)_nX$ containing some other bases such as K_2CO_3, Na_2CO_3, *t*-BuOK, EtOK, K_2HPO_4, KOH containing small amounts of H_2O, and CH_3COOK instead of NaH in DMF was studied, but the

Table 1. Preparation of Pyrimidinophanes from Pyrimidine Bases

Pyrimidines	$X(CH_2)_nX$		Product/Isolated yield, %[a]
	n	X	
1a	4	Br	**2a-4**/7, **3a-4**/7, **1a**/47[a]
1b	4	Br	**2b-4**/7, **3b-4**/7, **1b**/44[a]
1a	5	I	**2a-5**/10, **3a-5**/7
1a	5	Br	**2a-5**/8, **3a-5**/8, **1a**/43[a]
1b	5	I	**2b-5**/14, **3b-5**/8
1b	5	Br	**2b-5**/10, **3b-5**/8, **1b**/44[a]
1c	5	I	**2c-5**/14, **3c-5**/8
1a	6	I	**2a-6**/16, **3a-6**/14[b]
1b	6	I	**2b-6**/18, **3b-6**/17[b]
1a	7	Br	**2a-7**/12, **3a-7**/11
1b	7	Br	**2b-7**/15, **3b-7**/15
1c	7	Br	**2c-7**/14, **3c-7**/14
1a	9	Br	**2a-9**/10, **3a-9**/8, **4a-9**/2
1c	9	Br	**2c-9**/7, **3c-9**/8, **4c-9**/4
1a	10	I	**4a-10**/10[c]
1c	10	I	**4c-10**/11[c]
1a	11	Br	**2a-11**/3, **3a-11**/4, **4a-11**/14
1a	12	Br	**4a-12**/15[c]
1b	12	Br	**4b-12**/15[c]

a) Yield was based on pyrimidine base used, and the amount of the recovered pyrimidines was not determined except for the reaction of **1a** and **1b** with $Br(CH_2)_4Br$ and $Br(CH_2)_5Br$. b) The yields of **2a-4**, **2b-4**, **2a-6**, and **2b-6** may be changed place with those of **3a-4**, **3b-4**, **3a-6**, and **3b-6**, respectively. c) Isolation of **2** and **3** was not attempted.

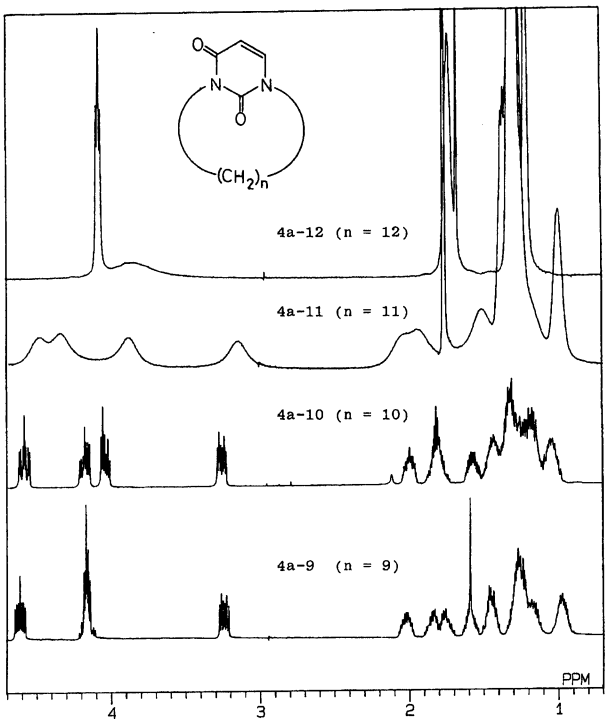


Fig. 1. ^1H NMR spectra of **4a-9**, **4a-10**, **4a-11**, and **4a-12** in $CDCl_3$ at 25 °C.

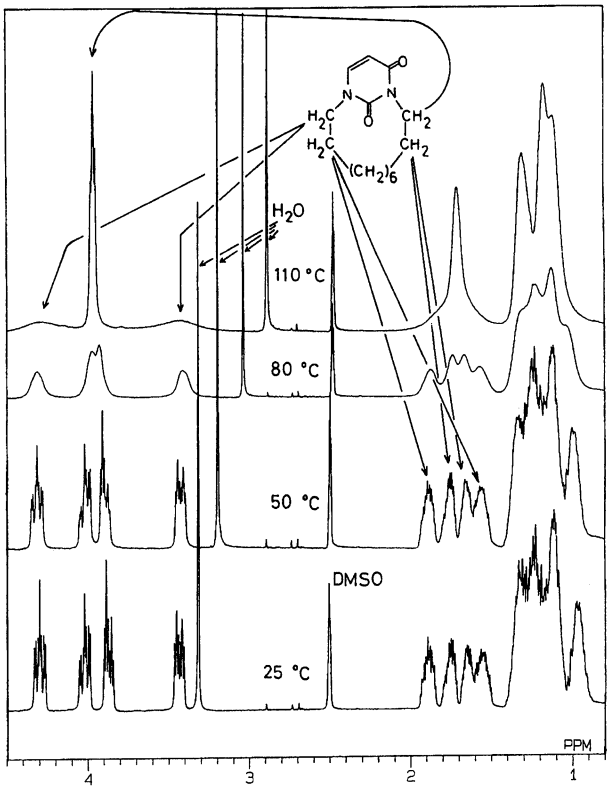


Fig. 2. Temperature-dependent ^1H NMR spectra of **4a-10** in DMSO-d_6.

pyrimidinophanes were not obtained as main products, although the reaction with K_2CO_3 and Na_2CO_3 gave a mixture of several products containing the pyrimidinophanes.[16] It is

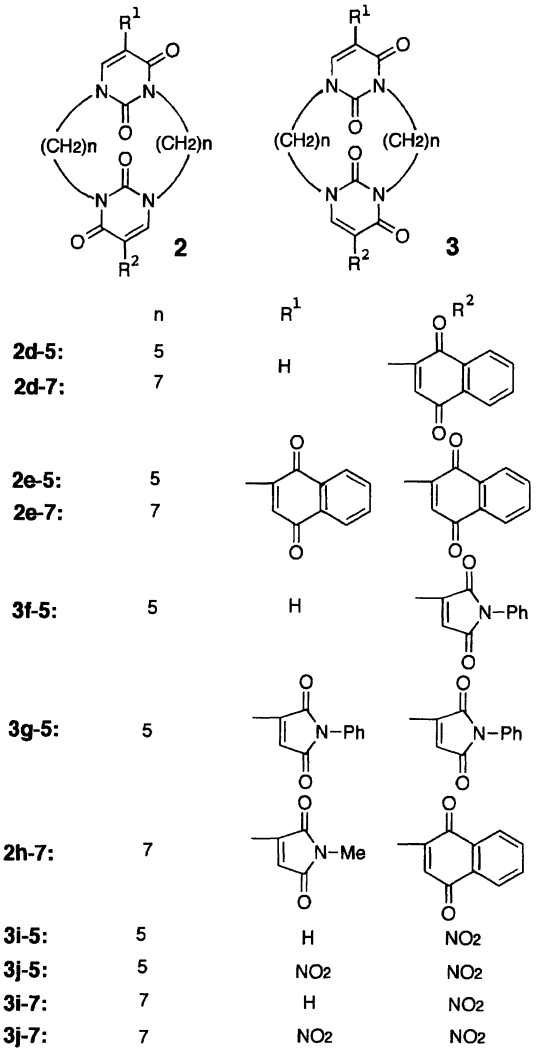


Chart 2.

Table 2. Alkenylation and Nitration of Pyrimidinophanes in the Presence of Palladium(II) Acetate

Pyrimidinophane	Addition	Recovered pyrimidinophane and product/Isolated yield, %[a]
2a-5	1,4-Naphthoquinone	**2a-5**/30; **2d-5**/22; **2e-5**/17
2a-7	1,4-Naphthoquinone	**2a-7**/32; **2d-7**/20; **2e-7**/17
3a-5	1-Phenylmalemide	**3a-5**/30; **3f-5**/23; **3g-5**/20
2d-7	1-Methylmalemide	**2d-7**/40; **2h-7**/32
3a-5	$NaNO_2$	**3a-5**/24; **3i-5**/23; **3j-5**/20
3a-7	$NaNO_2$	**3a-7**/27; **3i-7**/25; **3j-7**/17

a) Yield based on pyrimidinophane used.

synthetically of interest that the yields of pyrimidinophanes from a halogenated uracil such as **1c** were similar to those from **1a** and **1b**.

Some of the singly bridged pyrimidinophanes (**4**) show dynamic NMR behavior consistent with slow flipping of the chain, although heterocyclic meta-cyclophanes similar to **4**, such as [*n*](1,3)benzimidazolones,[17a] are known and the dynamic behavior is precedented.[17] Figure 1 shows the comparison of ^{1}H NMR spectra of **4a-9**, **4a-10**, **4a-11**, and **4a-12** in $CDCl_3$ at 25 °C: a relationship between the ring sizes of **4** and the conformations of their chains. It can be seen from Fig. 1 that the rotation among conformations of the polymethylene chains of **4a-9** and **4a-10** was restricted in the solution phase, in contrast to the free rotation of **4a-12**. Figure 2 shows the temperature-dependent ^{1}H NMR spectra of **4a-10** in DMSO-d_6. The nOe (nuclear Overhauser effect) experiments on **4a-10** (irrad. at the H-6) and its ^{1}H–^{1}H COSY and ^{13}C–^{1}H COSY NMR spectra led to the assignment shown in Fig. 2. The rotation among conformations of the chain of **4a-10** was restricted at 25 and 50 °C but the peaks at 80 and 110 °C were extremely broad due to slow exchange among conformations. The temperature-dependent ^{1}H NMR of **2a-4**, **3a-4**, **2b-4**, and **3b-4** in DMSO-d_6 also showed a dynamic NMR behavior consistent with slow flipping of the chain (see Experimental).

Some heterocyclic meta-cyclophanes, such as dimeric bridged benzimidazolinones and the related compounds, are known to show a selectivity in complexing calcium,[18] and the syntheses of two uracil units linked at the N-3 position with various spacers were reported in connection with the synthesis of ionophore.[19] These observations led us to investigate the synthesis of pyrimidinophanes with functional groups as precursors for host-guest molecules. Previously we reported the alkenylation of uracils with 1,4-naphthoquinone and maleimides[14] and the nitration with $NaNO_2$[15] in the presence of palladium(II) acetate. The reaction was applicable to the alkenylation and nitration of pyrimidinophanes. Treatment of **2a-5** with 1,4-naphthoquinone in the presence of palladium(II) acetate in acetic acid under nitrogen atmosphere at 100—110 °C for 14 h gave **2d-5** and **2e-5** (Chart 2). Similar treatment of **2a-7** gave **2d-7** and **2e-7**. Reaction of **3a-5** with 1-phenylmaleimide gave **3f-5** and **3g-5** and of **2d-7** with 1-methylmaleimide gave **2h-7**. Furthermore, treatment of **3a-5** and **3a-7** with $NaNO_2$ in the presence of $Pd(OAc)_2$ led to the formation of **3i-5**, **3j-5**, **3i-7**, and **3j-7**. These results are summarized in Table 2. These products have the same or different functional groups at two positions and therefore may be expected to be precursors for synthesis of supermolecules.

Experimental

The melting points were determined on a Yanagimoto micro melting-point apparatus and are uncorrected. The ^{1}H NMR spectra (400 MHz) and ^{13}C NMR spectra (100 MHz) were obtained with a JEOL GSX400 spectrometer. Chemical shifts were reported as ppm (δ) downfield from tetramethylsilane. Mass spectra were obtained with a JEOL JMS-D300 spectrometer. The elemental analyses were performed by the Analytical Center of Kyoto University.

Pyrimidinophanes from Uracil (1a), thymine (1b), and 5-fluorouracil (1c). Into a solution of **1** (10 mmol) and sodium hydride (20 mmol) in DMF (100 ml), $X(CH_2)_nX$ (X = Br or I, n = 4—12) (10 mmol) was added. The resulting mixture was stirred at room temperature for 15 h and then heated at 70 °C for 3 h. The reaction mixture was evaporated to give a residue which was submitted to chromatography over silica gel. By monitoring at 254 nm, elution of a mixture of hexane and ethyl acetate gave (**4**). Further elution of ethyl acetate (or a mixture of ethyl acetate and hexane) gave (**2**)

and (**3**) in that order. The spectral data are given below.

1,6,10,15-Tetraazatricyclo[13.3.1.1^{6,10}]eicosa-8,17-diene-7,16,19,20-tetrone (2a-4) (the sample may be 3a-4): Mp > 300 °C; ^{1}H NMR ($CDCl_3$) δ = 6.99 (d, 2H, J = 8.0 Hz), 5.67 (d, 2H, J = 8.0 Hz), 4.4—3.7 (broad, 8H), 1.80—1.50 (broad, 8H); ^{1}H NMR (DMSO-d_6, 27 °C) δ = 7.60 (d, 2H, J = 8.0 Hz), 5.61 (d, 2H, J = 8.0 Hz), 4.3—3.8 (broad, 4H), 3.7—3.2 (broad, 2H), 1.55—1.35 (broad, 8H); (DMSO-d_6, 50 °C) δ = 7.56 (d, 2H, J = 8.0 Hz), 5.59 (d, 2H, J = 8.0 Hz), 4.2—3.3 (broad, 8H), 1.55—1.40 (broad, 8H); (DMSO-d_6, 80 °C) δ = 7.51 (d, 2H, J = 8.0 Hz), 5.56 (d, 2H, J = 8.0 Hz), 3.90—3.80 (broad, 4H), 3.70—3.60 (broad, 4H), 1.60—1.40 (broad, 8H); ^{13}C NMR (DMSO-d_6) δ = 162.93, 149.57, 145.54, 98.72, 49.83, 38.05, 21.70, 21.08; MS *m/z* (rel intensity, %) 333 (22), 332 (100).

1,6,10,15-Tetraazatricyclo[13.3.1.1^{6,10}]eicosa-8,16-diene-7,18,19,20-tetrone (3a-4) (the sample may be 2a-4): Mp > 300 °C; ^{1}H NMR (DMSO-d_6, 27 °C) δ = 7.61 (d, 2H, J = 8.0 Hz), 5.62 (d, 2H, J = 8.0 Hz), 4.3—3.8 (broad, 4H), 4.6—4.1 (broad, 4H), 1.60—1.50 (broad, 4H), 1.40—1.30 (broad, 4H); (DMSO-d_6, 80 °C) δ = 7.52 (d, 2H, J = 8.0 Hz), 5.57 (d, 2H, J = 8.0 Hz), 3.90—3.85 (broad, 4H), 3.85—3.60 (broad, 4H), 1.60—1.55 (broad, 4H), 1.45—1.40 (broad, 4H); ^{13}C NMR (DMSO-d_6) δ = 162.92, 149.55, 145.41, 98.80, 49.64, 38.13, 21.55, 21.11.

8,17-Dimethyl-1,6,10,15-tetraazatricyclo[13.3.1.1^{6,10}]eicosa-8,17-diene-7,16,19,20-tetrone (2b-4) (the sample may be 3b-4): Mp > 300 °C; ^{1}H NMR (DMSO-d_6, 27 °C) δ = 7.51 (s, 2H) 4.3—3.8 (broad, 4H), 3.7—3.2 (broad, 4H), 1.78 (s, 6H), 1.55—1.30 (broad, 8H); (DMSO-d_6, 50 °C) δ = 7.46 (s, 2H), 4.8—3.3 (broad, 8H), 1.79 (s, 6H), 1.55—1.45 (broad, 4H), 1.45—1.35 (broad, 4H); (DMSO-d_6, 80 °C) δ = 7.40 (s, 2H), 3.90—3.80 (broad, 4H), 3.70—3.60 (broad, 4H), 1.79 (s, 6H), 1.57—1.50 (broad, 4H), 1.50—1.43 (broad, 4H); ^{13}C NMR (DMSO-d_6) δ = 163.66, 149.40, 141.64, 106.08, 49.48, 38.30, 21.86, 21.22, 12.02; MS *m/z* (rel intensity, %) 361 (M^+ + 1; 14), 360 (M^+; 65), 83 (100).

8,17-Dimethyl-1,6,10,15-tetraazatricyclo[13.3.1.1^{6,10}]eicosa-8,16-diene-7,18,19,20-tetrone (3b-4) (the sample may be 2b-4): Mp > 300 °C; ^{1}H NMR ($CDCl_3$) δ = 6.83 (s, 2H), 4.6—3.0 (broad, 8H), 1.92 (s, 6H), 1.8—1.5 (broad, 8H); (DMSO-d_6, 27 °C) δ = 7.52 (s, 2H) 4.3—3.8 (broad, 4H), 3.6—3.1 (broad, 4H), 1.79 (s, 6H), 1.6—1.4 (broad, 4H), 1.4—1.3 (broad, 4H); (DMSO-d_6, 80 °C) δ = 7.41 (s, 2H), 3.90—3.80 (broad, 4H), 3.70—3.60 (broad, 4H), 1.80 (s, 6H), 1.60—1.50 (broad, 4H), 1.42—1.35 (broad, 4H); ^{13}C NMR ($CDCl_3$) δ = 164.34, 150.07, 139.76, 108.89, 51.05, 39.41, 22.35, 21.65, 13.31; (DMSO-d_6) 163.66, 149.38, 141.52, 106.14, 49.53, 38.43, 21.62, 21.17, 12.63; MS *m/z* (rel intensity, %) 361 (M^+ + 1; 22), 360 (M^+; 100).

1,7,11,17-Tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,19-diene-8,18,21,22-tetrone (2a-5): Mp 203—205 °C; ^{1}H NMR ($CDCl_3$) δ = 7.05 (d, 2H, J = 8 Hz), 5.68 (d, 2H, J = 8 Hz), 4.06 (t, 4H, J = 6 Hz), 3.83 (broad, 4H), 1.8—1.6 (m, 8H), 1.25—1.1 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 163.24, 150.02, 142.10, 101.61, 48.33, 40.74, 29.53, 27.65, 23.10; MS *m/z* (rel intensity, %) 361 (M^+ + 1; 22), 360 (M^+; 100). Found: C, 59.91; H, 6.72; N, 15.54%. Calcd for $C_{18}H_{24}N_4O_4$: C, 59.98; H, 6.71; N, 15.55%.

1,7,11,17-Tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3a-5): Mp 263—266 °C; ^{1}H NMR ($CDCl_3$) δ = 7.05 (d, 2H, J = 8 Hz), 5.69 (d, 2H, J = 8 Hz), 4.04 (t, 4H, J = 6 Hz), 3.85 (broad, 4H), 1.8—1.6 (m, 8H), 1.35—1.25 (m, 2H), 1.25—1.15 (m, 2H); (DMSO-d_6, 25 °C) δ = 7.62 (d, 2H, J = 8 Hz), 5.61 (d, 2H, J = 8Hz), 3.85 (t, 4H, J = 6 Hz), 3.77 (broad, 4H), 1.7—1.6 (m, 4H), 1.6—1.5 (m, 4H), 1.1—0.95 (m, 4H); (DMSO-d_6, 80 °C) δ = 7.53 (d, 2H, J = 8 Hz), 5.57 (d, 2H, J = 8 Hz), 3.86 (t, 4H, J = 6 Hz), 3.80 (t, 4H, J = 6 Hz), 1.7—1.6 (m, 4H), 1.6—1.5 (m, 4H), 1.15—1.05 (m, 2H), 1.05—0.95 (m, 2H); ^{13}C NMR ($CDCl_3$) δ = 162.99, 152.29, 141.54, 102.09, 48.18, 41.22, 29.67, 28.23, 24.13, 23.16; MS *m/z* (rel intensity, %) 361 (M^+ + 1; 22), 360 (M^+; 100). Found: C, 59.81; H, 6.75; N, 15.60%. Calcd for $C_{18}H_{24}N_4O_4$: C, 59.98; H, 6.71; N, 15.55%.

9,19-Dimethyl-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,19-diene-8,18,21,22-tetrone (2b-5): Mp 285—288 °C; ^{1}H NMR ($CDCl_3$) δ = 6.91 (q, 2H, J = 1 Hz), 4.06 (t, 4H, J = 6 Hz), 3.8 (broad, 4H), 1.91 (d, 6H, J = 1 Hz), 1.8—1.6 (m, 8H), 1.3—1.1 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 163.99, 152.08, 138.11, 109.66, 47.77, 41.21, 29.89, 27.97, 23.29, 13.06; MS *m/z* (rel intensity, %) 389 (M^+ + 1; 17), 388 (M^+; 72), 166 (100). Found: C, 62.09; H, 7.40; N, 14.13%. Calcd for $C_{20}H_{28}N_4O_4$: C, 61.83; H, 7.27; N, 14.42%.

9,19-Dimethyl-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3b-5): Mp 247—250 °C; ^{1}H NMR ($CDCl_3$) δ = 6.88 (q, 2H, J = 1 Hz), 4.05 (t, 4H, J = 6 Hz), 3.83 (broad, 4H), 1.8—1.6 (m, 8H), 1.91 (d, 6H, J = 1 Hz), 1.35—1.25 (m, 2H), 1.25—1.10 (m, 2H); ^{13}C NMR ($CDCl_3$) δ = 163.70, 152.24, 137.85, 109.92, 47.92, 41.39, 29.75, 28.32, 24.14, 23.26, 13.03; MS *m/z* (rel intensity, %) 389 (M^+ + 1; 24), 388 (M^+; 100). Found: C, 61.99; H, 7.36; N, 14.49%. Calcd for $C_{20}H_{28}N_4O_4$: C, 61.83; H, 7.27; N, 14.42%.

9,19-Difluoro-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,19-diene-8,18,21,22-tetrone (2c-5): Mp 295—300 °C; ^{1}H NMR ($CDCl_3$) δ = 7.13 (d, 2H, J = 5 Hz), 4.09 (t, 4H, J = 6 Hz), 3.84 (broad, 4H), 1.8—1.6 (m, 8H), 1.3—1.15 (m, 4H); (DMSO-d_6, 30 °C) δ = 8.06 (d, 2H, J = 5.5 Hz), 3.89 (t, 4H, J = 6 Hz), 3.74 (broad, 4H), 1.65—1.55 (m, 8H), 1.1—1.0 (m, 4H); (DMSO-d_6, 80 °C) δ = 7.95 (d, 2H, J = 6 Hz), 3.90 (t, 4H, J = 6 Hz), 3.74 (t, 4H, J = 6 Hz), 1.7—1.6 (m, 8H), 1.1—1.0 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 157.32 (d, J = 25 Hz), 150.63, 140.10 (d, J = 234 Hz), 129.97 (d, J = 32 Hz), 48.28, 41.83, 29.61, 27.70, 23.29; MS *m/z* (rel intensity, %) 397 (M^+ + 1; 23), 396 (M^+; 100). Found: C, 54.27; H, 5.56; N, 14.00%. Calcd for $C_{18}H_{22}F_2N_4O_4$: C, 54.54; H, 5.59; N, 14.13%.

9,19-Difluoro-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3c-5): Mp 260—265 °C; ^{1}H NMR ($CDCl_3$) δ = 7.11 (d, 2H, J = 5 Hz), 4.07 (t, 4H, J = 6 Hz), 3.85 (broad, 4H), 1.8—1.6 (m, 8H), 1.4—1.25 (m, 2H), 1.25—1.1 (m, 2H); ^{13}C NMR ($CDCl_3$) δ = 157.11 (d, J = 25 Hz), 150.80, 140.24 (d, J = 234 Hz), 125.77 (d, J = 32 Hz), 48.46, 42.13, 29.56, 28.11, 24.07, 23.24; MS *m/z* (rel intensity, %) 397 (M^+ + 1; 22), 296 (M^+; 100). Found: C, 54.24; H, 5.86; N, 13.88%. Calcd for $C_{18}H_{22}F_2N_4O_4$: C, 54.54; H, 5.59; N, 14.13%.

1,8,12,19-Tetraazatricyclo[17.3.1.1^{8,12}]tetracosa-10,21-diene-9,20,23,24-tetrone (2a-6) (the sample may be 3a-6): ^{1}H NMR ($CDCl_3$) δ = 7.06 (d, 2H, J = 8 Hz), 5.67 (d, 2H, J = 8 Hz), 3.96 (t, 4H, J = 6 Hz), 3.73 (t, 4H, J = 6 Hz), 1.75—1.6 (m, 8H), 1.5—1.4 (m, 8H); ^{13}C NMR ($CDCl_3$) δ = 163.31, 151.27, 142.37, 101.31, 49.50, 40.20, 27.94, 26.75, 25.03, 24.86.

1,8,12,19-Tetraazatricyclo[17.3.1.1^{8,12}]tetracosa-10,20-diene-9,22,23,24-tetrone (3a-6) (the sample may be 2a-6): ^{1}H NMR ($CDCl_3$) δ = 7.05 (d, 2H, J = 8 Hz), 5.68 (d, 2H, J = 8 Hz), 3.96 (t, 4H, J = 6 Hz), 3.73 (t, 4H, J = 6 Hz), 1.75—1.6 (m, 8H), 1.4—1.3 (m, 8H); ^{13}C NMR ($CDCl_3$) δ = 163.26, 151.25, 142.13, 101.45, 49.32, 40.33, 28.10, 26.59, 25.15, 24.59.

10,21-Dimethyl-1,8,12,19-tetraazatricyclo[17.3.1.1^{8,12}]tetracosa-10,21-diene-9,20,23,24-tetrone (2b-6) (the sample may be 3b-6): Mp 237—240 °C; ^{1}H NMR ($CDCl_3$) δ = 6.91 (q, 2H, J = 1 Hz), 3.98 (t, 4H, J = 6 Hz), 3.70 (t, 4H, J = 6 Hz), 1.92 (d, 6H, J = 1 Hz), 1.7—1.57 (m, 8H), 1.4— 1.27 (m, 8H); ^{13}C NMR ($CDCl_3$) δ = 164.01, 151.20, 138.71, 109.30, 49.20, 40.41, 27.93,

26.86, 25.11, 24.92, 13.07.

10,21-Dimethyl-1,8,12,19-tetraazatricyclo[17.3.1.1^{8,12}]tetracosa-10,20-diene-9,22,23,24-tetrone (3b-6) (the sample may be 2b-6): Mp 223—225 °C; ^{1}H NMR ($CDCl_3$) δ = 6.90 (q, 2H, J = 1 Hz), 3.98 (t, 4H, J = 6 Hz), 3.70 (t, 4H, J = 6 Hz), 1.92 (d, 6H, J = 1 Hz), 1.75—1.6 (m, 8H), 1.4—1.3 (m, 8H); ^{13}C NMR ($CDCl_3$) δ = 163.98, 151.19, 138.43, 109.44, 49.06, 40.52, 28.11, 26.65, 25.25, 24.67, 13.09.

1,9,13,21-Tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,23-diene-10,22,25,26-tetrone (2a-7): Mp 173—175 °C; ^{1}H NMR ($CDCl_3$) δ = 7.06 (d, 2H, J = 8 Hz), 5.69 (d, 2H, J = 8 Hz), 3.97 (t, 4H, J = 6.5 Hz), 3.79 (t, 4H, J = 6 Hz), 1.7—1.57 (m, 8H), 1.35—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 163.07, 151.97, 141.69, 101.86, 48.58, 41.15, 29.69, 29.63, 27.64, 26.58, 25.97. MS m/z (rel intensity, %) 417 (M^+ + 1; 22) 416 (M^+; 100). Found: C, 63.07; H, 7.68; N, 13.49%. Calcd for $C_{22}H_{32}N_4O_4$: C, 63.44; H, 7.74; N, 13.45%.

1,9,13,21-Tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,22-diene-10,24,25,26-tetrone (3a-7): Mp 179—182 °C; ^{1}H NMR ($CDCl_3$) δ = 7.07 (d, 2H, J = 8 Hz), 5.68 (d, 2H, J = 8 Hz), 3.97 (t, 4H, J = 6.5 Hz), 3.79 (t, 4H, J = 6 Hz), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 162.99, 152.01, 141.68, 101.90, 48.73, 41.22, 30.04, 29.53, 29.49, 27.85, 26.61, 26.13; MS m/z (rel intensity, %) 417 (M^+ + 1; 23) 416 (M^+; 100). Found: C, 63.14; H, 7.46; N, 13.56%. Calcd for $C_{22}H_{32}N_4O_4$: C, 63.44; H, 7.74; N, 13.45%.

11,23-Dimethyl-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,23-diene-10,22,25,26-tetrone (2b-7): Mp 245—248 °C; ^{1}H NMR ($CDCl_3$) δ = 6.91 (s, 2H), 3.98 (t, 4H, J = 6.5 Hz), 3.77 (t, 4H, J = 6 Hz), 1.91 (s, 6H), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 163.75, 151.98, 137.82, 109.93, 48.10, 41.12, 29.87, 29.79, 27.76, 26.68, 25.99, 13.02; MS m/z (rel intensity, %) 445 (M^+ + 1; 26) 444 (M^+; 100). Found: C, 64.88; H, 8.17; N, 12.50%. Calcd for $C_{24}H_{36}N_4O_4$: C, 64.84; H, 8.16; N, 12.60%.

11,23-Dimethyl-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,22-diene-10,24,25,26-tetrone (3b-7): Mp 247—250 °C; ^{1}H NMR ($CDCl_3$) δ = 6.90 (s, 2H), 3.99 (t, 4H, J = 6.5 Hz), 3.76 (t, 4H, J = 6.5 Hz), 1.91 (s, 6H), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 163.69, 152.03, 137.77, 110.00, 48.35, 41.48, 30.23, 29.69, 29.67, 27.97, 26.68, 26.22, 13.02; MS m/z (rel intensity, %) 445 (M^+ + 1; 27) 444 (M^+; 100). Found: C, 64.54; H, 8.12; N, 12.64%. Calcd for $C_{24}H_{36}N_4O_4$: C, 64.84; H, 8.16; N, 12.60%.

11,23-Difluoro-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,23-diene-10,22,25,26-tetrone (2c-7): Mp 222—225 °C; ^{1}H NMR ($CDCl_3$) δ = 7.15 (d, 2H, J = 5 Hz), 4.01 (t, 4H, J = 6.5 Hz), 3.80 (t, 4H, J = 6 Hz), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 157.18 (d, J = 25 Hz), 150.43, 140.15 (d, J = 234 Hz), 125.98 (d, J = 32 Hz), 48.62, 42.02, 29.61, 29.48, 27.54, 26.57, 25.87; MS m/z (rel intensity, %) 453 (M^+ + 1; 16) 452 (M^+; 61), 100 (100). Found: C, 58.59; H, 6.79; N, 12.32%. Calcd for $C_{22}H_{30}F_2N_4O_4$: C, 58.40; H, 6.68; N, 12.38%.

11,23-Difluoro-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,22-diene-10,24,25,26-tetrone (3c-7): Mp 253—257 °C; ^{1}H NMR ($CDCl_3$) δ = 7.13 (d, 2H, J = 5 Hz), 4.01 (t, 4H, J = 6.5 Hz), 3.78 (t, 4H, J = 6.5 Hz), 1.7—1.6 (m, 8H), 1.4—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 157.13 (d, J = 25 Hz), 150.48, 140.21 (d, J = 234 Hz), 125.49 (d, J = 32 Hz), 48.93, 42.14, 29.97, 29.44, 29.39, 27.75, 26.53, 26.11; MS m/z (rel intensity, %) 453 (M^+ + 1; 14) 452 (M^+; 49), 444 (100). Found: C, 58.27; H, 6.62; N, 12.27%. Calcd for $C_{22}H_{30}F_2N_4O_4$: C, 58.40; H, 6.68; N, 12.38%.

1,11,15,25-Tetraazatricyclo[23.3.1.1^{11,15}]triaconta-13,27-diene-12,26,29,30-tetrone (2a-9): Mp 170—172 °C; ^{1}H NMR ($CDCl_3$) δ = 7.08 (d, 2H, J = 8 Hz), 5.70 (d, 2H, J = 8 Hz), 3.96 (t, 4H, J = 6.5 Hz), 3.77 (t, 4H, J = 6.5 Hz), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 20H); ^{13}C NMR ($CDCl_3$) δ = 163.16, 151.79, 141.95, 101.73, 49.20, 41.17, 29.41, 29.32, 29.15, 29.10, 27.47, 26.65, 26.12; MS m/z (rel intensity, %) 473 (M^+ + 1; 31) 472 (M^+; 100). Found: C, 65.78; H, 8.73; N, 11.77%. Calcd for $C_{26}H_{40}N_4O_4$: C, 66.07; H, 8.53; N, 11.86%.

1,11,15,25-Tetraazatricyclo[23.3.1.1^{11,15}]triaconta-13,26-diene-12,28,29,30-tetrone (3a-9): Mp 186—190 °C; ^{1}H NMR ($CDCl_3$) δ = 7.06 (d, 2H, J = 8 Hz), 5.70 (d, 2H, J = 8 Hz), 3.96 (t, 4H, J = 6.5 Hz), 3.76 (t, 4H, J = 6.5 Hz), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 20H); ^{13}C NMR ($CDCl_3$) δ = 163.12, 151.81, 141.84, 101.79, 49.26, 41.22, 29.58, 29.24, 29.21, 29.14, 29.11, 27.54, 26.65, 26.19; MS m/z (rel intensity, %) 473 (M^+ + 1; 15) 472 (M^+; 53), 96 (100). Found: C, 66.44; H, 8.50; N, 11.61%. Calcd for $C_{26}H_{40}N_4O_4$: C, 66.07; H, 8.53; N, 11.86%.

1,11-Diazabicyclo[9.3.1]pentadec-13-ene-12,15-dione (4a-9): Mp 92—93 °C; ^{1}H NMR ($CDCl_3$) δ = 7.08 (d, 1H, J = 8 Hz), 5.74 (d, 1H, J = 8 Hz), 4.61 (ddd, 1H, J = 14, 9, and 4.5 Hz), 4.22—4.10 (m, 2H), 3.24 (dt, 1H, J = 14 and 5 Hz), 2.08—1.97 (m, 1H), 1.9—1.8 (m, 1H), 1.8—1.7 (m, 1H), 1.64—1.53 (m, 1H), 1.5—1.4 (m, 2H), 1.35—1.1 (m, 6H), 1.05—0.93 (m, 2H); ^{13}C NMR ($CDCl_3$) δ = 163.30, 152.39, 142.44, 101.70, 49.26, 40.63, 25.48, 25.47, 25.14, 24.78, 23.54, 23.44, 23.27; MS m/z (rel intensity, %) 237 (M^+ + 1; 16) 236 (M^+; 100). Found: C, 66.01; H, 8.77; N, 11.77%. Calcd for $C_{13}H_{20}N_2O_2$: C, 66.07; H, 8.53; N, 11.86%.

13,27-Difluoro-1,11,15,25-tetraazatricyclo-[23.3.1.1^{11,15}]triconta-13,27-diene-12,26,29,30-tetrone (2c-9): Mp 238—241 °C; ^{1}H NMR ($CDCl_3$) δ = 7.15 (d, 2H, J = 5 Hz), 4.00 (t, 4H, J = 6.5 Hz), 3.77 (t, 4H, J = 6.5 Hz), 1.72—1.6 (m, 8H), 1.35—1.15 (m, 20H); ^{13}C NMR ($CDCl_3$) δ = 157.24 (d, J = 25 Hz), 150.24, 140.12, (d, J = 234 Hz), 126.21, (d, J = 32 Hz), 49.22, 42.00, 29.36, 29.29, 29.13, 29.03, 27.37, 26.62, 26.02; MS m/z (rel intensity, %) 509 (M^+ + 1; 5) 508 (M^+; 19), 364, (96), 68 (100). Found: C, 61.22; H, 7.51; N, 11.06%. Calcd for $C_{26}H_{38}F_2N_4O_4$: C, 61.40; H, 7.53; N, 11.02%.

13,27-Difluoro-1,11,15,25-tetraazatricyclo-[23.3.1.1^{11,15}]triconta-13,26-diene-12,28,29,30-tetrone (3c-9): Mp 215—218 °C; ^{1}H NMR ($CDCl_3$) δ = 7.16 (d, 2H, J = 5 Hz), 4.00 (t, 4H, J = 6.5 Hz), 3.76 (t, 4H, J = 6.5 Hz), 1.7—1.6 (m, 8H), 1.35—1.15 (m, 20H); ^{13}C NMR ($CDCl_3$) δ = 157.21 (d, J = 25 Hz), 150.26, 140.15, (d, J = 234 Hz), 126.11, (d, J = 32 Hz), 49.35, 42.04, 29.52, 29.20, 29.18, 29.15, 28.99, 27.43, 26.58, 26.13; MS m/z (rel intensity %) 509 (M^+ + 1; 20) 508 (M^+; 60), 491 (81), 385 (82), 364 (84), 68 (100). Found: C, 61.39; H, 7.55; N, 11.01%. Calcd for $C_{26}H_{38}F_2N_4O_4$: C, 61.40; H, 7.53; N, 11.02%.

13-Fluoro-1,11-Diazabicyclo[9.3.1]pentadec-13-ene-12,15-dione (4c-9): Mp 93—95 °C; ^{1}H NMR ($CDCl_3$) δ = 7.19 (d, 1H, J = 5 Hz), 4.64 (ddd, 1H, J = 14, 9, and 4.5 Hz), 4.23—4.13 (m, 2H), 3.21 (dt, 1H, J = 14 and 5 Hz), 2.05—1.90 (m, 1H), 1.9—1.7 (m, 2H), 1.7—1.55 (m, 1H), 1.55—1.4 (m, 2H), 1.4—1.1 (m, 6H), 1.0—0.85 (m, 2H); ^{13}C NMR ($CDCl_3$) δ = 157.30 (d, J = 25 Hz), 150.86, 140.14, (d, J = 234 Hz), 126.70, (d, J = 32 Hz), 49.29, 41.57, 25.59, 25.53, 25.23, 24.67, 23.48, 23.47, 23.29, MS m/z (rel intensity %) 255 (M^+ + 1; 17) 254 (M^+; 100). Found: C, 61.18; H, 7.52; N, 10.96%. Calcd for $C_{13}H_{19}FN_2O_2$: C, 61.40; H, 7.53; N, 11.02%.

1,12-Diazabicyclo[10.3.1]hexadec-14-ene-13,16-dione (4a-10): Mp 88—89 °C; ^{1}H NMR ($CDCl_3$) δ = 7.09 (d, 1H, J = 8 Hz), 5.74 (d, 1H, J = 8 Hz), 4.60 (ddd, 1H, J = 14, 8, and 4 Hz), 4.19

(ddd, 1H, J = 13, 10, and 5 Hz), 4.06 (dt, 1H, J = 13 and 6 Hz), 3.23 (dt, 1H, J = 14 and 5 Hz), 2.05—1.95 (m, 1H), 1.9—1.75 (m, 2H), 1.6—1.5 (m, 1H), 1.5—1.35 (m, 2H), 1.35—1.1 (m, 8H), 1.1—1.0 (m, 2H); N.O.e difference measurement ($CDCl_3$, 25 °C, irrad. at H-6) δ = 3.23 (2.5% enhancement) and 4.60 (1.0%); ^{13}C NMR and ^{13}C–^1H COSY NMR ($CDCl_3$) δ = 163.23, 152.67, 141.96 (δ = 7.09), 102,07, (δ = 5.74), 49.13 (δ = 4.60 and 3.23) 41.61 (δ = 4.19 and 4.06), 26.84, 26.69, 26.31, 26.26, 26.12, 25.32, 24.96, 24.90; MS *m/z* (rel intensity %) 251 (M^+ + 1; 18) 250 (M^+; 100). Found: C, 66.87; H, 9.03; N, 11.03%. Calcd for $C_{14}H_{22}N_2O_2$: C, 67.17; H, 8.86; N, 11.19%.

14-Fluoro-1,12-diazabicyclo[10.3.1]hexadec-14-ene-13,16-dione (4c-10): Mp 82—83 °C; ^1H NMR ($CDCl_3$) δ = 7.23 (d, 1H, J = 5 Hz), 4.63 (ddd, 1H, J = 14, 10, and 3 Hz), 4.25—4.15 (m, 1H), 4.11 (dt, 1H, J = 13 and 5 Hz), 3.22 (dt, 1H, J = 14 and 4.5 Hz), 2.05—1.90 (m, 1H), 1.88—1.78 (m, 1H), 1.65—1.52 (m, 1H), 1.50—1.40 (m, 1H), 1.40—1.10 (m, 8H), 1.10—0.95 (m, 2H), 0.90—0.80 (m, 1H); ^{13}C NMR ($CDCl_3$) δ = 157.33 (d, J = 25 Hz), 151.07, 140.24, (d, J = 234 Hz), 126.19, (d, J = 32 Hz), 49.10, 42.47, 26.74, 26.70, 26.24, 26.16, 26.15, 25.33, 24.84, 24.78; MS *m/z* (rel intensity %) 269 (M^+ + 1; 17) 268 (M^+; 100). Found: C, 62.82; H, 8.06; N, 10.35%. Calcd for $C_{14}H_{21}FN_2O_2$: C, 62.67; H, 7.89; N, 10.44%.

1,13,17,29-Tetraazatricyclo[27.3.1.1^{13,17}]tetratriaconta-15,31-diene-14,30,33,34-tetrone (2a-11): Mp 149—151 °C; ^1H NMR ($CDCl_3$) δ = 7.08 (d, 2H, J = 8 Hz), 5.71 (d, 2H, J = 8 Hz), 3.95 (t, 4H, J = 7 Hz), 3.75 (t, 4H, J = 7 Hz), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 28H); ^{13}C NMR ($CDCl_3$) δ = 163.18, 151.62, 141.99, 101.67, 49.47, 41.22, 29.45, 29.32, 29.26, 29.22, 29.13, 29.08, 27.47, 26.76, 26.25; MS *m/z* (rel intensity %) 529 (M^+ + 1; 33) 528 (M^+; 100). Found: C, 68.55; H, 9.38; N, 10.45%. Calcd for $C_{30}H_{48}N_4O_4$: C, 68.15; H, 9.15; N, 10.60%.

1,13,17,29-Tetraazatricyclo[27.3.1.1^{13,17}]tetratriaconta-15,30-diene-14,32,33,34-tetrone (3a-11): Mp 158—160 °C; ^1H NMR ($CDCl_3$) δ = 7.08 (d, 2H, J = 8 Hz), 5.71 (d, 2H, J = 8 Hz), 3.96 (t, 4H, J = 7 Hz), 3.75 (t, 4H, J = 7 Hz), 1.7—1.55 (m, 8H), 1.35—1.15 (m, 28H); ^{13}C NMR ($CDCl_3$) δ = 163.18, 151.64, 141.96, 101.69, 49.52, 41.22, 29.55, 29.38, 29.37, 29.31, 29.22, 29.12, 29.06, 27.48, 26.74, 26.28; MS *m/z* (rel intensity %) 529 (M^+ + 1; 32) 528 (M^+; 100). Found: C, 68.33; H, 9.48; N, 10.61%. Calcd for $C_{30}H_{48}N_4O_4$: C, 68.15; H, 9.15; N, 10.60%.

1,13-Diazabicyclo[11.3.1]heptadec-15-ene-14,17-dione (4a-11): Mp 83—84 °C; ^1H NMR ($CDCl_3$) δ = 7.07 (d, 1H, J = 8 Hz), 5.69 (d, 1H, J = 8 Hz), 4.6—3.8 (broad, 3H), 3.5—2.9 (broad, 1H), 2.1—1.4 (broad, 4H), 1.4—0.9 (m, 14H); ^{13}C NMR ($CDCl_3$) δ = 163.69, 151.24, 143.10, 100.85, 50.59, 40.29, 26.48, 26.17, 25.89, 25.79, 25.43, 24.46, 24.01, 22.67, 22.61; MS *m/z* (rel intensity %) 265 (M^+ + 1; 18) 264 (M^+; 100). Found: C, 63.78; H, 9.38; N, 9.91%. Calcd for $C_{15}H_{24}N_2O_2 \cdot H_2O$: C, 63.80; H, 9.28; N, 9.92%.

1,14-Diazabicyclo[12.3.1]octadec-16-ene-15,18-dione (4a-12): Mp 68—69 °C; ^1H NMR ($CDCl_3$) δ = 7.09 (d, 1H, J = 8 Hz), 5.72 (d, 1H, J = 8 Hz), 4.07 (t, 2H, J = 6 Hz), 3.85 (broad, 2H), 1.8—1.65 (m, 8H), 1.35—1.15 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 163.39, 152.09, 142.21, 101.59, 49.11, 40.82, 28.23, 27.49, 27.12, 27.00, 26.71, 26.66, 26.15, 26.08, 24.78, 24.36; MS *m/z* (rel intensity %) 279 (M^+ + 1; 18) 278 (M^+; 100). Found: C, 64.73; H, 9.55; N, 9.52%. Calcd for $C_{16}H_{26}N_2O_2 \cdot H_2O$: C, 64.83; H, 9.52; N, 9.45%.

16-Methyl-1,14-diazabicyclo[12.3.1]octadec-16-ene-15,18-dione (4b-12): Mp 78—79 °C; ^1H NMR ($CDCl_3$) δ = 6.94 (s, 1H), 4.09 (t, 2H, J = 6 Hz), 3.8 (broad, 2H), 1.95 (s, 3H), 1.8—1.6 (m, 4H), 1.4—1.1 (m, 16H); ^{13}C NMR ($CDCl_3$) δ = 164.03, 152.10, 138.33, 109.65, 48.62, 40.96, 28.40, 27.46, 27.15, 27.10, 26.83, 26.72, 26.18, 26.15, 24.80, 24.44, 13.15; MS *m/z* (rel intensity %) 293 (M^+ + 1; 21) 292 (M^+; 100). Found: C, 69.30; H, 9.75; N, 9.41%. Calcd for $C_{17}H_{28}N_2O_2$: C, 69.82; H, 9.96; N, 9.58%.

Coupling of Pyrimidinophanes with 1,4-Naphthoquinone or Maleimides by Palladium(II) Acetate. Mixture of **2a** such as **2a-5** and **2a-7** (1 mmol) and 1,4-naphthoquinone (2 mmol) in the presence of palladium(II) acetate (2 mmol) in acetic acid (100 ml) was heated at 100—110 °C under nitrogen atmosphere for 14 h. The reaction mixture was evaporated and chromatographed over silica gel by monitoring at 254 nm. Elution with ethyl acetate gave the coupling products such as **2d-5**, **2e-5**, **2d-7**, and **2e-7** together with recovered pyrimidinophanes. Under similar conditions, treatment of **3a-5** (1 mmol) and 1-phenylmaleimide (2 mmol) in the presence of palladium(II) acetate (2 mmol) gave **3f-5** and **3g-5**. The reaction of **2d-7** (1 mmol) with 1-methylmaleimide (1 mmol) in the presence of palladium(II) acetate (1 mmol) gave **2h-7**. The yields are summarized in Table 2. The spectral data of the coupling products are given below.

9-(1,4-Dihydro-1,4-dioxo-2-naphthyl)-1,7,11,17-tetraazabicyclo[15.3.1.1^{7,11}]docosa-9,19-diene-8,18,21,22-tetrone (2d-5): Mp 212—215 °C; ^1H NMR ($CDCl_3$) δ = 8.12—8.06 (m, 2H), 7.94 (s, 1H), 7.56—7.73 (m, 2H), 7.67 (s, 1H), 7.04 (d, 1H, J = 8 Hz), 5.63 (d, 1H, J = 8 Hz), 4.13 (t, 2H, J = 5.5 Hz), 4.06 (t, 2H, J = 5.5 Hz), 3.98 (broad, 2H), 3.83 (broad, 2H), 1.8—1.65 (m, 8H), 1.35—1.20 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 184.88, 184.46, 163.17, 161.32, 152.13, 150.85, 145.82, 141.95, 138.93, 136.36, 134.04, 133.72, 132.46, 132.00, 127.04, 125.97, 104.89, 101.80, 49.27, 48.39, 41.68, 40.82, 29.86, 29.75, 27.83, 27.80, 23.42, 23.41; MS *m/z* (rel intensity %) 516 (M^+; 10), 226 (26), 61 (100). Found: C, 64.84; H, 5.71; N, 11.04%. Calcd for $C_{28}H_{28}N_4O_6$: C, 65.10; H, 5.46; N, 10.85%.

9,19-Bis(1,4-dihydro-1,4-dioxo-2-naphthyl)-1,7,11,17-tetraazabicyclo[15.3.1.1^{7,11}]docosa-9,19-diene-8,18,21,22-tetrone (2e-5): Mp > 300 °C; ^1H NMR ($CDCl_3$) δ = 8.01—7.98 (m, 1H), 7.94—7.91 (m, 1H), 7.90 (s, 2H), 7.68—7.62 (m, 2H), 7.57 (s, 2H), 4.15 (t, 4H, J = 5.5 Hz), 3.98 (broad, 4H), 1.85—1.75 (m, 8H), 1.40—1.25 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 184.68, 184.27, 161.23, 150.86, 145.74, 139.09, 136.23, 133.89, 133.63, 132.26, 131.82, 126.91, 125.86, 105.02, 49.48, 41.44, 29.71, 27.67, 23.34. Found: C, 67.56; H, 4.81; N, 8.12%. Calcd for $C_{38}H_{32}N_4O_8$: C, 67.85; H, 4.80; N, 8.33%.

11-(1,4-Dihydro-1,4-dioxo-2-naphthyl)-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,23-diene-10,22,25,26-tetrone (2d-7): Mp 114—115 °C; ^1H NMR ($CDCl_3$) δ = 8.12—8.06 (m, 2H), 7.94 (s, 1H), 7.76—7.73 (m, 2H), 7.67 (s, 1H), 7.05 (d, 1H, J = 8 Hz), 5.67 (d, 1H, J = 8 Hz), 4.05 (t, 2H, J = 6.5 Hz), 3.97 (t, 2H, J = 6.5 Hz), 3.94 (t, 2H, J = 6.5 Hz), 3.79 (t, 2H, J = 6.5 Hz), 1.8—1.6 (m, 8H), 1.4—1.2 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 184.84, 184.52, 163.02, 161.12, 152.01, 150.75, 145.62, 141.65, 138.89, 136.41, 134.02, 133.67, 132.44, 132.02, 126.98, 125.96, 104.89, 101.92, 49.37, 48.57, 41.96, 41.19, 29.82, 29.69, 29.67, 29.67, 27.69, 27.64, 26.63, 26.59, 26.02, 25.99. Found: C, 67.01; H, 6.19; N, 9.36%. Calcd for $C_{32}H_{36}N_4O_6$: C, 67.11; H, 6.34; N, 9.78%.

11,23-Bis(1,4-dihydro-1,4-dioxo-2-naphthyl)-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,23-diene-10,22,25,26-tetrone (2e-7): Mp 123—124 °C; ^1H NMR ($CDCl_3$) δ = 8.09—8.04 (m, 4H), 7.92 (s, 2H), 7.74—7.71 (m, 2H), 7.64 (s, 2H), 4.06 (t, 4H, J = 6.5 Hz), 3.94 (t, 4H, J = 6.5 Hz), 1.8—1.6 (m, 8H), 1.4—1.2 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 184.80, 184.51, 161.11, 150.80, 145.54, 138.90, 136.45, 134.01, 133.67, 132.42, 132.01, 126.97, 125.97, 104.98, 49.39, 42.01, 29.86, 29.67, 27.68, 26.62, 26.05. Found: C, 68.97; H, 5.68; N, 7.59%. Calcd for $C_{42}H_{40}N_4O_8$: C,

69.21; H, 5.53; N, 7.69%.

9-(2,5-Dihydro-2,5-dioxo-1-phenyl-1*H*-pyrrol-3-yl)-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3f-5): Mp 242—245 °C; ^{1}H NMR ($CDCl_3$) δ = 8.86 (s, 1H), 7.56 (s, 1H), 7.46 (tt, 1H, J = 8 and 1 Hz), 7.39—7.31 (m, 4H), 7.02 (d, 1H, J = 8 Hz), 5.65 (d, 1H, J = 8 Hz), 4.12 (t, 2H, J = 6 Hz), 4.02 (t, 2H, J = 6 Hz), 3.98 (broad, 2H), 3.83 (broad, 2H), 1.8—1.6 (m, 8H), 1.35—1.15 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 170.75, 169.79, 162.93, 160.77, 152.33, 150.62, 145.42, 141.56, 135.12, 131.43, 129.11, 127.94, 126.27, 124.26, 103.82, 102.04, 49.42, 47.95, 41.91, 41.21, 29.64, 29.59, 28.26, 28.05, 24.19, 23.08; MS *m/z* (rel intensity, %) 531 (M^+; 3), 73 (100). Found: C, 63.16; H, 5.63; N, 12.98%. Calcd for $C_{28}H_{29}N_5O_6$: C, 63.26; H, 5.50; N, 13.18%.

9,19-Bis(2,5-dihydro-2,5-dioxo-1-phenyl-1*H*-pyrrol-3-yl)-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3g-5): Mp 190—193 °C; ^{1}H NMR ($CDCl_3$) δ = 8.86 (s, 2H), 7.56 (s, 2H), 7.45 (tt, 2H, J = 8 and 1 Hz), 7.39—7.28 (m, 8H), 4.13 (t, 4H, J = 6 Hz), 3.98 (broad, 4H), 1.85—1.7 (m, 8H), 1.4—1.2 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 170.67, 169.73, 160.79, 150.73, 145.41, 134.98, 131.26, 129.12, 127.99, 126.21, 124.26, 103.88, 49.24, 42.00, 29.67, 28.13, 24.36, 23.10. Found: C, 63.96; H, 4.57; N, 12.07%. Calcd for $C_{38}H_{32}N_6O_8 \cdot H_2O$: C, 63.50; H, 4.77; N, 11.69%.

11-(2,5-Dihydro-1-methyl-2,5-dioxo-1*H*-pyrrol-3-yl)-23-(1,4-dihydro-1,4-dioxo-2-naphthyl)-1,9,13,21-tetraazatricyclo-[19.3.1.1^{9,13}]hexacosa-11,23-diene-10,22,25,26-tetrone (2h-7): Mp 240—243 °C; ^{1}H NMR ($CDCl_3$) δ = 8.84 (s, 1H), 8.11—8.06 (m, 2H), 7.90 (s, 1H), 7.77—7.73 (m, 2H), 7.64 (s, 1H), 7.38 (s, 1H), 4.05 (t, 2H, J = 6 Hz), 4.04 (t, 2H, J = 6 Hz), 3.94 (broad, 4H), 3.01 (s, 3H), 1.8—1.6 (m, 8H), 1.4—1.2 (m, 12H); ^{13}C NMR ($CDCl_3$) δ = 184.83, 184.51, 171.78, 171.25, 161.08, 160.84, 150.78, 150.46, 145.47, 145.05, 138.82, 136.44, 135.24, 134.09, 133.74, 132.33, 131.95, 126.96, 126.01, 125.96, 124.04, 104.96, 130.95, 49.51, 49.23, 42.03, 41.90, 29.91, 29.89, 29.66, 29.65, 27.63, 27.63, 26.59, 26.59, 25.97, 25.91, 23.67. Found: C, 64.90; H, 5.61; N, 10.29%. Calcd for $C_{37}H_{39}N_5O_8$: C, 65.18; H, 5.77; N, 10.27%.

Nitration of Pyrimidinophanes with Sodium Nitrate in the Presence of Palladium(II) Acetate. Mixture of **3a-5** (1 mmol) and $NaNO_2$ (4 mmol) in the presence of $Pd(OAc)_2$ (2 mmol) was heated at 100—110 °C for 7 h under nitrogen atmosphere. The reaction mixture was evaporated and submitted to chromatography over silica gel. By monitoring at 254 nm, elution of ethyl acetate gave **3i-5** and **3j-5**. Similar treatment of **3a-7** gave **3i-7** and **3j-7**.

9-Nitro-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3i-5): Mp 204—207 °C; ^{1}H NMR ($CDCl_3$) δ = 8.59 (s, 1H), 7.04 (d, 1H, J = 8 Hz), 5.66 (d, 1H, J = 8 Hz), 4.10 (t, 2H, J = 6 Hz), 4.04 (broad, 2H), 4.03 (t, 2H, J = 6 Hz), 3.88 (broad, 2H), 1.9—1.8 (m, 2H), 1.8—1.65 (m, 6H), 1.4—1.3 (m, 2H), 1.3—1.2 (m, 2H); ^{13}C NMR ($CDCl_3$) δ = 162.91, 153.98, 152.50, 150.27, 146.10, 141.53, 125.37, 102.23, 50.10, 47.84, 42.90, 41.26, 29.85, 29.79, 28.29, 27.99, 24.29, 23.21. Found: C, 53.06; H, 5.76; N, 17.17%. Calcd for $C_{18}H_{23}N_5O_6$: C, 53.33; H, 5.72; N, 17.28%.

9,19-Dinitro-1,7,11,17-tetraazatricyclo[15.3.1.1^{7,11}]docosa-9,18-diene-8,20,21,22-tetrone (3j-5): Mp > 300 °C; ^{1}H NMR ($CDCl_3$) δ = 8.49 (s, 2H), 4.09 (t, 4H, J = 6 Hz), 4.1 (broad, 4H), 1.9—1.8 (m, 4H), 1.8—1.7 (m, 4H), 1.5—1.4 (m, 2H), 1.3—1.2 (m, 2H); ^{1}H NMR (DMSO-d_6, room temperature) δ = 9.25 (s, 2H), 3.97 (broad, 4H), 3.88 (t, 4H, J = 6 Hz), 1.7—1.6 (m, 4H), 1.6—1.5 (m, 4H), 1.25—1.15 (m, 2H), 1.15—1.05 (m, 2H); (DMSO-d_6, 70 °C) δ = 9.14 (s, 2H), 3.97 (t, 4H, J = 5.5 Hz), 3.90 (t, 4H, J = 6 Hz), 1.75—1.65 (m, 4H), 1.65—1.55 (m, 4H), 1.25—1.15 (m, 2H), 1.15—1.05 (m, 2H); ^{13}C NMR (DMSO-d_6) δ = 154.08, 150.15, 148.48, 142.90, 48.68, 41.72, 29.22, 27.71, 23.42, 21.92. Found: C, 48.26; H, 4.85; N, 18.54%. Calcd for $C_{18}H_{22}N_6O_8$: C, 48.00; H, 4.92; N, 18.66%.

11-Nitro-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,22-diene-10,24,25,26-tetrone (3i-7): Mp 237—240 °C; ^{1}H NMR ($CDCl_3$) δ = 8.64 (s, 1H), 7.06 (d, 1H, J = 8 Hz), 5.70 (d, 1H, J = 8 Hz), 4.05 (t, 2H, J = 6 Hz), 3.98 (t, 2H, J = 6 Hz), 3.97 (t, 2H, J = 6 Hz), 3.80 (t, 2H, J = 6 Hz), 1.8—1.7 (m, 2H), 1.7—1.55 (m, 6H), 1.4—1.3 (m, 2H), 1.3—1.15 (m, 10H); ^{13}C NMR ($CDCl_3$) δ = 162.93, 153.94, 152.06, 149.97, 145.97, 141.53, 125.37, 102.07, 50.62, 48.50, 42.74, 41.27, 29.84, 29.64, 29.54, 29.29, 27.74, 27.62, 26.61, 26.51, 26.06, 25.91. Found: C, 57.02; H, 6.82; N, 15.07%. Calcd for $C_{22}H_{31}N_5O_6$: C, 57.25; H, 6.77; N, 15.18%.

11,23-Dinitro-1,9,13,21-tetraazatricyclo[19.3.1.1^{9,13}]hexacosa-11,22-diene-10,24,25,26-tetrone (3j-7): Mp 283—286 °C; ^{1}H NMR ($CDCl_3$) δ = 8.61 (s, 2H), 4.04 (t, 4H, J = 6 Hz), 3.98 (t, 4H, J = 6 Hz), 1.8—1.7 (m, 4H), 1.7—1.6 (m, 4H), 1.45—1.35 (m, 2H), 1.35—1.25 (m, 6H), 1.25—1.15 (m, 4H); ^{13}C NMR ($CDCl_3$) δ = 153.89, 150.04, 145.82, 125.46, 50.40, 42.70, 29.57, 29.56, 29.05, 27.46, 26.43, 25.80. Found: C, 52.15; H, 5.87; N, 16.60%. Calcd for $C_{22}H_{30}N_6O_8$: C, 52.17; H, 5.98; N, 16.59%.

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