[Chem. Pharm. Bull. 23(10)2295—2300(1975)]

UDC 547.963.32.057 : 547.438.1.04 : 547.439

A New Method for Synthesis of Nucleoside 3′,5′-Cyclic Phosphates. Cyclization of Nucleoside 5′-Trichloromethylphosphonates

Ryuji Marumoto, Tatsuo Nishimura, and Mikio Honjo

Central Research Division, Takeda Chemical Industries, Ltd.[1]

(Received March 6, 1975)

The reaction of various nucleosides (III) with trichloromethylphosphonic acid dichloride in triethyl phosphate or *m*-cresol afforded nucleoside 5′-trichloromethylphosphonates (IV). The intramolecular cyclization of IV with potassium *t*-butoxide in dimethyl sulfoxide or N,N-dimethylformamide led to the synthesis of nucleoside 3′,5′-cyclic phosphates (I) in high yields by fission of the C-P bond of the phosphonate (IV).

Adenosine 3′,5′-cyclic phosphate (cAMP) is well known to play an important role in the control of various biochemical processes in the cell. Hence, a number of nucleoside 3′,5′-cyclic phosphates (I) have been synthesized to study their biological effects.[2] The synthesis of the 3′,5′-cyclic phosphate ring system is generally performed by either of the following methods: i) the reaction of a nucleoside 5′-phosphate (II) with N,N′-dicyclohexylcarbodiimide (DCC) in pyridine[3] and ii) the reaction of an active ester of II with potassium t-butoxide (KOBu^t) in dimethylsulfoxide (DMSO) or N,N-dimethylformamide (DMF).[4] Of these, the former method (i) is most widely used. This cyclization method, however, possesses a drawback in that some nucleotides (*e.g.*, guanosine 5′-phosphate) are hardly soluble in pyridine and require some chemical modification to more soluble derivatives (*e.g.*, N^2-benzoylguanosine 5′-phosphate) prior to the cyclization, and the blocking group must be removed after the cyclization.[5] It is also a drawback of this method that the product of the reaction of II (*e.g.*, 2-chloroadenosine 5′-phosphate) with DCC in pyridine is, in some cases contaminated with inseparable by-products.[6] According to the latter method (ii) one should first convert II to an active ester (*e.g.*, *p*-nitrophenylester), the yield of which being low,[7] before the intramolecular cyclization, and besides it is difficult to separate one of the products derived from a leaving group (*e.g.*, *p*- nitrophenol).[7] Thus, it is of interest to develop a new method for the synthesis of I. This paper deals with a one-step synthesis of a novel active ester of II from a nucleoside (III), and with its intramolecular cyclization to give I.

The C-P bond of monoalkylphosphonic acid is generally stable to alkali, but the bonds of β-monohalogenoalkylphosphonic acid (*e.g.*, β-chloroethylphosphonic acid),[8] *p*-nitrophenylmethylphosphonic acid[9] and diethyl trichloromethylphosphonate[10,11] are known to be cleaved with aqueous alkali. The authors' attention was drawn to the fission of the C-P bond of

1) Location: *Jusohonmachi, Yodogawa-ku, Osaka, 532, Japan.*
2) P. Greengard and G.A. Robison (ed.), "Advances in Cyclic Nucleotide Research," Vol. 3, Raven Press, New York, N.Y., 1973, p. 294.
3) R. Lohrmann and H.G. Khorana, *J. Am. Chem. Soc.*, **88**, 829 (1966).
4) R.K. Borden and M. Smith, *J. Org. Chem.*, **31**, 3247 (1966).
5) M. Smith, G.I. Drummond, and H.G. Khorana, *J. Am. Chem. Soc.*, **83**, 698 (1961).
6) The intramolecular cyclization of II possessing a halogen atom in the purine nucleus with DCC in pyridine afforded several compounds.
7) R.K. Borden and M. Smith, *J. Org. Chem.*, **31**, 3241 (1966).
8) J.A. Maynard and J.M. Swan, *Proc. Chem. Soc.*, **1963**, 61.
9) A. Meister and J.M. Swan, *Australian J. Chem.*, **16**, 725 (1963).
10) I.S. Bengelsdorf, *J. Am. Chem. Soc.*, **77**, 6611 (1955).
11) J.P. Berry, J.R. Arnold, and A.F. Isbell, *J. Org. Chem.*, **33**, 1664 (1968).

diethyl trichloromethylphosphonate, and it was our feeling that a nucleoside 5′-trichloromethylphosphonate (IV), a new substance, might be a possible intermediate for the synthesis of I, since the trichloromethyl group might decompose to give dichlorocarbene and chloride ion *via* trichloromethide ion,[11] and thus easily be removed from the reaction mixture. Adenosine (IIIa) was thus allowed to react with trichloromethylphosphonic acid dichloride[12] in triethyl phosphate[13] at about 0°. The reaction mixture was hydrolysed with water, and neutralized with alkali. A portion of the solution was subjected to paper electrophoresis (PE). The main product migrated to the anode about twice the distance of adenosine in PE (A) (borate buffer, pH 9.2) and about half the distance of adenosine 5′-phosphate (IIa) in PE (B) (phosphate buffer, pH 7.5) and gave a positive color reaction with periodate-benzidine test,[14] indicating that the compound has one negative charge and the vicinal hydroxyl groups. The compound was thus presumed to be 5′-trichloromethylphosphonate (IVa). The reaction mixture was desalted with active charcoal[15] and purified by the diethylaminoethyl (DEAE)-cellulose column chromatography to afford a white powder ($C_{11}H_{12}O_6N_5PCl_3 \cdot NH_4$, the ammonium salt of IVa) in 63% yield based on IIIa.[16] Similar phosphonation of various nucleosides (III) gave the corresponding 5′-trichloromethylphosphonate (IV) (Table I). Compound IVa is stable on standing at room temperature even for one year. It is also stable in 0.1N aqueous barium hydroxide at room temperature for 20 hr, in pyridine under reflux for 2 hr and in methylcellosolve solution containing morpholine at 140° for 10 hr. It decomposes quantitatively to IIa on standing in 2N aqueous lithium hydroxide at 50° for 10 hr. The phosphonation of IIIa with trichloromethylphosphonic acid dichloride was then done using *m*-cresol[18] and acetonitrile[18] as solvent instead of triethyl phosphate, whereby adenine was produced concomitantly with IVa. A similar phosphonation of IIIa in DMF did not yield IVa, but almost quantitatively gave a compound (Va) which migrated to the anode faster than IIIa in PE (A)

Table I. Phosphonation[a] of Nucleoside with Trichloromethylphosphonic Acid Dichloride in Triethyl Phosphate

Nucleoside	Temperature (°)	Yield of nucleoside 5′-trichloromethylphosphonate(%)[b]
Adenosine	0	93
Guanosine	0	84
Cytidine	0	91
Uridine	25	77
2′-Deoxyadenosine	−20	35[c]
2′-Deoxyuridine	25	80
2-Chloroadenosine	25	83
2-Bromoadenosine	25	89
2-Chloro-8-bromoadenosine	25	80
Aristeromycin	25	70

a) The reaction conditions were described in Experimental section.
b) determined by paper electrophoresis
c) When the reaction was carried at 5°, a quantitative cleavage of the glycosyl bond was observed.

12) A.M. Kinnear and E.A. Perren, *J. Chem. Soc.*, **1952**, 3437.
13) M. Yoshikawa, T. Kato, and T. Takenishi, *Tetrahedron Letters*, **1967**, 5065.
14) M. Viscontini, D. Hoch, and P. Karrer, *Helv. Chim. Acta*, **38**, 642 (1955).
15) The eluate was evaporated to complete dryness. The residue (crude IV) could be applied to the following intramolecular cyclization reaction.
16) The reaction of a ribonucleoside with diethyl trichloromethylphosphonate instead of trichloromethylphosphonic acid dichloride in DMF afforded the ribonucleoside 2′(3′)-phosphate ethylester, which was hydrolysed with aqueous lithium hydroxide to the ribonucleoside 2′(3′)-phosphate.[17]
17) A. Holý, *Tetrahedron Letters*, **1972**, 157.
18) K. Imai, S. Fuji-i, K. Takanohashi, Y. Furukawa, T. Masuda, and M. Honjo, *J. Org. Chem.*, **34**, 1547 (1969).

and about half the distance of IIa in PE (B). Compound Va showed a negative color reaction with periodate-benzidine test and was converted substantially into adenosine 2′(3′)-phosphate (VIa) by treatment with 2N aqueous lithium hydroxide at 60° for 4 hr. The facts indicate that Va is adenosine 2′(3′)-trichloromethylphosphonate. The phosphonation of III in triethyl phosphate was greatly influenced by the reaction temperatures. At 0° IIIa and cytidine afforded the corresponding IV, while at 20° the 2′(3′)-phosphonate and 2′(3′),5′-diphosphonate were formed in addition to IV. The phosphonation of uridine and 2-chloroadenosine at 0° yielded no reaction product, but at 20° the corresponding IV was produced in high yield.

The reaction of IV with KOBu^t in anhydrous DMSO (or DMF) at room temperature quantitatively afforded I. This cyclization presents a novel method for the synthesis of I, utilizing fission of the C-P bond of halogenoalkylphosphonic acids with a strong base. Compound IV is, therefore, a novel type of the active ester of II. The intramolecular cyclization is presumed to be caused by nucleophilic attack of the 3′-hydroxyl anion on the intermediate, nucleoside 5′-metaphosphate, which is generated by fission of the C-P bond of IV by KOBu^t. The reaction of IV with sodium ethoxide instead of KOBu^t afforded I and the ethyl ester (VII) of II in about 80 and 20% yield, respectively, showing a favorable cyclization even with sodium ethoxide (Chart 1).

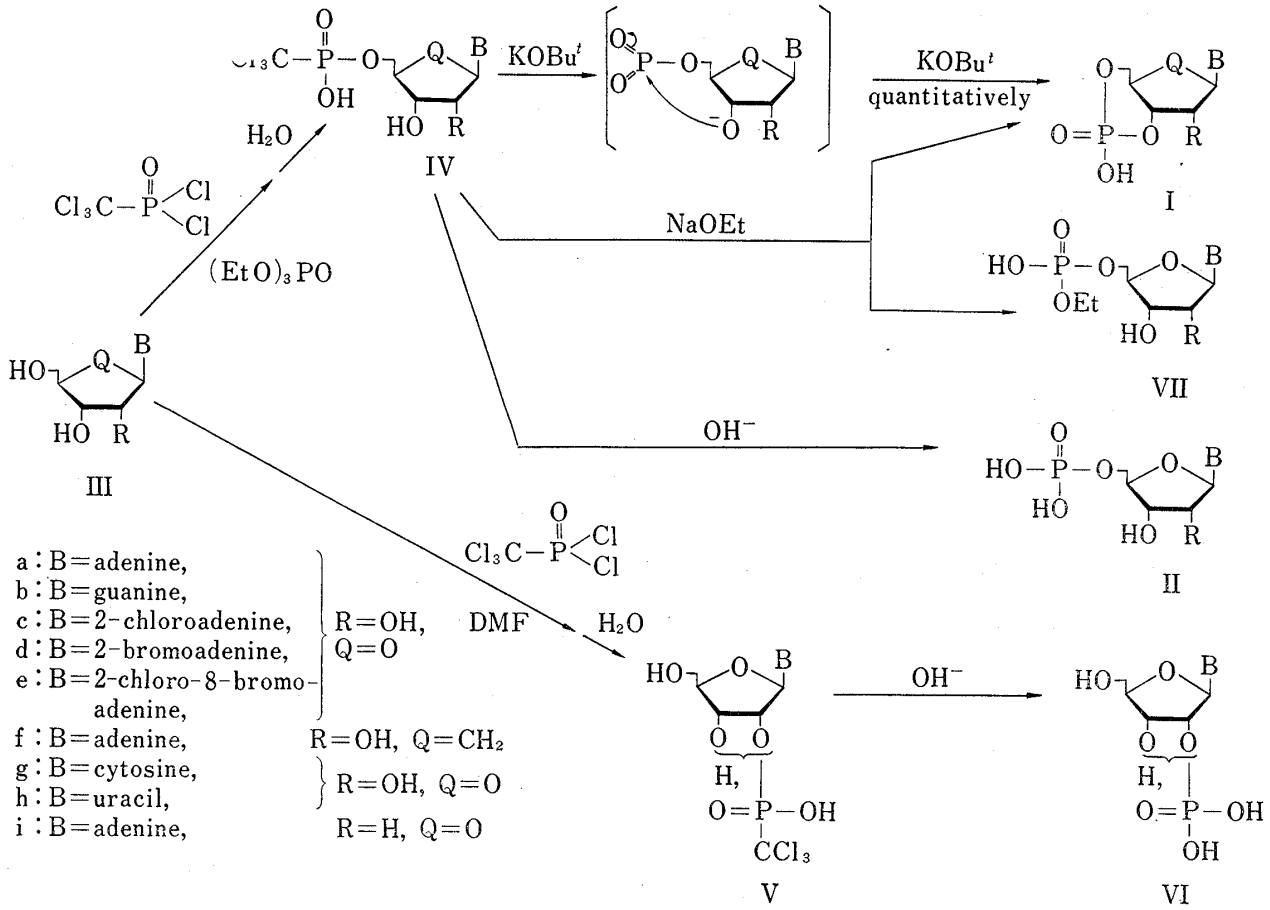

Chart 1

Use of dichloromethylphosphonic acid dichloride[12] or β-chloroethylphosphonic acid dichloride[12] instead of trichloromethylphosphonic acid dichloride for the phosphonation of III in triethyl phosphate afforded nucleoside 5′-dichloromethylphosphonate or 5′-(β-chloroethyl)phosphonate, respectively. It was difficult to cyclize these compounds to I.

The reaction mixture of IV with KOBu^t was subjected to the DEAE-cellulose column chromatography to isolate I. The structural confirmation of I thus obtained was done by the

Table II. *Rf* Values and Mobilities of Nucleotides

Compound	*n*-BuOH–AcOH–H_2O (5:2:3) ascending	PE (A)		PE (B)	
Adenosine 5′-phosphate (IIa)	0.20				
Adenosine 3′,5′-cyclic phosphate (Ia)	0.27	0.53		0.64	
Adenosine 5′-trichloromethylphosphonate (IVa)	0.45	0.78	a)	0.54	$M_{5'\text{-AMP}}$
Adenosine 2′(3′)-trichloromethyl phosphonate (Va)	0.44	0.50	$M_{5'\text{-AMP}}$	0.64	
Adenosine (IIIa)	0.51	0.40			
Guanosine 5′-phosphate (IIb)	0.14				
Guanosine 3′,5′-cyclic phosphate (Ib)	0.17	0.57		0.58	$M_{5'\text{-GMP}}$
Guanosine 5′-trichloromethylphosphonate (IVb)	0.34	0.72	$M_{5'\text{-GMP}}$	0.52	
Guanosine (IIIb)	0.34	0.50			
Cytidine 5′-phosphate (IIg)	0.16				
Cytidine 3′,5′-cyclic phosphate (Ig)	0.23	0.56		0.69	$M_{5'\text{-CMP}}$
Cytidine 5′-trichloromethylphosphonate (IVg)	0.43	0.78	$M_{5'\text{-CMP}}$	0.56	
Cytidine (IIIg)	0.42	0.47			
Uridine 5′-phosphate (IIh)	0.18				
Uridine 3′,5′-cyclic phosphate (Ih)	0.19	0.76		0.68	$M_{5'\text{-UMP}}$
Uridine 5′-trichloromethylphosphonate (IVh)	0.38	0.76	$M_{5'\text{-UMP}}$	0.58	
Uridine (IIIh)	0.42	0.42			
Deoxyadenosine 5′-phosphate (IIi)	0.31				
Deoxyadenosine 3′,5′-cyclic phosphate (Ii)	0.36			0.62	$M_{5'\text{-dAMP}}$
Deoxyadenosine 5′-trichloromethyl phosphonate (IVi)	0.35			0.50	
Deoxyadenosine (IIIi)	0.60				

a) The ratio of the migration distance of a sample to that of 5′-AMP.

elemental analysis, paper chromatography, PE and its conversion to II with bovine heart phosphodiesterase.

The present method provides a facile synthesis of I starting from III. Especially, it is possible by this method to prepare various nucleoside 3′,5′-cyclic phosphates whose synthesis has hitherto been found to be difficult or complicated.

Experimental

All melting points were uncorrected. $(EtO)_3PO$, DMF, DMSO and MeCN were dried over molecular sieve. Paper electrophoresis (PE) was run at a constant voltage of 22 V/cm for 60 min using the following buffers: (A), 0.05M borate buffer (pH 9.2) and (B), 0.1M phosphate buffer (pH 7.5). Paper chromatography was carried out by the ascending method using *n*-BuOH–AcOH–H_2O (5:2:3). The enzymatic hydrolysis of nucleoside 3′,5′-cyclic phosphate to nucleoside 5′-phosphate was conducted as follows:[19] To a solution of the sample (3 μmoles) in water (0.1 ml) was added 0.1M Tris buffer (pH 7.5, 0.2 ml), 0.2M $MgSO_4$ (0.1 ml) and the phosphodiesterase preparation[20] (0.5 ml). The mixture was kept at 25° for 20 hr. The hydrolysis was examined by PE (B).

Adenosine 5′-Trichloromethylphosphonate (IVa)·NH_4 Salt——To the ice-cooled stirred suspension of adenosine (0.5 g, 1.85 mmoles) in $(EtO)_3PO$ (20 ml) was dropwise added trichloromethylphosphonic acid dichloride[12] (CCl_3POCl_2, 4 g, 17 mmoles). The mixture was stirred at 0—5° for 20 hr and poured to the ice-water (100 ml). The solution was adjusted to pH 3 with 1N NaOH and applied to a column of activated charcoal (5 g). The column was washed with water and eluted with EtOH–H_2O–28% NH_4OH (9:10:1,

19) H.U. Bergmeyer, "Methoden der Enzymatischen Analyse," Vol. 2, Verlag Chemie, Weinheim, 1970, p. 2060.

20) A commercial preparation (Boehringer Mannheim GmbH, a suspension of the phosphodiesterase from beef heart in 3.2M $(NH_4)_2SO_4$ having a specific activity of *ca.* 0.1 unit/mg) was diluted 30 times with 0.05M Tris buffer (pH 3.5).

300 ml). The eluate was concentrated and adsorbed on a column of DEAE-cellulose (HCO_3^- form, 200 ml). The column was washed with water (300 ml) and eluted with 0.05M NH_4HCO_3 (200 ml). The eluate was evaporated to dryness *in vacuo* and the residue was dissolved in 50% aq. MeOH. The solution was evaporated to dryness to afford a white powder (700 mg, 81%), which is somewhat hygroscopic and very soluble in H_2O, MeOH, EtOH and pyridine. *Anal.* Calcd. for $C_{11}H_{12}O_6N_5PCl_3 \cdot NH_4$: P, 6.66; Cl, 22.84. Found: P, 6.62; Cl, 24.12.

Alkaline Degradation of IVa——A solution of IVa (10 mg) in 2N LiOH (2 ml) was heated at 50° for 10 hr. PE (A) of the solution revealed an almost quantitative formation of IIa and the presence of a small amount of adenine.

Reaction of IVa with Morpholine——To a solution of IVa (10 mg) in methylcellosolve (2 ml) was added morpholine (0.2 ml). The mixture was heated at 140° for 10 hr. No reaction product was detected by PE (A, B) or thin-layer chromatography (silica gel, *n*-BuOH saturated with water).

Adenosine 2′(3′)-Trichloromethylphosphonate (Va)——To the ice-cooled stirred solution of adenosine (50 mg, 0.185 mmole) in DMF (4 ml) was added CCl_3POCl_2 (200 mg, 0.85 mmole). The mixture was stirred at 0—5° for 20 hr and poured to the ice-water (10 ml). The solution was neutralized with 1N NaOH and gave an almost single UV absorbing spot at $M_{adenosine}$[21]=1.2 and M_{cAMP}=1.0 by PE (A) and (B), respectively.

Adenosine 3′,5′-Cyclic Phosphate (Ia)——i) To a solution of IVa (200 mg, 0.43 mmole) in DMF (10 ml) was added 1N $KOBu^t$ (10 ml). The mixture was kept at 20° for 20 hr and poured to the ice-water (50 ml). The solution was adjusted to pH 3 with 1N HCl and applied to a column of activated charcoal (2 g). The column was washed with water (100 ml) and eluted with EtOH–H_2O–28% NH_4OH (9: 10: 1, 200 ml). The eluate was evaporated to dryness *in vacuo*.. The residue was dissolved in water (50 ml) and the solution was applied to a column of DEAE-cellulose (HCO_3^- form, 300 ml). The column was eluted with 0.05M NH_4HCO_3 (100 ml), and the eluate was evaporated to dryness to afford a white powder. The crude compound was dissolved in 50% aq. EtOH (1 ml) and the solution was adjusted to pH 2 with 1N HCl and kept in the refrigerator to yield colorless needles (120 mg, 80%). mp 240° (decomp.). The compound was hydrolyzed to IIa with the phosphodiesterase from bovine heart at the same rate as that of an authentic sample of Ia. ii) To a solution of IVa (100 mg) in DMSO (10 ml) was added 1N NaOEt (10 ml). The mixture was treated as in the case of i). The desalted solution gave two ultraviolet (UV) absorbing spots by PE (A). One (80% yield) migrated the same distance as that of Ia and the other (20% yield) moved a little longer distance than that of IVa. The latter of the two compounds had the UV absorbing spectrum superimposable with that of IIa and almost the same *Rf* value in the thin-layer chromatography (silica gel, *n*-BuOH saturated with water) as that of Ia. The former compound was thus identified as Ia and the latter compound as 5′-AMP[22] ethyl ester (VIIa).

Guanosine 3′,5′-Cyclic Phosphate (Ib)——The mixture of guanosine (2 g, 7 mmoles), $(EtO)_3PO$ (120 ml) and CCl_3POCl_2 (20 g, 85 mmoles) was reacted at *ca.* 0° for 20 hr. The solution was poured to the ice-water (400 ml), adjusted to pH 3 with 1N NaOH and applied to a column of activated charcoal (20 g). The column was washed with water and eluted with EtOH–H_2O–28% NH_4OH (9: 10: 1, 2 liter). PE (A) of the eluate revealed the presence of guanosine 5′-trichloromethylphosphonate [IVb, 84% yield, $M_{5'\text{-GMP}}$[22]=0.72, PE (A)] and guanosine (16%). The eluate was evaporated to dryness to afford a white powder, which was dried over P_2O_5. The powder containing IVb was dissolved in DMSO (200 ml). The solution, after the addition of 1N $KOBu^t$ (180 ml), became yellow immediately and deposited a yellow solid. The mixture was kept for 20 hr and poured to the ice-water (1 liter). The solution was desalted with active charcoal (40 g) and purified by DEAE-cellulose (HCO_3^- form, 600 ml) column chromatography using 0.05M NH_4HCO_3 (2 liter) as the eluting solvent. The eluate was evaporated to dryness. The residue was triturated with EtOH to afford a white powder (1.5 g, 54%). UV $\lambda_{max}^{pH\,2}$ nm: 257, 275 (sh); $\lambda_{max}^{pH\,12}$ nm: 264 (plateau). $[\alpha]_D^{25}$: −48.9° (c=1.03, 1N NaOH). *Anal.* Calcd. for $C_{10}H_{15}O_7N_6P \cdot 2H_2O$: C, 30.15; H, 4.81; N, 21.10; P, 7.79. Found: C, 30.10; H, 4.80; N, 21.19; P, 7.94. The sample was hydrolyzed completely to 5′-GMP with the phosphodiesterase from bovine heart.

2-Chloroadenosine 3′,5′-Cyclic Phosphate (Ic)·NH_4 Salt——The mixture of 2-chloroadenosine (1 g), $(EtO)_3PO$ (80 ml) and CCl_3POCl_2 (10 g) was similarly treated as in the case of IVa to give a colorless oil (IVc). The mixture of IVc, 1N $KOBu^t$ (100 ml) and DMSO (100 ml) was similarly treated as in the case of Ia to afford a white crystalline powder (Ic·NH_4 salt, 500 mg, 36%). mp 210° (decomp.). $[\alpha]_D^{25}$: −28.3° (c=0.93, 1N NaOH). $M_{2\text{-chloroadenosine}}$=1.23 [PE (A)]. *Anal.* Calcd. for $C_{10}H_{10}O_6N_5PCl \cdot NH_4 \cdot 2H_2O$: C, 28.82; H, 4.35; N, 20.17; P, 7.44. Found: C, 28.63; H, 4.40; N, 20.11; P, 7.44.

2-Bromoadenosine 3′,5′-Cyclic Phosphate (Id)·NH_4 Salt——2-Bromoadenosine (1 g) was similarly treated as in the case of Ic to yield a white crystalline powder (Id·NH_4 salt, 630 mg, 59%). mp 205° (decomp.). $M_{2\text{-bromoadenosine}}$=1.3 [PE (A)]. *Anal.* Calcd. for $C_{10}H_{10}O_6N_5PBr \cdot NH_4 \cdot 1/2H_2O$: C, 27.67; H, 3.48; N, 19.36; P, 7.13; Br, 18.41. Found: C, 27.96; H, 3.90; N, 18.89; P, 7.00; Br, 18.35.

21) Ratio of the migration distance of the sample to that of adenosine.
22) 5′-AMP, Adenosine 5′-phosphate; 5′-GMP, Guanosine 5′-phosphate.

2-Chloro-8-bromoadenosine 3′,5′-Cyclic Phosphate (Ie)·NH_4 Salt——2-Chloro-8-bromoadenosine[23] (7 g) was similarly treated as in the case of Id to afford a white powder (Ie·NH_4 salt, 3.5 g, 40%). $M_{2\text{-chloro-8-bromoadenosine}}=1.25$ [PE (A)]. *Anal.* Calcd. for $C_{10}H_9O_6N_5PClBr\cdot NH_4\cdot 1/2C_2H_5OH$: C, 27.37; H, 3.34; N, 17.41; P, 6.42. Found: C, 26.95; H, 3.85; N, 17.75; P, 6.73.

Aristeromycin 3′,6′-Cyclic Phosphate (If)——The mixture of aristeromycin[24] (1 g, 3.8 mmoles), $(EtO)_3PO$ (40 ml) and CCl_3POCl_2 (10 g, 42.5 mmoles) was similarly treated as in the case of IVa to give a white powder (aristeromycin 6′-trichloromethylphosphonate·NH_4 salt, 1.2 g, 70% yield). $M_{aristeromycin}=2.0$ [PE (A)]. To the solution of the powder in DMSO (60 ml) was added 1N $KOBu^t$ (60 ml). The mixture was kept at 20° for 20 hr and desalted with activated charcoal (10 g). The eluate (1 liter) was evaporated to dryness and the residue was dissolved in 50% aq. EtOH (5 ml). The solution was adjusted to pH 2 with 1N HCl and kept in the refrigerator to deposit colorless prisms (0.6 g, 47% yield). mp>300°. $[\alpha]_D^{25}$: −42.2° ($c=1.07$, 1N NaOH). *Anal.* Calcd. for $C_{11}H_{14}O_5N_5P$: C, 40.36; H, 4.31; N, 21.40; P, 9.48. Found: C, 40.10; H, 4.47; N, 21.24; P, 9.44.

Adenosine 5′-Dichloromethylphosphonate·NH_4 Salt——The mixture of adenosine (300 mg), $(EtO)_3PO$ (6 ml), and dichloromethylphosphonic acid dichloride[12] (bp_9 79°, 2 ml) was similarly treated as in the case of IVa to afford a white powder (420 mg). The sample gave a single UV absorbing spot of $M_{adenosine}=1.8$ by PE (A) and showed a positive Beilstein's reaction.

Adenosine 5′-(β-Chloroethyl)phosphonate·NH_4 Salt——The mixture of adenosine (100 mg), $(EtO)_3PO$ (4 ml) and β-chloroethylphosphonic acid dichloride[12] (bp_6 75—76°, 0.5 ml) was similarly treated as in the case of IVa to give a white powder (140 mg). The sample gave a single UV absorbing spot of $M_{adenosine}=2.1$ by PE (A).

Acknowledgement The authors are grateful to Dr. S. Tatsuoka for his encouragement throughout this work. Thanks are also due to Dr. T. Kishi for his kindness in supplying aristeromycin and to the members of the Analytical Section for microanalyses.

23) O. Miyashita, unpublished.
24) T. Kishi, M. Muroi, T. Kusaka, M. Nishikawa, K. Kamiya, and K. Mizuno, *Chem. Commun.*, **1967**, 852.