Other workers reporting transformations of orthophosphates to condensed phosphates in presumably primitive Earth conditions have used condensing agents such as potassium cyanate[14,16], *N*-cyanoguanidine[5] and sodium dithionate (unpublished results of N. Gabel). Because of its simplicity, thermal condensation of inorganic orthophosphates at relatively low temperatures is very attractive as a general source of condensed phosphate on the primitive Earth and supports the suggestion[16] that thermal processes may have provided one of the most likely sources of inorganic polyphosphate, a potential phosphorylating and condensing agent in primitive syntheses[8,14,17].

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1 Katchman, B. J., *Phosphorus and its Compounds* (edit. by Van Wazer, J. R.) (Interscience Publishers, New York, 1961).
2 Brown, D. M., *Advances in Organic Chemistry, Methods and Results* (edit. by Raphael, R. A., Taylor, E. C., and Wynberg, H.) (Interscience Publishers, New York, 1963).
3 Khorana, H. G., *Some Recent Developments in the Chemistry of Phosphate Esters of Biological Interest* (John Wiley and Sons, New York, 1961).
4 Cherbuliez, E., Colak-Antic, S., Prince, R., and Rabinowitz, J., *Helv. Chim. Acta*, **47**, 1657 (1964).
5 Schofield, J. A., and Todd, A. R., *J. Chem. Soc.*, 2316 (1961).
6 Kirby, A. J., and Warren, S. G., *The Organic Chemistry of Phosphorus* (Elsevier, New York, 1967).
7 Steinman, G., Lemmon, R. M., and Calvin, M., *Proc. US Nat. Acad. Sci.*, **52**, 27 (1964).
8 Waehneldt, T. V., and Fox, S. W., *Biochim. Biophys. Acta*, **134**, 1 (1967).
9 Ponnamperuma, C., and Mack, R., *Science*, **148**, 1221 (1965).
10 Skoda, J., and Moravek, J., *Tetrahedron Lett.*, 4167 (1966).
11 Moravek, J., and Skoda, J., *Collection Czech. Chem. Commun.*, **32**, 206 (1967).
12 Karl-Kroupa, E., *Anal. Chem.*, **28**, 1091 (1956).
13 Fuchs, R. J., and Czeck, F. W., *Anal. Chem.*, **35**, 769 (1963).
14 Miller, S. L., and Parris, M., *Nature*, **204**, 1248 (1964).
15 Van Wazer, J. R., *Phosphorus and its Compounds*, chap. 10 (Interscience, New York, 1958).
16 Beck, A., and Orgel, L. E., *Proc. US Nat. Acad. Sci.*, **54**, 664 (1965).
17 Harold, F. M., *Bact. Rev.*, **30**, 772 (1966).

Phosphorylation of Adenosine with Linear Polyphosphate Salts in Aqueous Solution

LINEAR condensed phosphates are produced when orthophosphate salts are heated[1]. The lower members of the series—di and tripolyphosphate—are formed from monobasic salts at temperatures well below 200° C (see preceding communication). Pyrophosphate has also been produced in aqueous solution, in what have been suggested as possible prebiological conditions[2–4]. The stabilities of polyphosphate salts in aqueous solution are surprisingly high. The tripolyphosphate ion, for example, has a half life at room temperature and neutrality of the order of years[5]. We have been interested in water soluble polyphosphate salts as possible prebiological phosphorylating agents. This communication reports the synthesis of adenosine-2′, 3′ and 5′-phosphates, by the simple heating of an aqueous solution of adenosine and linear polyphosphate salts.

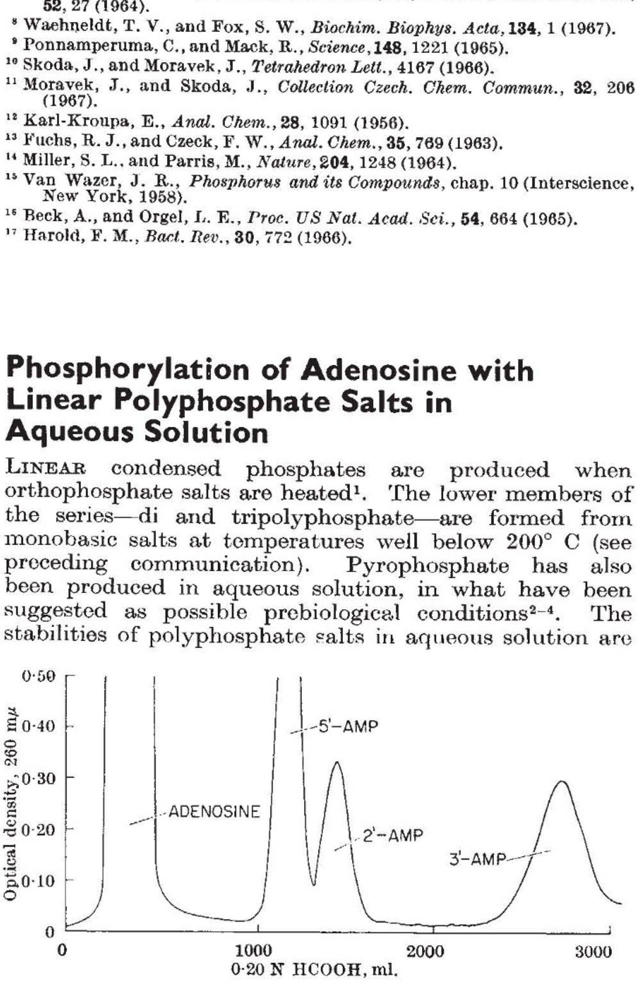

Fig. 1. Fractionation of the products of the phosphorylation of adenosine with $Na_5P_3O_{10}$. See Table 1 for conditions.

Table 1. COMPOSITIONS OF REACTION MIXTURES AND PRODUCTS OF THE PHOSPHORYLATION OF ADENOSINE

Phosphate	*p*H range*	Reflux (h)	Relative yields of products (%) 5′ AMP	2′ AMP	3′ AMP	Total conversion of adenosine (%)
$Na_4P_2O_7$	9·7–10·5	5·0	—	—	—	0
$Na_5P_3O_{10}$	7·5–8·0	5·0	54	18	28	1·08
Graham's salt	5·7–6·7	6·0	57	17	26	0·94
Graham's salt	9·7–10·5†	4·0	25	30	45	1·52

* The highest *p*H in each case was that at the start of the reaction; the lowest *p*H was measured at the conclusion of the reaction.
† The reaction was run at 100° C in a sealed tube in 0·75 N NH_4OH.

Adenosine, $Na_4P_2O_7$ and $Na_5P_3O_{10}$ were commercial products, the purity of which was checked chromatographically. A Graham's salt preparation was made by melting NaH_2PO_4, holding the melt at 650° C for 4 h, and quick cooling. The preparation was shown to be composed primarily of linear polyphosphate chains, with no species smaller than tripolyphosphate detectable by thin-layer chromatography[6]. In a typical reaction, an amount of polyphosphate salt, corresponding to 20 mmoles of phosphorus, and 2 mmoles of adenosine were weighed into a 50 ml. round bottom flask. The mixture was dissolved with heat in 20 ml. of water (or in dilute NH_4OH), and the solution was refluxed for 4–6 h. The hot solution was then diluted to 30–40 ml. with H_2O cooled, and run directly onto a 2·5 × 42 cm column of 'Dowex' 1 × 2 formate (200–400 mesh). Elution was begun immediately with 0·20 N HCOOH. Fig. 1 illustrates the fractionation of the products obtained with $Na_5P_3O_{10}$. The identities of the isomers were established by standardization of the column with authentic samples, and by thin-layer chromatography. In addition, the three isomers were shown to be degraded to adenosine by *E. coli* alkaline phosphatase. The 2′ and 3′ isomers were further shown to be resistant to periodate oxidation, while the 5′ isomer was oxidized.

Pyrophosphate did not phosphorylate adenosine in the conditions studied. Tripolyphosphate and Graham's salt, however, were effective phosphorylating agents. The reaction conditions and the isomeric composition of the adenosine phosphates produced are presented in Table 1. A marked difference was observed in the product composition obtained with Graham's salt in acid and basic conditions, although significant yields were obtained in all conditions studied. The observation that polyphosphates will serve to phosphorylate a nucleoside for a wide range of *p*Hs makes these materials even more attractive as possible prebiological phosphorylating agents. Experiments at more extreme *p*H (for example, in 0·5 N NaOH) have produced conversions of adenosine to AMP of 10 per cent, with a further shift in the isomeric composition towards production of the 2′(3′) phosphate. The mechanism of this *p*H effect, as well as other details of the reaction, are now being investigated.

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1 Thilo, E., *Angew. Chem. Intern. Ed.*, **4**, 1061 (1965).
2 Miller, S. L., and Parris, M., *Nature*, **204**, 1248 (1964).
3 Steinman, G., Lemmon, R. M., and Calvin, M., *Proc. US Nat. Acad. Sci.*, **52**, 27 (1964).
4 Beck, A., and Orgel, L. E., *Proc. US Nat. Acad. Sci.*, **54**, 664 (1965).
5 Van Wazer, J. R., *Phosphorus and its Compounds*, **1**, 653 (Interscience, New York, 1958).
6 Aurenge, J., Degeorges, M., and Normand, J., *Bull. Soc. Chim. France*, 508 (1964).