Table I. Electrolytic Carbomethoxylation of Styrene[a]

Pt–carbonyl complex, g. (wt. of Pt)	Total yield of esters, %[b]	Dimethyl ether, % IV	Ester, % I	Ester, % II	Ester, % III
0.9	23	32	14	8	1
1.5	35	23	21	13	1
2.8	43	10	17	16	10

[a] Fifteen grams (0.15 mole) of styrene was used. [b] Based on styrene used.

When α-methylstyrene (17.7 g., 0.15 mole) was used in the presence of platinum–carbonyl complex (2.9 g.), methyl *trans*-β-methylcinnamate (V) was obtained as the main product, in 18% yield (4.5 g.), along with methyl 3-phenyl-3-butenoate (VI, 2.7 g., 11%), methyl β-methyl-β-phenylpropionate (VII, 0.6 g., 2%), and α-methylstyrene glycol dimethyl ether (VIII, 2.5 g., 9.3%). Moreover, in the case of 1,1-diphenylethylene (18.0 g., 0.10 mole) in the presence of platinum–carbonyl complex (1.0 g.), methyl β-phenylcinnamate (IX) was obtained as the main product (7.6 g., 30%), along with 1,1-diphenylethylene glycol dimethyl ether (X, 5.0 g., 25%).

Infrared spectroscopic, gas chromatographic, and elemental analyses, and, in part, n.m.r. data and also mixture melting points (as free acids, with authentic specimens), were used to identify these compounds.

In these electrochemical reactions, it may be assumed that the formation of unsaturated esters proceeds by the addition[5] of the Pt–$COOCH_3$ group in the platinum–carbonyl complex to the olefinic double bond *via* anodic process. The above consideration was supported by the following experimental results: (a) Without the platinum–carbonyl complex, the electrolysis of styrene gave dimethyl ether (IV[6]) as the sole product (23%). (b) In the absence of electric current, the reaction of these olefins with the platinum–carbonyl complex gave no products for 16 hr. at 0 to 150°. (c) The electrolysis with both the catholyte and anolyte containing the platinum–carbonyl complex, styrene, and sodium methoxide in separated compartments under nitrogen atmosphere resulted in the formation of the esters I and II in the anode compartment while no product was detected in the cathode compartment. (d) With the increase in the concentration of the platinum–carbonyl complex, the yield of these esters increased; on the contrary, that of dimethyl ether (IV) decreased, as shown in Table I. (e) These esters were obtained by the catalytic amount of the platinum–carbonyl complex, as shown in Table I. (f) Interestingly, the infrared spectrum of the platinum–carbonyl complex isolated from the electrolyzed solution[4] has characteristic absorption bands at about 1642, 1280, and 1180 cm.$^{-1}$, besides absorption bands at about 2015 (v.s.) and 2145 cm.$^{-1}$ (w.) (the terminal carbonyl group) and at about 1860 (m.s.) and 1840 cm.$^{-1}$ (m.s.) (the bridged carbonyl group). The former strong absorption bands may be due to the ester group attached to platinum, as has been reported in other metal carbonyl compounds.[7]

The structure of this carbonyl complex and the mechanism of these noble electrochemical syntheses are under investigation, and detailed description of this and further work will be reported shortly.

Acknowledgment. We wish to thank Dr. Yoshinobu Odaira and Dr. Menbo Ryang for their useful suggestions and encouragement.

(5) The addition of a metal–carbon σ-bond to an olefinic double bond has recently been reported by several workers; for example, (a) R. F. Heck, *J. Am. Chem. Soc.*, **85**, 3116 (1963); (b) R. F. Heck, *ibid.*, **85**, 3383 (1963); (c) J. B. Wilford, P. M. Treichel and F. G. A. Stone, *J. Organometal. Chem.* (Amsterdam), **2**, 119 (1964); J. B. Wilford and F. G. A. Stone, *Inorg. Chem.*, **4**, 93 (1965).

(6) Dimethyl ether derivatives would be produced by the reaction of the methoxy radical with olefins, as has been reported before: T. Inoue and S. Tsutsumi, *Bull. Chem. Soc. Japan*, **38**, 661 (1965).

(7) T. Kruck and M. Noack, *Ber.*, **97**, 1693 (1964).

Tadao Inoue, Shigeru Tsutsumi
Department of Chemical Technology
Faculty of Engineering, Osaka, University
Miyakojima-ku, Osaka, Japan
Received May 4, 1965

Oligonucleotide Synthesis on a Polymer Support[1,2]

Sir:

With the objective of simplifying procedures for the stepwise synthesis of complex substances such as polynucleotides and polypeptides, we undertook a study of chemical reactions on insoluble supports. In a previous paper it was shown that functional groups on styrene–divinylbenzene popcorn polymer are available for many conventional chemical reactions and that a dipeptide may be prepared on and removed from this polymer.[3] The present communication reports experiments illustrating the use of a polymer support in the synthesis of oligonucleotides.

The general scheme is typified by the preparation of deoxycytidylyl-(3′→5′)-thymidine (V) outlined in Chart I. All reactions on the polymer support (a–f) were carried out at room temperature. In the initial step (a) 5 g. of polymer acid chloride, Ⓟc–COCl,[3b,4] was stirred with 2.8 g. (6.0 mmoles) of 5′-O-trityldeoxycytidine[5] in 50 ml. of dry pyridine for 2 days. Methanol was then added to convert residual acid chloride to ester, and the solid polymer (6.3 g.) was separated by filtration (1.2 g. of trityldeoxycytidine was recovered from the solvent). Phosphorylation (b) was effected by stirring 12 g. of I (from two experiments) with pyridinium β-cyanoethyl phosphate[6] (obtained from 5.1 g., 15 mmoles, of the barium salt trihydrate) and 6.2 g. of dicyclohexylcarbodiimide for 7 days. After filtration, treatment with 50% aqueous pyridine (c), and successive washing with methanol, ethanol, 1:1 ethanol–cyclohexane, and ether, a portion of the polymer (9.5 g.) was stirred with 2.5 g. (11 mmoles) of mesitylenesulfonyl chloride[7] (d) in 100 ml. of pyridine for 1 day. The polymer was then removed and mixed with 2.1 g. (9 mmoles) of dry thymidine (e)

(1) Part II in a series on Nucleotide Chemistry. Paper I: R. L. Letsinger, J. Fontaine, V. Mahadevan, D. A. Schexnayder, and R. E. Leone, *J. Org. Chem.*, **29**, 2615 (1964).

(2) This research was supported by the Division of General Medical Sciences, National Institutes of Health, Grant 10265.

(3) (a) R. L. Letsinger and M. J. Kornet, *J. Am. Chem. Soc.*, **85**, 3045 (1963); (b) R. L. Letsinger, M. J. Kornet, V. Mahadevan, and D. M. Jerina, *ibid.*, **86**, 5163 (1964).

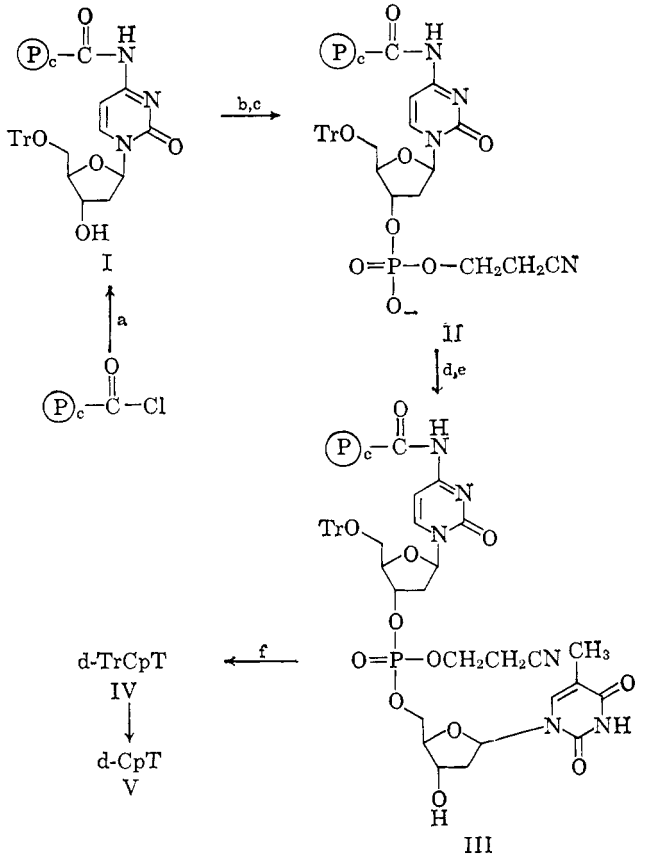
(4) The polymer had 1.0 mmole of acid chloride groups/g.

(5) A. M. Michelson and A. R. Todd, *J. Chem. Soc.*, 34 (1954).

(6) G. M. Tener, *J. Am. Chem. Soc.*, **83**, 159 (1961).

(7) H. G. Khorana, J. P. Vizsolyi, and R. K. Ralph, *ibid.*; **84**, 414 (1962); T. M. Jacob and H. G. Khorana, *ibid.*, **86**, 1630 (1964).

Chart I



in 40 ml. of pyridine. After 2 days the solid was separated and washed carefully. Nucleotidic material was cleaved from the support by four successive 3-hr. treatments with 40-ml. portions of 0.2 *M* sodium hydroxide (f) in 1:1 dioxane–ethanol. The resulting alkaline solution was neutralized with Dowex-50 resin (pyridinium form), concentrated, and chromatographed on DEAE-cellulose with a linear gradient of triethylammonium bicarbonate. From 1.215 g. of III was obtained 1340 $O.D._{267}$[8] units of 5′-O-trityldeoxycytidylylthymidine (IV), which was isolated as the triethylammonium salt (101 mg.) by concentration and lyophilization; R_f 0.78[9]; electrophoretic mobility relative to deoxycytidine 5′-phosphate at pH 10.8, 0.32; λ_{max} 267 mμ, λ_{min} 244 mμ. Some 5′-O-trityldeoxycytidine (32 mg.), deoxycytidine (10 mg.), thymidine (16 mg.), and a trace of a compound corresponding to trityldeoxycytidine 3′-phosphate were also obtained.

Detritylation of IV with 80% aqueous acetic acid afforded deoxycytidylylthymidine (V), which was isolated as the ammonium salt; R_f 0.33; electrophoretic mobility relative to deoxycytidine 5′-phosphate at pH 10.8, 0.58; ultraviolet at pH 6.9, λ_{max} 267 mμ, λ_{min} 240 mμ.; at pH 2.15, λ_{max} 275 mμ, λ_{min} 239 mμ. In the presence of phosphodiesterase from Russel's viper venom[10] IV hydrolyzed completely to thymidine 5′-phosphate (R_f 0.16) and 5′-O-trityldeoxycytidine (R_f 0.85). With spleen phosphodiesterase[11] V was hydrolyzed extensively (~95%) to deoxycytidine 3′-phosphate (R_f 0.13) and thymidine (R_f 0.70).

(8) T. M. Jacob and H. G. Khorana, *J. Am. Chem. Soc.*, **87**, 372 (1965).
(9) The paper chromatograms were all run on Whatman 3MM paper with isopropyl alcohol–ammonium hydroxide–water (7:1:2).
(10) Calbiochem, Los Angeles, Calif.
(11) Nutritional Biochemical Corp., Cleveland, Ohio.

In addition to the polymer support aspect, this synthetic route has two other novel features: (1) mesitylenesulfonyl chloride was used to activate a phosphodiester rather than a phosphomonoester and (2) a nucleoside with both the 3′- and 5′-hydroxyl groups free was employed. As a check on the selectivity of the condensation step (e), deoxycytidylyl-(3′→5′)-thymidine was prepared independently by using 3′-O-2,4-dinitrobenzenesulfenylthymidine[1] in place of thymidine in the synthetic sequence. Following the condensation step and prior to cleavage (f), the dinitrobenzenesulfenyl group was removed by treating the insoluble polymer with excess thiophenol in pyridine at room temperature. The dinucleotide obtained had the same physical and chromatographic properties as V prepared directly from thymidine, and it behaved the same on enzymatic degradation, indicating that step (e) with thymidine involves attack at the 5′-hydroxyl. The selectivity probably depends upon the fact that the hydroxyl group must approach a relatively hindered phosphorus in the condensation step.

Following the general procedure outlined in the flow sheet, the 5′-O-trityl derivatives of deoxycytidylyldeoxycytidine, deoxycytidylylthymidylyldeoxyadenosine, and deoxycytidylylthymidylylthymidine have been prepared.

Robert L. Letsinger, V. Mahadevan
Division of Biochemistry of the Department of Chemistry
Northwestern University, Evanston, Illinois
Received May 13, 1965

Electron Spin Resonance of Tropenyl Radical[1]

Sir:

There is considerable current experimental[2,3] and theoretical[4] interest in the highly symmetrical π-electron radicals such as $C_5H_5\cdot$, $C_6H_6^{\pm}$, $C_6(CH_3)_6^{+}$, $C_7H_7\cdot$, and $C_8H_8^{-}$, especially with regard to the removal of spatial degeneracy in these species. We have prepared the tropenyl (cycloheptatrienyl) radical ($C_7H_7\cdot$) in solution by homolytic thermal cleavage of bitropenyl[5,6] and have investigated its electron spin resonance spectrum.[7] There have been only a few previous e.s.r. investigations[8] in which well-character-

(1) This research was supported by the Department of the Army through the U. S. Army Research Office (Durham) (Grants DA-ARO-(D)-31-124-G-254 and -G-362).
(2) (a) R. W. Fessenden and S. Ogawa, *J. Am. Chem. Soc.*, **86**, 3591 (1964); (b) T. R. Tuttle and S. I. Weissman, *ibid.*, **80**, 5342 (1958); (c) M. K. Carter and G. Vincow, *Bull. Am. Phys. Soc.*, **10**, 374 (1965); (d) A. Carrington and I. C. P. Smith, *Mol. Phys.*, **7**, 99 (1963–1964); (e) H. L. Strauss, T. J. Katz, and G. K. Fraenkel, *J. Am. Chem. Soc.*, **85**, 2360 (1963).
(3) (a) H. J. Silverstone, D. E. Wood, and H. M. McConnell, *J. Chem. Phys.*, **41**, 2311 (1964); (b) R. G. Lawler, J. R. Bolton, G. K. Fraenkel, and T. H. Brown, *J. Am. Chem. Soc.*, **86**, 520 (1964); (c) T. R. Tuttle, Jr., *ibid.*, **84**, 1492, 2839 (1962); (d) J. R. Bolton, A. Carrington, A. Forman, and L. E. Orgel, *Mol. Phys.*, **5**, 43 (1962); (e) A. Carrington and P. F. Todd, *ibid.*, **7**, 533 (1963–1964).
(4) (a) H. M. McConnell and A. D. McLachlan, *J. Chem. Phys.*, **34**, 1 (1961); (b) H. M. McConnell, *ibid.*, **34**, 13 (1961); (c) A. D. McLachlan and L. C. Snyder, *ibid.*, **36**, 1159 (1962); (d) T. H. Brown and M. Karplus, *ibid.*, **39**, 1115 (1963).
(5) A. G. Harrison, L. R. Honnen, H. J. Dauben, Jr., and F. P. Lossing, *J. Am. Chem. Soc.*, **82**, 5593 (1960).
(6) Homolysis studied mass spectrometrically by Lossing and coworkers.
(7) H. J. Dauben, Jr., Abstracts, 145th National Meeting of the American Chemical Society, New York, N. Y., Sept. 1963, p. 7S.
(8) D. M. Gardner and G. K. Fraenkel, *J. Am. Chem. Soc.*, **78**, 3279 (1956); M. R. Das, A. V. Patankar, and B. Venkataraman, *Proc. Indian Acad. Sci.*, **53**, 273 (1961); L. H. Piette, F. A. Johnson, K. A. Booman, and C. B. Colburn, *J. Chem. Phys.*, **35**, 1481 (1961).