reaction accounts for all the observed products by means of reasonable intermediate reactions.

Ethyl Iodide and Mixed Halides.—The possibilities in the ethyl iodide reaction are much more numerous than with methyl iodide alone. The ethyl radical on colliding with ethyl iodide may combine with hydrogen (from either of the two carbon atoms in ethyl iodide), with iodine, methyl, iodomethyl, iodoethyl, or ethyl groups. None of these reactions can be eliminated as completely impossible. The formation of propane and butane is indicated by the equations

$$C_2H_5 + CH_3CH_2I \longrightarrow C_3H_8 + CH_2I$$
$$C_2H_5 + C_2H_5I \longrightarrow C_4H_{10} + I$$
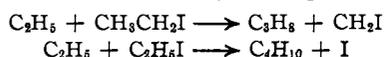
These reactions are expected to be about equally probable. Unsaturated products, including carbon, arise as before from CH_2I. The appearance of a little methane in the gases collected from the ethyl iodide reaction means either that the C–C chain is broken in the original reaction or, what is more likely, in a subsequent reaction of the type shown in equation (8) below.

$$C_2H_5 + C_2H_5I \longrightarrow C_2H_5CH_2I + CH_3 \qquad (8)$$
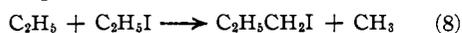
That the propane is not formed by union of methyl and ethyl radicals is shown by the experiments with the mixed halides where the greatly increased concentration of methyls does not result in any appreciable increase in propane. That the propane production is not diminished by addition of methyl iodide to ethyl iodide means that methyls can enter into some propane-producing reaction with ethyl iodide, and ethyls can enter into a propane-producing reaction with

methyl iodide, the most obvious suggestions being

$$CH_3 + C_2H_5I \longrightarrow C_3H_8 + I$$
$$C_2H_5 + CH_3I \longrightarrow C_3H_8 + I$$
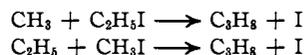
There is no evidence for the union of either like or unlike alkyl radicals under the conditions of our experiments and it is possible in certain other reaction systems where saturated hydrocarbons have been attributed to this kind of process, that alternative sources are responsible.

Acknowledgment.—The authors express their thanks to Dr. Milton Burton for helpful discussion of many aspects of the work reported in this paper.

Conclusions and Summary

On the basis of a free radical mechanism, one would expect a gas phase Wurtz reaction to be very complicated, and this is found to be true experimentally. The reaction of methyl iodide or ethyl iodide or a mixture of the two at a pressure of about 200 mm. at 320° produces hydrogen, free carbon, saturated and unsaturated hydrocarbons and possibly smaller amounts of higher halides. The character of the products is in harmony with current views concerning free radical reactions.

Combinations of two alkyl radicals to give saturated molecules seem not to occur in this system. Most of the primarily formed free radicals disappear by reaction with excess halide molecules, and the secondary radicals containing iodine disappear either by reacting with each other or by reaction with sodium.

Alkylation of α-Naphthoquinones with Esters of Tetravalent Lead

BY LOUIS F. FIESER AND FREDERIC C. CHANG[1]

This investigation originated in a chance observation made by one of us in attempting to improve a known procedure[2,3] for converting butadiene-toluquinone (I) into 2-methyl-1,4-naphthoquinone. Treatment of the isomerization product II with silver oxide affords the highly sensitive quinone III, and powerful oxidizing agents lead to some destruction. With chromic anhydride,

as in comparable cases,[4] II can be converted into IV in about 50% yield.

The use of lead tetraacetate was thought to offer a possibility for improvement, for the intermediate quinone III might undergo acetoxylation in one of the activated methylene groups or give a glycol diacetate by an addition to the double bond, and either intermediate should lose acetic acid readily with the formation of IV. When the hydroquinone II was warmed on the steam-bath

(1) On leave of absence from the Department of Chemistry, Lingnan University, Canton, China.

(2) Fieser, Tishler and Wendler, THIS JOURNAL, 62, 2861 (1940).

(3) Tishler, Fieser and Wendler, ibid., 62, 2866 (1940).

(4) Fieser, Campbell and Fry, ibid., 61, 2206 (1939).

in acetic acid with just two moles of lead tetraacetate, there was obtained a crystalline product which melted slightly above the melting point of pure 2-methyl-1,4-naphthoquinone (m. p. 106–107°) and seemed reminiscent of the intermediate yellow products of unknown nature isolated on partial oxidation of other 5,8-dihydro-1,4-naphthohydroquinones with chromic acid.[4] Since these intermediates are convertible to the naphthoquinones by further oxidation, the experiment was repeated with three moles of lead tetraace-

It was ascertained that the result is the same when the hydroquinone II is first oxidized with silver oxide to the quinone III, and this is then treated with lead tetraacetate. When either II or III is employed as the starting material, the reaction with lead tetraacetate in acetic acid at the steam-bath temperature is characterized by a rapid evolution of gas containing carbon dioxide in amounts corresponding to approximately 1.4 moles per mole of hydroquinone II. When methylnaphthoquinone was submitted to similar treatment (thirty-six hours), there was no gas evolution or consumption of the reagent, and the starting material was recovered unchanged. It was observed also that when the quinone III is refluxed with lead tetraacetate in benzene solution it is converted in moderate yield into methylnaphthoquinone (IV), and affords none of the dimethyl compound V.

In a further investigation of the unusual reaction, the action of lead tetraacetate on 5,8-dihydro-1,4-naphthohydroquinone was found to give a small amount of 2,3-dimethyl-1,4-naphthoquinone. 2,6,7-Trimethyl-5,8-dihydro-1,4-naphthohydroquinone (VI) was prepared by the isomeri-

tate, all of which was consumed. The reaction product melted at 126.5–127.5°, and analyses of the substance and of its sharply melting hydroquinone diacetate pointed to the formula $C_{12}H_{10}O_2$, whereas methylnaphthoquinone is $C_{11}H_8O_2$. The Craven test[5] was found to be completely negative, indicating the absence of a free position in the quinonoid ring, and the substance was identified by direct comparison as 2,3-dimethyl-1,4-naphthoquinone (V).

The action of excess lead tetraacetate on 2-methyl-5,8-dihydro-1,4-naphthohydroquinone thus involves a remarkable methylation reaction.

zation of the addition product from 2,3-dimethylbutadiene and toluquinone and treated with excess lead tetraacetate. The reaction product corresponded in melting point with 2,3,6,7-tetramethyl-1,4-naphthoquinone (VII), as described by Bergmann and Bergmann,[6] and its identity was established by comparison with a sample of this substance synthesized by adding 2,3-dimethylbutadiene to o-xyloquinone and oxidizing the isomerized product with chromic acid. The oxidation was also conducted with lead tetraacetate, and in this case the reaction proceeded normally and likewise yielded the tetramethylnaphthoquinone VII. The methylation of the trimethyl compound VI in the lead tetraacetate reaction bears some resemblance to the conversion of 2,6,7-trimethyl-1,4-naphthoquinone to the 2,3,-6,7-tetramethyl compound VII by the action of diazomethane, observed by Bergmann and Berg-

(5) Craven, J. Chem. Soc., 1605 (1931).

(6) F. Bergmann and F. Bergmann, J. Org. Chem., 3, 125 (1938).

mann.[6,7] The resemblance is superficial, however, for the latter reaction very probably proceeds through the formation and decomposition of a pyrazoline, as in the example studied in this Laboratory.[8]

That the methyl group introduced in the course of the curious reaction comes from lead tetraacetate was initially discounted because of the observation that the reagent is without action on methylnaphthoquinone at the same temperature (steam-bath). That the 5,8-dihydride III under the same conditions enters into a brisk reaction, suggested that it may serve the dual rôle of providing the carbon substituent, through an allylic intermediate,[9] as well as acting as acceptor of the methyl group.

In an attempt to separate the two functions, malonic acid was selected as a component having an activated methylene group, and methylnaphthoquinone was employed as an acceptor which itself is not attacked under the conditions of the experiment. When an acetic acid solution of approximately equivalent amounts of methylnaphthoquinone and malonic acid was heated on the steam-bath and treated with successive portions of lead tetraacetate, a steady gas evolution ensued, nearly five moles of reagent were consumed, and the reaction product proved to be 2,3-dimethyl-1,4-naphthoquinone. Since the product is
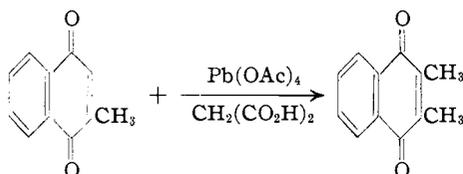
easily isolated in a pure condition and the yield is 45–50% of the theoretical amount, this constitutes a practical method of methylation. The fact that no reaction occurred in the absence of malonic acid seemed to indicate that this substance had functioned as the methylating agent even though it is itself attacked by lead tetraacetate, probably in a reaction analogous to the conversion of malonic ester into acetylmalonic ester.[10,11]

Other active-hydrogen components were tried with varying results. Ethyl acetoacetate was

found to function about as satisfactorily as malonic acid, but when diethyl malonate was employed the starting material was recovered unchanged. In experiments conducted under the same conditions (90–95°), triphenylmethane, cyclopentadiene, acenaphthene and dimethylmalonic acid proved ineffective in comparison with malonic acid, and at least a large part of the starting material was recovered. Methylmalonic acid was then tried and found to promote a characteristic gas evolution and to afford a transformation product in yield as high as that obtained with malonic acid. If the alkyl group introduced is derived from the malonic acid, methylmalonic acid should afford 2-methyl-3-ethyl-1,4-naphthoquinone. The product obtained, however, proved to be the 2,3-dimethyl compound (V). Therefore, although the active-hydrogen component promotes the alkylation, it is not the alkylating agent. This conclusion was confirmed by the observation that methylnaphthoquinone can be converted into the 2,3-dimethyl derivative by the action of lead tetraacetate in combination with C-ethyl ethyl acetoacetate as promoter.

A method of testing the possibility that lead tetraacetate functions as the methylating agent was to attempt the introduction of higher alkyl groups by means of appropriate esters of tetravalent lead. Thus lead tetrapropionate would be expected to afford an ethyl substituent. Since preformed lead tetraacetate is not required in typical oxidations with this reagent but can be replaced by a combination of red lead and acetic acid,[12] we adopted this method of operation both as a matter of convenience and in order to extend the scope of experimentation. Thus methylnaphthoquinone was dissolved in propionic acid, an equivalent amount of ethyl acetoacetate was added as a promoter, and red lead was added in portions, with heating and stirring. A smooth reaction ensued, affording in 49.5% yield a product melting at 72–72.6° and having the composition of the methylethyl compound. Karrer and Epprecht[13] observed the melting point 73° for a sample of 2-methyl-3-ethyl-1,4-naphthoquinone (VIII) synthesized from ar.-β-methyltetralin. As a possible means of obtaining a sample for direct comparison, we attempted the methylation of 2-ethyl-1,4-naphthoquinone (IX) with lead tetraacetate in the presence of malonic acid. The re-
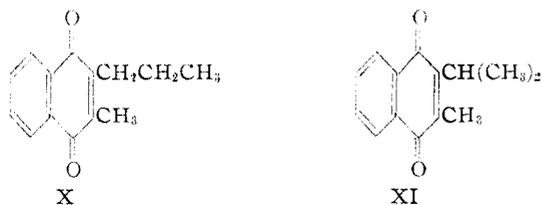
(7) We do not agree with the interpretation which these authors advance of the nature of the product obtained from 2,6-dimethyl-1,4-naphthoquinone and diazomethane by Fieser and Seligman, THIS JOURNAL, **56**, 2690 (1934).

(8) Fieser and Hartwell, THIS JOURNAL, **57**, 1479 (1935).

(9) Fieser, ibid., **61**, 3467 (1939).

(10) Dimroth and Schweizer. Ber., **56**, 1375 (1923).

(11) Bak, Ann., **537**, 291 (1938).

(12) Ward, THIS JOURNAL, **60**, 325 (1938); Fieser and Cason, ibid., **62**, 432 (1940); Scanlan and Swern, ibid., **62**, 2305 (1940).

(13) Karrer and Epprecht. Helv. Chim. Acta, **23**, 272 (1940).
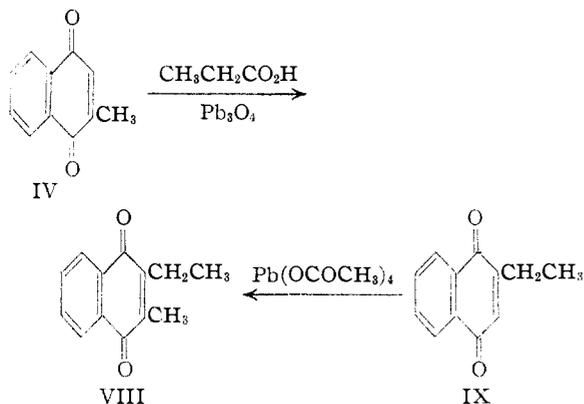
action proceeded satisfactorily and the product obtained proved to be identical with that resulting from the ethylation experiment. The organometallic ester is thereby identified as the alkylating agent.

The behavior of methylnaphthoquinone under the same conditions with red lead in combination with n-butyric acid and with isobutyric acid was then investigated. Each reaction yielded a different, fully substituted quinone (negative Craven test), and these melted at 65° and 112°, respectively, and had the expected composition of the methylpropyl compounds. It was established that these substances have the structures X and XI, respectively, corresponding to normal alkyla-

tions, and that the substituent does not suffer isomerization in the course of the reaction, by the above expedient of introducing the groups in the alternate order. 2-n-Propyl-1,4-naphthoquinone,[4] when treated with lead tetraacetate and malonic acid, afforded a product identical with the lower melting isomer, obtained in the propylation experiment employing n-butyric acid. One of the two routes to the disubstituted compound shows that it contains a normal propyl group in the quinonoid ring, and the other indicates the presence of a similarly situated methyl group; the structure X therefore is fully established. Evidence was likewise obtained in support of formula XI for the isomer. A small sample of β-isopropylnaphthalene was oxidized with chromic acid and the crude, oily quinone obtained was methylated

with lead tetraacetate; this afforded a product identical with the higher melting methylpropyl compound. In the preparation of these comparison samples, it was observed that the methylation reaction proceeds less readily when the quinonoid ring carries an ethyl or propyl substituent than when a 2-methyl group is initially present. A higher temperature is required, and the yields are lower.

No comparable limitation was observed with respect to the introduction of higher alkyl groups into 2-methyl-1,4-naphthoquinone. The above ethylation and propylation reactions proceeded as smoothly as the methylation of this compound, giving yields as high as 59%, and alkylation of the same quinone with n-caprylic acid and red lead was conducted with success. When a stirred mixture of the quinone, the fatty acid and malonic ester was treated with red lead at 120–130°, the oxide dissolved steadily if slowly, and the reaction afforded in 34% yield a quinone of composition and properties consistent with the structure of 2-methyl-3-n-heptyl-1,4-naphthoquinone (XII). Quinones of this type heretofore have been obtainable only in a rather elaborate sequence of synthetic operations.[13,14] By a similar process,
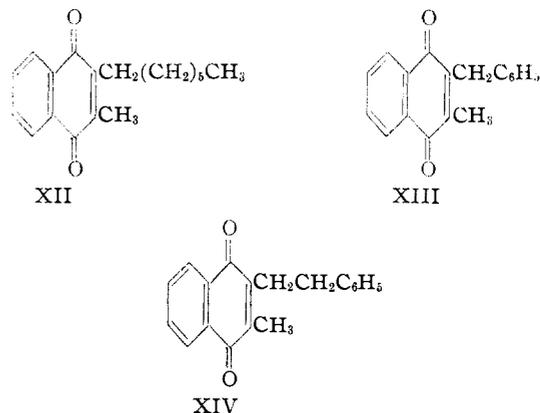
phenylacetic acid afforded in 65% yield a product which was fully identified as the 2-methyl-3-benzyl compound XIII by direct comparison with a sample of the substance obtained previously in this Laboratory by another synthesis.[15] An alkylation utilizing hydrocinnamic acid yielded a new quinone which, in analogy with the other examples of the reaction, can be assigned the probable structure of 2-methyl-3-β-phenylethyl-1,4-naphthoquinone (XIV). Attempted alkylation

(14) Fernholz, Ansbacher and MacPhillamy, THIS JOURNAL, 62, 430 (1940).

(15) Fieser, Campbell, Fry and Gates, ibid., 61, 3216 (1939).

with γ-phenylbutyric acid thus far has been unsuccessful.

The alkylation of naphthoquinones with esters of tetravalent lead is at least a fairly general phenomenon, and it is evident that the alkyl group introduced is derived from an acyl radical of the ester. The carbon dioxide evolved evidently is derived from the same source, and it appears that under certain conditions lead tetraacetate suffers decomposition to lead acetate, carbon dioxide and either actual or potential methyl radicals. Of significance in this connection is the early observation by Dimroth and Schweizer[10] that when lead tetraacetate is heated with acetic acid and acetic anhydride at the reflux temperature a small amount of an inflammable gas is evolved, which presumably is ethane. A consideration of the mechanism of the breakdown of the lead tetraacetate molecule will be deferred to reports of further investigations being conducted by other workers in this Laboratory. An observation made by R. C. Clapp and W. H. Daudt suggested the possibility of initiating the alkylation reaction without the use of an active-hydrogen promoter, and it was found that, although methylnaphthoquinone is recovered unchanged after a prolonged period of warming with lead tetraacetate and acetic acid on the steam-bath, alkylation sets in, with evolution of carbon dioxide, if the temperature is raised to the point of refluxing. The 2,3-dimethyl compound is thus obtainable without the use of a promoter, although malonic acid or similar reagent definitely facilitates the reaction. Criegee[16] found that the velocity of the cleavage of glycols by lead tetraacetate in acetic acid solution is accelerated enormously by the addition of another solvent such as methanol or water. Following an observation by S. T. Putnam that the activating effect applies to still other reactions of lead tetraacetate, we discovered that methanol can be used to promote the alkylation reaction at 90–95°. When acetic acid is employed as the sole solvent, crystals of added lead tetraacetate remain colorless and undissolved until the reaction is initiated by adding a promoter or by raising the temperature to the boiling point. Although the alkylation appears to be subject to catalysis, it seems from the present results to require being maintained in progress, as well as being initiated.

It is now evident that, in the initial experiment

(16) Criegee, *Ber.*, **73**, 563 (1940).

which led to the discovery of the remarkable alkylating action of lead tetraacetate, the unsaturated compound II played the dual role of providing a source of methylnaphthoquinone and of functioning as a promoter of the methylation reaction.

Experimental Part[17]

Action of Lead Tetraacetate on 2-Methyl-5,8-dihydro-1,4-naphthohydroquinone, II (L. F. F.).—In a first trial, 0.18 g. of II[2] (m. p. 173–174°) in 5 cc. of acetic acid was treated with 0.95 g. of lead tetraacetate, and the mixture was warmed until solution was complete and allowed to stand for two days, when the test for tetravalent lead was negative. The product, when crystallized from methanol, melted at 107–110.5° and showed a depression (*ca.* 90°) when mixed with 2-methyl-1,4-naphthoquinone. In another experiment a solution of 0.70 g. of II in 10 cc. of acetic acid was heated on the steam-bath and treated in the course of about four hours with a total of 5.54 (3.1 equivalents) of lead tetraacetate, added in portions. The reagent was all consumed, and on adding water there was precipitated a slightly sticky solid, m. p. 117–119°. One crystallization from methanol gave yellow needles, m. p. 124–125°, and after four more crystallizations the substance melted constantly at 126.5–127.5°; the Craven test was negative. In another experiment, 1.4 g. of II in 25 cc. of acetic acid took up a total of 13.9 g. (3.92 equivalents) of reagent under similar conditions and the once crystallized product (0.38 g.) melted at 124–126°. The fully purified material melted at 126.5–127.5° and gave no depression when mixed with **2,3-dimethyl-1,4-naphthoquinone.** Analyses of the two preparations were carried out with the following results.

Anal. Calcd. for $C_{12}H_{10}O_2$: C, 77.40; H, 5.41. Found: C, 77.37, 77.36; H, 5.66, 5.82.

The **hydroquinone diacetate,** prepared by reductive acetylation of the quinone with zinc dust, acetic anhydride and pyridine, melted initially at 189.5–190.5°. The substance crystallized from alcohol in the form of diamond-shaped, laminated plates, m. p. 190–190.5°.

Anal. Calcd. for $C_{16}H_{16}O_4$: C, 70.57; H, 5.92. Found: C, 70.70; H, 6.16.

The following experiments were run in parallel at the steam-bath temperature. In the first, 0.70 g. of II in 15 cc. of acetic acid was heated with 7.08 g. (4 equiv.) of lead tetraacetate. Carbon dioxide was evolved steadily and the starch–iodide test was negative only after four hours, when 0.5 g. more reagent was added. The test was negative after three hours, and the product was precipitated with water, extracted with ether and crystallized from methanol. The yield of 2,3-dimethyl-1,4-naphthoquinone, m. p. 124–125°, was 0.21 g. (28%). In the second experiment, 0.70 g. of II in 15 cc. of dry ether was shaken for one-half hour with 2 g. of silver oxide and magnesium sulfate, and the yellow solution was filtered and evaporated. The residue was a bright yellow, light-sensitive solid, m. p. 86–87°, consisting of the quinone III. This was dissolved in 15 cc. of acetic acid and treated as above with 5.32 g. (3

(17) Microanalyses by Lyon Southworth and E. Werble. All melting points are corrected.

equiv.) of lead tetraacetate. Gas was evolved at first and tetravalent lead was still present after heating for seven hours. After destroying the excess reagent by the addition of 3 drops of glycerol, the product was precipitated and worked up as above. The once crystallized product, m. p. 124.5–125.5°, was identified as the 2,3-dimethyl compound by mixed melting point determination; yield 0.16 g. (22%).

Another 0.70-g. lot of II was oxidized with silver oxide to the quinone and a solution of this in 15 cc. of benzene was refluxed with 5.32 g. of lead tetraacetate for fifteen hours. The mixture was filtered and the solution shaken with dilute hydrochloric acid until the precipitated lead dioxide was dissolved. The crude product (0.7 g.) obtained on evaporation afforded, on crystallization from methanol, 0.20 g. of yellow needles, m. p. 103–104°. The recrystallized material melted at 106–107° and did not depress the m. p. of 2-methyl-1,4-naphthoquinone. Treatment of 0.70 g. of II in acetic acid with a slight excess of chromic anhydride afforded 0.40 g. of methylnaphthoquinone, m. p. 102–103°. When pure methylnaphthoquinone (0.69 g.) was heated on the steam-bath in acetic acid with one equivalent of lead tetraacetate, there was no gas evolution, and unconsumed reagent was still present after thirty-six hours. The collected product proved to be unchanged starting material, m. p. 106–106.5°.

Extension of the Experiments.—Some improvements were made in the preparation of the starting material. The addition of butadiene (16 g.) to toluquinone (20 g., steam distilled) was conducted in the presence of benzene (20 cc.) in a capped bottle at 70° for six hours. The resulting solution was clarified with Norit, concentrated and diluted with ligroin (70–90°). The addition product I which crystallized was obtained after washing with ligroin as pale yellow crystals, m. p. 80–81°; yield 24.4 g. (84%). When this substance was heated with lead tetraacetate in acetic acid, there was no gas evolution, and no dimethylnaphthoquinone could be isolated. Isomerization to 2-methyl-5,8-dihydro-1,4-naphthohydroquinone was accomplished satisfactorily by the method reported[2] only when working with small quantities. With larger amounts it was found best to reflux the addition product for a few minutes in acetic acid containing about 1% of concentrated hydrochloric acid and a trace of stannous chloride; a colorless crystalline product invariably resulted, and either separated from the boiling medium or crystallized on dilution with water. A typical methylation experiment conducted with four equivalents of lead tetraacetate afforded 2,3-dimethyl-1,4-naphthoquinone in 28% yield; the hydroquinone diacetate melted at 190.5–191.5°.

Approximate determinations of the amount of carbon dioxide evolved in the course of the reaction were made. In one experiment with 3.1600 g. of II, the net weight of carbon dioxide evolved was 1.0910 g., whence the ratio moles CO_2/moles II = 1.38. In another run, 2.1397 g. of II gave rise to 0.7526 g. of carbon dioxide, corresponding to the molecular ratio 1.41:1.

Methylation of 5,8-Dihydro-1,4-naphthohydroquinone.—The starting material[18] was obtained by isomerization of the corresponding addition product with boiling acetic acid containing hydrochloric acid and stannous chloride; the

substance crystallized on dilution in elongated prisms, m. p. 212–214°. A solution of 1.62 g. of the hydroquinone was treated with 16 g. (3.6 equivalents) of lead tetraacetate at 90°. Rapid gas evolution had ceased after one hour, although the test for oxidizing agent was negative only after four hours. The collected product was an oil which partially crystallized. Washing with methanol afforded 0.1 g. (5%) of brown crystals, m. p. 112–115°, and the recrystallized material melted at 122–124° and did not depress the melting point of 2,3-dimethyl-1,4-naphthoquinone.

2,3,6,7-Tetramethyl-1,4-naphthoquinone, VII. (a) By the Methylation Reaction.—For the preparation of the starting material, 8.6 g. of toluquinone was refluxed with 13.5 cc. of 2,3-dimethylbutadiene in 15 cc. of alcohol for four hours. The product[6] which separated on ice cooling was recrystallized once from alcohol and afforded 9.3 g. (67%) of material melting at 91–92°; this was isomerized by the method described above to **2,6,7-trimethyl-5,8-dihydro-1,4-naphthohydroquinone**[6] (VI), m. p. 214–215°. Methylation of 1.43 g. of VI was accomplished by treatment with lead tetraacetate as in the previous experiments. The sticky solid obtained as the crude reaction product on crystallization from methanol gave 0.32 g. (21%) of the tetramethyl compound VII in two crops (m. p. 164–165.5°). Recrystallization afforded well-formed yellow crystals melting at 167–168.5°. Bergmann and Bergmann[6] report the melting point 167–168°.

(b) By Synthesis.—o-Xyloquinone was prepared from o-xylidine by oxidation with manganese dioxide.[19] A mixture of 1.65 g. of the quinone, 4 cc. of 2,3-dimethylbutadiene, and 5 cc. of absolute alcohol was refluxed for eight hours. The addition product, **2,3,6,7-tetramethyl-5,8,9,10-tetrahydro-1,4-naphthoquinone**, separated on cooling as small, colorless needles, m. p. 105–106.5°; yield 2.22 g. (80%).

Anal. Calcd. for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 76.87; H, 8.24.

This was isomerized in the usual way to 2,3,6,7-tetramethyl-5,8-dihydro-1,4-naphthohydroquinone, which when purified from dioxane–ligroin melted at 269–270.5° (Bergmann and Bergmann[6] obtained in a different way a substance melting at 232° which they regarded as having this structure).

Oxidation of the hydroquinone with chromic acid in acetic acid gave a product which crystallized from methanol in yellow leaflets melting at 169.5–170°, and this did not depress the melting point of the quinone obtained by method (a). Oxidation of the hydroquinone with lead tetraacetate likewise afforded VII (m. p. 166–168°). Samples of the quinone prepared by methods (a) and (b) were submitted to reductive acetylation and in each case afforded a colorless **hydroquinone diacetate** melting at 216–217°; the samples when mixed showed no depression.

Anal. Calcd. for $C_{18}H_{20}O_4$: C, 71.98; H, 6.71. Found: C, 71.84; H, 6.54.

Action of Lead Tetraacetate on 2-Methyl-1,4-naphthoquinone, IV, (a) with Malonic Acid.—A solution of 0.86 g. (0.005 mole) of IV and 0.6 g. of malonic acid in 15 cc. of

(18) Diels and Alder, *Ber.*, **62**, 2361 (1929).

(19) Fieser, "Experiments in Organic Chemistry," D. C. Heath and Co., Boston, Mass., 1935, p. 228.

acetic acid was treated with 5 g. of lead tetraacetate and heated on a water-bath to 50–60°, when a brownish solid soon began to separate from the upper part of the solution and gas bubbles began to appear. After heating for about one hour, the precipitate had lightened in color and appeared as a curdy white solid which filled the entire solution. The same substance is formed in the absence of methylnaphthoquinone and probably is a lead salt of malonic acid. After heating for another hour at 75° the solid had all dissolved, no more gas was evolved, and the test with starchiodide paper was negative. When an additional 2-g. portion of lead tetraacetate was added it was consumed rather rapidly, with further gas evolution. When the reaction slackened, another 2-g. portion was added. This process was repeated until, at the end of six and one-quarter hours (total), no more gas was evolved, the solution was of a clear, golden color, and excess reagent was present; a total of 10.5 g. (4.7 equivalents) of lead tetraacetate had been used. The excess reagent was destroyed with glycerol (6 drops) and the solution was poured into water. The crystalline yellow precipitate on one crystallization from methanol yielded 0.45 g. (49%) of yellow needles, m. p. 118–125°. On recrystallization, the sample melted at 122–124° and was identified by mixed melting point determination as 2,3-dimethyl-1,4-naphthoquinone. A trace of starting material (m. p. 102–104°) was recovered from the aqueous filtrate by extraction with ether and crystallization. In later experiments conducted at the steambath temperature, no starting material was detected and the yield of methylated product was better.

(b) **With Ethyl Acetoacetate.**—In an experiment with 0.86 g. of IV and 0.6 cc. of acetoacetic ester in 15 cc. of acetic acid, heated on the steam-bath, no solid intermediate appeared, but gas was evolved and a total of 4.16 equivalents of lead tetraacetate was consumed. The product was identified as the 2,3-dimethyl compound. Other experiments indicated that the results are better when a full molecular equivalent of the promoter is used than with 0.4 equivalent.

(c) **With C-Ethyl Ethyl Acetoacetate (L. F. F.).**—The following rapid procedure gave good results with this promoter but was less satisfactory when malonic acid or acetoacetic ester was used. A mixture of 0.86 g. of IV, 8.8 g. (3.7 equiv.) of lead tetraacetate, and 10 cc. of acetic acid was heated on the steam-bath and a solution of 1.03 g. (1.3 equiv.) of C-ethyl ethyl acetoacetate in 5 cc. of acetic acid was run in from a dropping funnel in the course of one-half hour, during which time gas was evolved steadily. A few remaining crystals of lead tetraacetate subsequently dissolved, but after heating for one and one-half hours excess reagent was still present. This was discharged with glycerol (4 drops) and the solution was diluted and extracted with ether. The ethereal extract was washed with dilute nitric acid and with sodium carbonate solution and shaken with aqueous sodium hydrosulfite solution to effect reduction of the quinone. The hydroquinone was then extracted with three portions of 5% potassium hydroxide containing 2% of sodium hydrosulfite and the yellow vat solutions were drawn off under ether, combined and acidified. [9] The hydroquinone was extracted with ether and the solution was washed with soda solution,

dried, shaken with silver oxide and magnesium sulfate, filtered and evaporated. The residue was a bright yellow solid, m. p. 120–122° (recrystallized: 124–125°); yield 0.43 g. (46%).

(d) **With Diethyl Malonate.**—In an experiment conducted as in (a) except for the substitution of malonic ester in place of malonic acid, there was but little gas evolution at the steam-bath temperature and after heating for twelve hours a considerable part of the initial 5-g. lot of lead tetraacetate remained unconsumed and crystallized when the solution was cooled. The filtered solution afforded only starting material, m. p. 103–104°.

In another run performed in the same way but at the reflux temperature and with excess lead tetraacetate, methylation proceeded satisfactorily and the dimethyl compound was produced.

(e) **With Methylmalonic Acid.**—This reagent, when employed under the conditions defined for malonic acid (a), gave entirely comparable results and afforded 2,3-dimethyl-1,4-naphthoquinone in good yield. The only difference noticed was that no intermediate white salt precipitated, although at the beginning of the reaction the solution was slightly cloudy.

(f) **With Tartronic Acid.**—When tartronic acid[11] (m. p. 159°, dec.) was used, a curdy white solid at first separated and then dissolved on the addition of more reagent. Dimethylnaphthoquinone again was a product of the reaction.

(g) **With Dimethylmalonic Acid.**—With this reagent,[21] employed under the conditions of (a), about half the usual amount of lead tetraacetate was consumed, there was relatively little gas evolution, and the product after one crystallization melted at 95–100° and after a second at 99–102°. This, apparently, consisted largely of starting material, but on reëxamination it was found to afford after further crystallizations a small amount of material melting at 113–115°; a mixture with the dimethyl compound melted at 115–120°.

(h) **With Methanol.**—A solution of 0.86 g. of the quinone IV in 15 cc. of acetic acid and 5 cc. of methanol was treated at the steam-bath temperature with a total of 9 g. (4.1 equiv.) of lead tetraacetate, added in portions. At the end of the reaction the clear solution was decanted from a small amount of dark precipitate and processed as usual. After two crystallizations the product melted at 120–122° and was identified as the dimethyl compound VII.

(i) **Without a Promoter.**—When a mixture of 5.16 g. of methylnaphthoquinone, 30 cc. of acetic acid, and 25 g. of lead tetraacetate was heated to the reflux temperature, the reaction started promptly, with vigorous gas evolution. As the reagent was used up, further 5-g. portions were added until, when a total of 67 g. (5 equiv.) of lead tetraacetate had been added, the reaction subsided. Refluxing was continued for a total of five hours. The dark brown mixture was poured into water and the product extracted with ether and processed as usual. The solid material obtained from the residual oil when purified afforded 0.42 g. of 2,3-dimethyl-1,4-naphthoquinone, m. p. 123–125°: the mother liquor remained as an oil even on sublimation and yielded no additional product. Better results were

(20) Compare procedure for the isolation of vitamin K₁.[9]

(21) Bartlett, Fraser and Woodward, THIS JOURNAL, **63**, 495 (1941).

obtained in an earlier experiment employing less reagent (4 equiv.) and more acetic acid; the yield was not determined accurately but appeared to be comparable with those in the experiments with added malonic acid.

(j) **With Reactive Hydrocarbons.**—In trials with cyclopentadiene and with acenaphthene as possible promoters, the starting material was recovered unchanged. With triphenylmethane, the reaction seemed to proceed as in the successful methylations, but the only crystalline product isolated from the oily reaction mixture was a colorless solid, m. p. 88–90° (probably triphenylmethyl acetate, m. p. 87–88°).

2-Methyl-3-ethyl-1,4-naphthoquinone. (a) By Ethylation.—A solution of 3.44 g. (0.02 mole) of 2-methyl-1,4-naphthoquinone and 3.2 cc. (0.025 mole) of ethyl acetoacetate in 50 cc. of propionic acid was heated with stirring on the steam-bath and 60 g. (4.37 equiv.) of red lead was added in 5-g. portions. The reaction started on the addition of the first lot of oxide, as evidenced by the rapid evolution of gas. After a time the gas evolution noticeably lagged. The first 40 g. of red lead was consumed within forty-five minutes and the remainder had largely disappeared after a total time of about two hours, when the reaction appeared to be at an end. Heating and stirring were continued for a total of three hours. In this and similar alkylations it seems advisable to continue heating for about one hour after evident gas evolution ceases. The mixture, which gave a positive test for tetravalent lead, was cooled somewhat, with continued stirring, and ether was added to extract the product. The ethereal solution was decanted and the semisolid residue containing red lead and lead salts was extracted several times with fresh portions of ether. The combined ethereal solution was washed with saturated sodium bicarbonate solution until neutral, dried with calcium chloride, and evaporated. A voluminous white precipitate of a basic lead salt sometimes appears in the washing with sodium bicarbonate solution; in this case the ethereal solution is acidified, shaken thoroughly with 10% nitric acid, and then washed again with bicarbonate solution. The residual oil obtained from the ether crystallized when cooled and manipulated. The crystalline product was transferred to a Hirsch funnel and washed with methanol, giving 0.75 g. of yellow needles, m. p. 69–70.5°. Concentration of the mother liquor and washings afforded 0.87 g. of material melting at 66–70.5°. The total amount collected represents a yield of 40.5%; additional material is retained in the mother liquor. After two further crystallizations the quinone melted at 72–72.6° and sublimation of the sample produced no change (Karrer, et al.,[13] 73°).

Anal. Calcd. for $C_{13}H_{12}O_2$: C, 77.98; H, 6.04. Found: C, 78.36, 78.38; H, 6.48, 6.44.

The **hydroquinone diacetate** crystallized from dilute acetic acid in needles melting at 106–108°, and remelting at 116–117°.

Anal. Calcd. for $C_{17}H_{18}O_4$: C, 71.37; H, 6.34. Found: C, 71.69; H, 6.34.

(b) **By Methylation.**—2-Ethyl-1,4-naphthoquinone (1.86 g.) was methylated with lead tetraacetate in acetic acid in the presence of malonic acid (1.3 g.) by the procedure described above. The yield of once crystallized product, m. p. 65–68°, was 0.3 g. (15%). Sublimation, followed by

crystallization from ether–petroleum ether raised the melting point to 71.4–72.4° and admixture of the sample with that described in (a) did not depress the melting point. The second crop of crystals from the mother liquor melted below 60° and contained a considerable amount of starting material.

2-Methyl-3-n-propyl-1,4-naphthoquinone. (a) By Propylation.—The reaction was conducted with 1.72 g. of methylnaphthoquinone, 1.5 g. of malonic acid (1.4 equiv.), 45 cc. of n-butyric acid, and 35.7 g. (5.2 equiv.) of red lead. The mixture was poured into water and the viscous oily layer which appeared was washed with water by decantation and extracted with ether. The crude reaction product was obtained as a yellow oil which crystallized on cooling. Crystallization from methanol afforded the following crops of material: 0.07 g. (m. p. 65–65.5°), 0.72 g. (64–64.5°), 0.21 g. (63–64.2°); combined yield 47%. Sublimation at 53–58° at 1 mm. gave quinone melting at 65–65.4°.

Anal. Calcd. for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.69; H, 6.90.

The **hydroquinone diacetate** was prepared by reductive acetylation of the quinone with acetic anhydride, zinc dust and a trace of pyridine. It separated from methanol in diamond-shaped crystals, m. p. 93.5–95°.

Anal. Calcd. for $C_{18}H_{20}O_4$: C, 71.98; H, 6.71. Found: C, 72.00; H, 7.11.

(b) **By Methylation.**—The 2-n-propyl-1,4-naphthoquinone required as starting material was prepared by hydrogenating a sample of the 2-allyl compound,[4] oxidizing the resulting hydroquinone, crystallizing the quinone from ether–petroleum ether, and finally subliming the sample slowly at 40° and 8 mm. This gave canary-yellow material melting at 40.5–41° (compare 39–39.5°[4]). Methylation with lead tetraacetate (and malonic acid) was first attempted at steam-bath temperature, but the starting material was recovered unchanged. The reaction proceeded successfully, however, when conducted at the boiling point of the acetic acid solution. The crude product melted at 50–55°, and recrystallization gave well formed needles, m. p. 58–60°. Slow sublimation afforded in the terminal fraction material melting at 61–63.5°, and a mixture of this with the sample (a) melted at 63.5–65°.

2-Methyl-3-isopropyl-1,4-naphthoquinone. (a) By Propylation.—The alkylation of methylnaphthoquinone (1.72 g.) with isobutyric acid and red lead afforded 1.27 g. (59%) of satisfactory product in two crops, m. p. 106–108° (0.95 g.) and 104–107° (0.32 g.). Recrystallization from methanol and sublimation at 80–85° and 1 mm. afforded canary-yellow material, m. p. 110–111.2°.

Anal. Calcd. for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.61; H, 6.77.

The **hydroquinone diacetate** crystallized from methanol in colorless, diamond-shaped needles, m. p. 115–116°.

Anal. Calcd. for $C_{18}H_{20}O_4$: C, 71.98; H, 6.71. Found: C, 72.20; H, 7.03.

(b) **By Methylation.**—The method first tried for the preparation of the required β-isopropylnaphthalene proved unsuccessful. Dimethyl-β-naphthylcarbinol was obtained by the reaction of β-acetonaphthalene (24.6 g.) with methylmagnesium iodide (from 3.5 g. of magnesium) in ether; the acid-hydrolyzed and washed ethereal layer was

neutralized with sodium bicarbonate solution, decolorized with Darco, concentrated to about 100 cc., and diluted with petroleum ether, which caused the separation of 19.7 g. (72%) of crystalline carbinol, m. p. 60–63°. Recrystallization from ligroin (70–90°) gave colorless leaflets, m. p. 65–65.5°.

Anal. Calcd. for $C_{13}H_{14}O$: C, 83.83; H, 7.58. Found: C, 84.08; H, 7.88.

Reduction was attempted by refluxing the carbinol in acetic acid and shaking the resulting solution with hydrogen and Adams catalyst,[22] but very little hydrogen was absorbed and the hydrocarbon appeared to have polymerized. Reduction with red phosphorus and potassium iodide[23] likewise gave a polymer.

β-Isopropylnaphthalene finally was prepared by the Friedel and Crafts reaction according to Haworth and co-workers,[24] although the reaction proceeded poorly and afforded a hydrocarbon fraction boiling at 120–135° (8 mm.) in only 14% yield. The crude hydrocarbon (4.5 g.) was oxidized with chromic anhydride[15] and the quinone extracted by the vatting procedure,[9] which afforded 1.5 g. of crude 2-isopropyl-1,4-naphthoquinone as a dark yellow, viscous oil. The entire product was methylated in boiling acetic acid solution with lead tetraacetate and malonic acid. The oily product partially crystallized when cooled, and the crystals when collected and washed with methanol melted at 95–110°. Fractional sublimation gave material melting progressively higher, and the best sample melted at 109–110°. A mixture with the 2-methyl-3-isopropyl-1,4-naphthoquinone described in (a) melted at 108.5–110°, while the substance strongly depressed the melting point both of 1,4-naphthoquinone and its 2-methyl derivative.

2-Methyl-3-*n*-heptyl-1,4-naphthoquinone.—The *n*-caprylic acid used was obtained by fractional distillation of commercial 90% acid; b. p. 120–126° (12 mm.). The alkylation of methylnaphthoquinone (1.72 g.) with *n*-caprylic acid (30 cc.), red lead (35 g.) and diethyl malonate (1.5 cc.) was conducted in an oil-bath maintained at 120–130°. The hot reaction mixture was poured into water and the nearly solid cake which separated was disintegrated by prolonged manipulation with ether and dilute nitric acid (see next section for a better method of processing the reaction mixture). The material recovered from the washed and dried ethereal solution afforded, on crystallization from methanol, 0.55 g. of product, m. p. 77–78°, and 0.36 g., m. p. 75–78°; total yield 34%. Sublimation at 70–76° (1 mm.) gave canary-yellow crystals, m. p. 80.4–80.8°. Malonic acid also was found satisfactory as the promoter.

Anal. Calcd. for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20. Found: C, 80.22, 80.20; H, 8.55, 8.58.

The hydroquinone diacetate separated from methanol as colorless silken needles, m. p. 64–65°.

Anal. Calcd. for $C_{22}H_{28}O_4$: C, 74.13; H, 7.92. Found: C, 74.44; H, 8.25.

2-Methyl-3-benzyl-1,4-naphthoquinone.—The reaction was conducted with 1.72 g. of methylnaphthoquinone, 35 g. of phenylacetic acid, 1.7 cc. of ethyl acetoacetate, and

excess red lead. The mixture was stirred in an oil-bath kept at 110–120° and toward the end of the reaction benzene was added to facilitate stirring of the otherwise pasty mixture. The addition of a diluent before the melt cools and solidifies also simplifies the processing of the reaction mixture. When benzene has been added as a thinning medium, the mixture can be cooled, with continued stirring, and enough ether added to dissolve the organic material. The solution is then filtered from oxides and salts of lead, washed with 10% nitric acid and then with sodium bicarbonate solution, dried and evaporated. In the present instance the crude product weighed 1.7 g. (65%), m. p. 98–104°. Crystallization from ethanol gave 1.13 g. of product melting at 107–108° but having the odor of phenylacetic acid. The odor was not removed entirely by sublimation at 80° (1 mm.), but two recrystallizations from ether–petroleum ether gave odorless, hexagonal, yellow prisms, m. p. 108–108.5°.

Anal. Calcd. for $C_{18}H_{14}O_2$: C, 82.41; H, 5.38. Found: C, 82.08; H, 5.60.

No depression in the melting point was observed when the material was mixed with a sample of the quinone (m. p. 107.5–108°) prepared by a different method.[16] The **hydroquinone diacetate** crystallized from methanol in clusters of colorless needles, m. p. 163–164.5°.

Anal. Calcd. for $C_{22}H_{20}O_4$: C, 75.84; H, 5.79. Found: C, 75.63; H, 5.50.

2-Methyl-3-β-phenylethyl-1,4-naphthoquinone.—The reaction was carried out with 1.7 g. of methylnaphthoquinone, 25 g. of hydrocinnamic acid, 1.7 cc. of ethyl acetoacetate, and excess red lead in a bath at 120–130° (four hours). The crude product when washed with methanol amounted to 0.40 g. (14.5%), m. p. 72–73° (additional material was retained in the mother liquor but was not recovered). After sublimation and crystallization from ether–petroleum ether, the substance was obtained as yellow crystals, m. p. 73–73.5°.

Anal. Calcd. for $C_{19}H_{16}O_2$: C, 82.58; H, 5.86. Found: C, 82.46; H, 5.90.

The hydroquinone diacetate formed microcrystals, 140.5–141.2°, from ether–petroleum ether.

Summary

Under certain experimental conditions lead tetraacetate is capable of functioning as a methylating agent. Thus 2-methyl-1,4-naphthoquinone can be converted into 2,3-dimethyl-1,4-naphthoquinone in yields as high as 50% by interaction with this reagent. The reaction can be caused to occur in acetic acid solution by operating at the reflux temperature, but proceeds more smoothly and at a lower temperature in the presence of a promoter such as malonic acid, methylmalonic acid acetoacetic ester or methanol. 2-Methyl-5,8-dihydro-1,4-naphthohydroquinone functions both as acceptor of the methyl group and as a promoter of the alkylative decomposition of lead tetraacetate. Other alkyl groups can be introduced into the

(22) See procedure of Fieser and Joshel, THIS JOURNAL, **62**, 957 (1940).

(23) Miescher and Billeter, *Helv. Chim. Acta*, **22**, 601 (1939).

(24) Haworth, Letsky and Mavin, *J. Chem. Soc.*, 1790 (1932).

naphthoquinone nucleus by treatment with an acid, a promoter and excess red lead. The 3-ethyl, 3-*n*-propyl and 3-isopropyl derivatives of 2-methylnaphthoquinone were synthesized with the use of propionic, *n*-butyric, and isobutyric acid, respectively, and the structures were established by the preparation of identical sub-

stances by the action of lead tetraacetate on 2-ethyl, 2-*n*-propyl, and 2-isopropyl-1,4-naphthoquinone. The 3-*n*-heptyl, 3-benzyl, and 3-β-phenylethyl derivatives of 2-methyl-1,4-naphthoquinone were synthesized by the new method.

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Methylation of Aromatic Nitro Compounds with Lead Tetraacetate

By LOUIS F. FIESER, RICHARD C. CLAPP AND WILLIAM H. DAUDT

In an initial experiment, 2,4,6-trinitrotoluene was treated in acetic acid solution with lead tetraacetate in the expectation of introducing an acetoxyl group into the reactive methyl substituent. Much to our surprise, the only pure reaction product isolated proved to be trinitro-*m*-xylene. The reaction appears to constitute a second instance
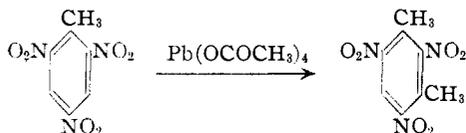
of the methylating action of lead tetraacetate, observed in this Laboratory as applied to various α-naphthoquinones.[1] In further analogy with the naphthoquinone methylation, it was found that carbon dioxide is evolved copiously in the reaction with trinitrotoluene and that a large excess of lead tetraacetate is consumed. Since an efficient method of methylating nitrohydrocarbons might have practical applications of value in the production of high explosives, an exploratory survey was made to test the applicability and efficiency of the novel reaction.

At the time the study was commenced, the parallel work in the quinone field was at a stage where it appeared that the methylating function of lead tetraacetate is evoked only in the presence of an active-hydrogen component such as malonic acid, which is itself attacked by the reagent. We thought at first that a part of the trinitrotoluene might be undergoing acetoxylation in the methyl group and thereby serving as the initiator of the methylation reaction. In the first applications of the reaction to *s*-trinitrobenzene and to *m*-dinitrobenzene, a suitable amount of malonic acid was incorporated in the reaction mixture compris-

ing the nitro compound, lead tetraacetate and acetic acid. Although the reactions proceeded under these conditions, it was subsequently discovered that the malonic acid serves only as a promoter of reactions which can be realized in the absence of this or similar component. The methylation reaction, which becomes quite evident from the gas evolution as well as by a marked darkening of the solution, often can be initiated by brief refluxing of the mixture, or by local heating of the flask with a free flame. Once the reaction has been set in progress, it will proceed briskly at a temperature previously found insufficient to cause it to start promptly. No significant differences, in this respect, were observed between trinitrobenzene and trinitrotoluene. In one experiment with the latter compound which was conducted throughout at the steam-bath temperature, the reaction started only after an induction period of about five hours but then proceeded easily to completion. Malonic acid, added as a promoter, promptly induces reaction at the temperature of the steam-bath, and methanol has the same influence. These reagents, however, seem to have no advantages over the method of initiating the reaction by heat, and they merely consume an additional mount of lead tetraacetate. In several parallel experiments the yields were essentially the same whether or not a promoter was used.

The conversion of trinitrotoluene to trinitro-*m*-xylene constitutes a particularly favorable case for study because the product is much less soluble and higher-melting than the starting material. The dimethyl compound also appears to be an end-product, for lead tetraacetate was found to be without action on trinitro-*m*-xylene in refluxing acetic acid. On treating trinitrotoluene with varying amounts of lead tetraacetate in the ab-

(1) Fieser and Chang, THIS JOURNAL, 64, 2043 (1942).