heated on the steam-bath for twenty-four hours. The solution on cooling deposited 0.03 g. of anthraquinone, m. p. 275–280°, and 0.06 g. more was obtained by dilution. Crystallization of the combined crops gave 0.08 g. of anthraquinone, m. p. and mixed m. p. 278–280°.

Oxidation of 9-Acetoxy-2-methylanthracene (X)

Preparation.—A solution of 10 g. of 2-*p*-xylylbenzoic acid[17] in 80 cc. of acetic acid and 50 cc. of acetic anhydride was refluxed with 0.5 g. of anhydrous zinc chloride for two hours; water was then added cautiously to the point of saturation. On cooling 7.5 g. (68.5%) of X, m. p. 137.5–139°, separated, and processing of the mother liquor gave 1.2 g. (11%), m. p. 135–137°. Further crystallization from alcohol (yellow plates) and from benzene-ligroin (nearly colorless aggregates) raised the melting point to 140–141.3°. The compound has been described by Barnett and Goodway.[18]

Oxidation.—Lead tetraacetate (17.5 g.) was added in portions over a period of fifteen hours to a stirred solution of 9-acetoxy-2-methylanthracene (9.8 g.) in acetic acid (500 cc.) at 70–80°. The course of the oxidation was followed by tests with starch–iodide paper. The solution was concentrated *in vacuo* and the product recovered by ether extraction and crystallized from 70–90° ligroin. A total of 5.1 g. (49%) of crude *10-acetoxy-2-methylanthrone-9*, m. p. 105–110°, was isolated, and four recrystallizations from ligroin gave 2.4 g. of colorless, cottony needles, m. p. 113–114°; a mixture with the synthetic product described below melted at 113–114°. The substance is very soluble in cold alcohol or acetone, readily soluble in ether, and moderately soluble in hot ligroin.

Anal. Calcd. for $C_{17}H_{14}O_3$: C, 76.67; H, 5.30. Found: C, 76.41, 76.91; H, 5.33, 5.44.

The mother liquor of the oxidation mixture yielded small amounts of β-methylanthraquinone, m. p. 171.5–172.5° (mixed m. p.) and of a substance melting of 209–211.4° that is probably dimethyldianthrone.[19]

Synthesis of 10-Acetoxy-2-methylanthrone-9 (XIII).—2 Methylanthrone-9[18] (5 g., m. p. 100.5–102°) was brominated at 0° in carbon bisulfide according to Barnett, Low and Morrison[20] and gave 6.2 g. (91%) of 10-bromo-2-methylanthrone-9, m. p. 123–124°, dec. A solution of 1 g. of this substance in 100 cc. of acetic acid was treated with 0.6 g. of silver acetate and the suspension stirred for one hour at room temperature. The solution was filtered from silver bromide and diluted, when a white precipitate separated consisting of 0.8 g. (85%) of XIII, m. p. 109–112°. Two crystallizations from ligroin gave colorless needles, m. p. 113.4–114°.

Summary

It has been found that the first step in the oxidation of anthracene with lead tetraacetate consists in the addition of acetoxyl groups to the two *meso* positions to give a mixture of the *cis* and *trans* isomers. Both substances lose acetic acid readily and yield 9-acetoxyanthracene, and this substance on further oxidation again adds two acetoxyl groups to give an intermediate that easily loses acetic anhydride to yield oxanthrone acetate. The formation of this oxidation product, observed by K. H. Meyer in 1911, is thus fully accounted for. The addition mechanism is further substantiated by the results of the oxidation of a derivative in which the two *meso* positions are distinguishable by virtue of the presence of a marking methyl group at the 2-position.

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[17] Prepared in yields varying from 54 to 83% by reduction of the keto acid with zinc and ammonia, m. p. 132–134°; compare Fieser and Heymann, THIS JOURNAL, **64**, 376 (1942).

[18] Barnett and Goodway, *J. Chem. Soc.*, 1754 (1929).

[19] Limpricht, *Ann.*, **314**, 243 (1901).

[20] Barnett, Low and Morrison, *Ber.*, **64**, 1568 (1931).

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

Rate of Oxidation of Aromatic Hydrocarbons by Lead Tetraacetate[1]

BY LOUIS F. FIESER AND STEARNS T. PUTNAM[2]

Qualitative observations have shown that the most potently active carcinogenic hydrocarbons are remarkably susceptible to oxidation by lead tetraacetate and that in some of the series investigated there is a rough correlation between carcinogenic activity and this form of chemical reactivity.[3,4] We have now made a quantitative study of the reaction. While the work was in progress, Eckhardt[5] reported the results of a study of the rates of oxidation of some of the same hydrocarbons by perbenzoic acid. Our results on the one reaction thus supplement those of Eckhardt on the other, and where the same compounds were studied the results are in general agreement.

The oxidation experiments were made in dilute solution (approximately 0.0015 molar) at 25 ± 0.1° with a large excess of reagent (approximately nine moles per mole of hydrocarbon). The rate of consumption of the reagent was determined by essentially the method used by Criegee[6] and by Hockett and McClenahan[7]; aliquots were withdrawn, decomposed with potassium iodide–sodium acetate buffer, and the liberated iodine titrated with 0.05 N thiosulfate solution. The results were expressed in terms of the ratio of moles of lead tetraacetate consumed to moles of hydrocarbon originally present, and in five parallel experiments with anthracene in 99% acetic acid (up to fifty hours) the lowest precision in the determination of this ratio was ±0.05 and the average ±0.03.

Criegee and Büchner[8] recently found that the rate of cleavage of glycols by lead tetraacetate in

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[1] This paper is based upon results presented by Stearns T. Putnam in a Dissertation of May 1, 1942.

[2] Present address: Hercules Powder Company, Experiment Station, Wilmington, Delaware.

[3] Fieser and Hershberg, THIS JOURNAL, **60**, 1893, 2542 (1938).

[4] Badger and Cook, *J. Chem. Soc.*, 802 (1939).

[5] Eckhardt, *Ber.*, **73**, 13 (1940).

[6] Criegee, *Ber.*, **64**, 260 (1931); *Ann.*, **495**, 211 (1932).

[7] Hockett and McClenahan, THIS JOURNAL, **61**, 1667 (1939).

[8] Criegee and Büchner, *Ber.*, **73**, 563 (1940).

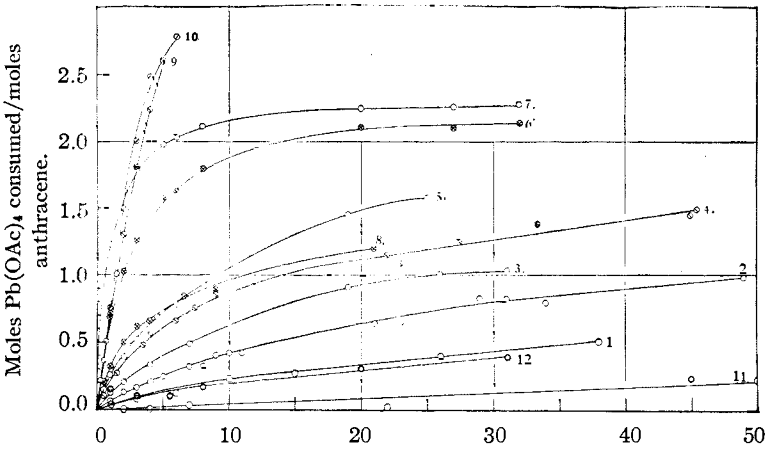

Fig. 1.—Effect of solvent on the oxidation of anthracene: 1, 99.9% HOAc (av. of 2); 2, 99% HOAc (av. of 5); 3, 98.9% HOAc; 4, 98.6% HOAc; 5, 95% HOAc-H_2O; 6, 90% HOAc–10% H_2O; 7, 85% HOAc–15% H_2O; 8, 99% HOAc–0.5 *M* KOAc; 9, 50% HOAc–50% CH_3OH; 10, 25% HOAc–75% CH_3OH; 11, 50% HOAc–50% C_6H_6; 12, 25% HOAc–75% C_6H_6.

acetic acid is increased enormously by the addition of up to 75% of water. Added methanol was not quite half so effective as water, and benzene was about one-tenth as effective as water. A study of the effect of added solvents on the rate of oxidation of anthracene by lead tetraacetate gave the striking results shown in Fig. 1. The addition of only 0.6% of water shortens the time required for the consumption of 0.5 mole of reagent from forty to fourteen hours, and the rate of oxidation increases progressively as the water content is raised further. The proportion of water cannot be increased beyond 15% because, then, lead tetraacetate undergoes decomposition faster than the hydrocarbon is oxidized, but it is possible to use mixtures containing as much as 75% methanol and so produce an enormous acceleration. The consumption of the first mole of reagent required a little more time in 50% acetic acid–50% methanol than in 85% acetic acid–15% water, and hence methanol produces less acceleration than water in this oxidation as well as in glycol cleavage.[8] Potassium acetate accelerates the oxidation of anthracene as it does the cleavage reaction,[8] and on a molar basis the effect is of about the same magnitude as that produced by added water. Unlike the behavior noted in the glycol cleavage,[8] benzene does not accelerate the oxidation of anthracene. The relationship between curves 11 and 12 would seem to indicate that the reaction is slower in the solvent mixture containing the lower percentage of benzene, but the experimental accuracy in this range of very low reaction rate is not sufficient to establish the point.

Kinetic calculations for the results presented do not distinguish between a first and second order reaction and hence have little significance. Typical rate constant calculations are given in Table I because they afford a measure of the accelerating effect of water. The situation is complicated by the occurrence of three principal reactions that may proceed concurrently[9] and require one, two and three moles of reagent: an addition–elimination process giving 9-acetoxyanthracene, a second addition–elimination yielding oxanthrone acetate, and probably a process of substitution–elimination leading to anthraquinone. It is of interest that in the water-accelerated oxidations the second mole of reagent is consumed very much more slowly than the first, and this may mean that an acetoxyl group already present hinders the further addition to the *meso* positions. In the oxidation conducted in 85% acetic acid–15% water (Curve 7) the first mole of reagent is taken up in 0.8 hour and the second in 5.5 hours; the reaction then slows down tremendously and in thirty-two hours reaches a total consumption of only 2.28 moles. The result suggests that in this solvent mixture the terminal substitution reaction of oxanthrone acetate proceeds extremely slowly, and it may be that water catalyzes only the addition reaction. A qualitative oxidation in the mixed solvent with two moles of lead tetraacetate gave a 71% yield of a crude product that contained principally oxanthrone acetate and only a small amount of anthraquinone. A different relationship is observable in the oxidations in acetic acid–methanol mixtures, as can be seen from the slopes of curves 9 and 10. Here there is relatively little diminution in the reaction rate after the consumption of the second mole of reagent. In 50% acetic acid–50% methanol the first, second and third moles of tetraacetate were taken up in 1.05, 3.4 and 6.5 hours, and at the end of the period of experimentation (eight hours) the consumption was 3.4 moles and the oxidation was still proceeding without appreciable diminution in rate. It would appear that the oxidation takes a different course in this solvent mixture and that anthraquinone is not the end product.

TABLE I

OXIDATION OF ANTHRACENE

Solvent	$k^{25°}$ first order	$k^{25°}$ second order
95% HOAc– 5% H_2O	2.2×10^{-5}	5.5×10^{-3}
90% HOAc–10% H_2O	7.8×10^{-5}	15.2×10^{-3}
85% HOAc–15% H_2O	20.9×10^{-5}	36.7×10^{-3}

The majority of the other hydrocarbons investigated probably react with the first mole of lead

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[9] Fieser and Putnam, THIS JOURNAL, **69**, 1038 (1947).

tetraacetate by substitution rather than addition. Methylcholanthrene and 10-methyl-1,2-benzanthracene appear to react in this manner, for an acetoxyl group is introduced at a meso methyl or methylene position.[3] 3,4-Benzpyrene affords a substitution product in high yield under very mild conditions[3] and since the hydrocarbon has no additive power for maleic anhydride[10] this very probably is a primary product. Badger and Cook[4] found that 9,10-dimethylanthracene can be converted by reaction with lead tetraacetate into 9,10-diacetoxymethylanthracene, but the rate of reaction (Fig. 2) presents an anomaly. The initial reaction is very rapid in comparison to the oxidation of anthracene, but after the consumption of one mole of reagent the reaction slows down abruptly and soon proceeds at very nearly the same rate as the anthracene oxidation; the two curves became parallel and just one mole apart. The relationship, coupled with the known high additive power of this particular hydrocarbon, suggests that 9,10-dimethylanthracene reacts by a process of addition and rearrangement analogous to that demonstrated by Sandin and Fieser[11]

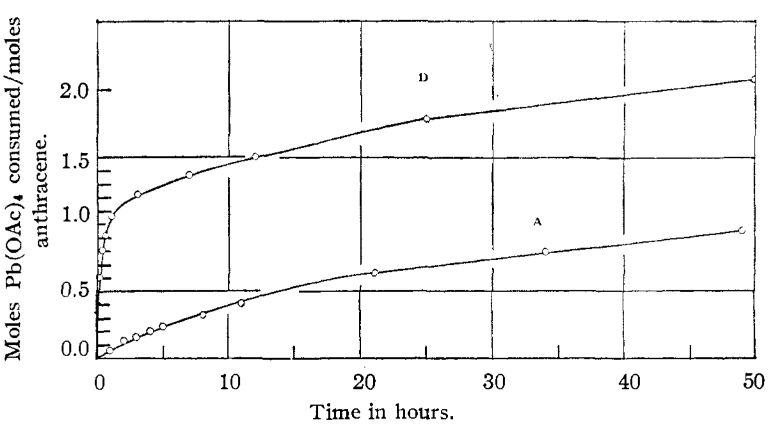
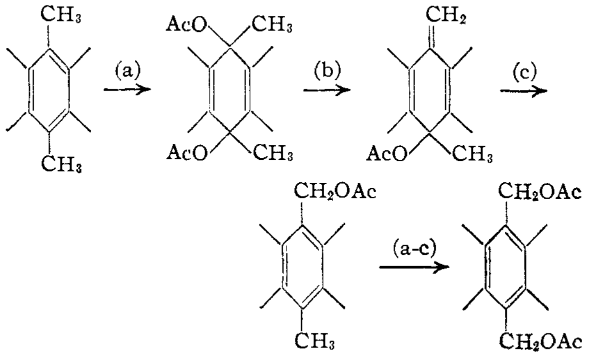


Fig. 2.—Oxidation of 9,10-dimethylanthracene in 99% acetic acid.



For the investigation of a number of carcinogenic and non-carcinogenic hydrocarbons we employed the technique outlined above and adopted 99% acetic acid as the standard solvent. Probably the initial rate of oxidation affords the most significant basis for comparison and characterizes the most susceptible point of attack in the molecule. As a means of summarizing the results in a form suitable for comparison, we have listed in Table II the time required for the consumption of 0.1, 0.5 and 1.0 mole of reagent per mole of each of the hydrocarbons studied whenever the figures are available. A record is included of the melting points of the samples submitted to oxidation; the samples were derived from previous researches in this Laboratory but were recrystallized where necessary.

The compounds in Table II are arranged in groups according to structure. In the series of 1,2-benzanthracene derivatives the order of chemical reactivity for the first six hydrocarbons corresponds to the order of carcinogenic potency, namely (decreasing order): 9,10-dimethyl, 10-methyl, 10-ethyl, 9-methyl, 7-methyl, parent hydrocarbon. However, among the homologous 10-alkyl derivatives the carcinogenic potency falls off sharply with increasing size of the alkyl group but the rate of oxidation remains the same. Also, the biologically highly active 9,10-dimethyl-1,2-benzanthracene is not so reactive to lead tetraacetate as the weakly carcinogenic 9,10-dimethylanthracene. Another discrepancy is that a 3-methoxyl group reduces the carcinogenic activity of a 10-alkyl-1,2-benzanthracene but markedly enhances susceptibility to oxidation. Discrepancies are observable also in the limited series of methylcholanthrene and 3,4-benzpyrene derivatives investigated; in each instance an added methyl group reduces carcinogenic potency but increases the rate of oxidation. Also the inactive model substance aceanthrene undergoes oxidation at the same rate as methylcholanthrene. The initial consumption of lead tetraacetate by the two hydro derivatives is probably due to a process of dehydrogenation.

The order of reactivity of methylcholanthrene, 3,4-benzpyrene and 1,2,5,6-dibenzanthracene corresponds to the order of carcinogenic potency, as measured for example by the following "carcinogenic indexes": 145, 105, 65.[12] However, it is an anomaly that 1,2,5,6-dibenzanthracene does not react at all with lead tetraacetate even under forcing conditions,[3] and in view of this fact it can hardly be argued that chemical reactivity of the type measured by susceptibility to lead tetraacetate is essential to carcinogenic activity. It is also evident that no general correlation exists between the two properties. The most that can be said is that among the most potent of the hydro-

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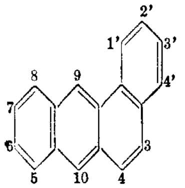
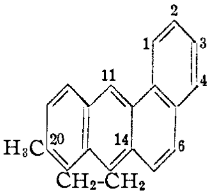
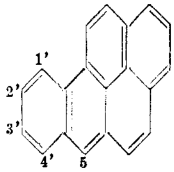
(10) W. E. Bachmann, see Fieser and Hershberg, THIS JOURNAL, **60**, 2545 (1938).

(11) Sandin and Fieser, *ibid.*, **62**, 3098 (1940).

(12) Shimkin and Andervont, *J. Natl. Cancer Inst.*, **1**, 57 (1940).

TABLE II

RATE OF OXIDATION BY LEAD TETRAACETATE IN 99% ACETIC ACID AT 25°

Compound	M. p. of sample used, °C.	Time in hours for consumption of the following molar quantities of $Pb(OAc)_4$ 0.1	0.5	1.0	Carcinogenic activity in mice[13]
Anthracene	216.0–216.6	1.6	14.5	49.4	–
9,10-Dimethylanthracene	183.6–184.2			0.8	+[14]
1,2-Benzanthracene 	161–161.5	36			±
9,10-Dimethyl-	121.8–123	0.22	1.9	9.1	++++
10-Methyl-	140–141	1.9	17.6	(58)	+++
9-Methyl	138.4–138.8	4.6	30.8	(75)	++
7-Methyl	183–183.5	19.0			+
10-Ethyl-	112.4–113	2.7	26		++
10-*n*-Propyl-	107–108	1.1	30		–
10-*n*-Butyl	96.8–97.5	2.2	34.5		–
10-*n*-Amyl	82.5–83.5	2.2	29.3	(98.5)	–
6-Methyl-10-ethyl-	182.5–183.5	14.0			?
10-Methyl-5,6,7,8-tetrahydro	72.5–73.5		No reaction		–
3-Methoxy-10-methyl-1,2-benzanthracene	183–183.5			0.9	++
3-Methoxy-10-ethyl-1,2-benzanthracene	161–161.5			2.2	+
3-Methoxy-10-*n*-propyl-1,2-benzanthracene	136–137			2.6	–
1,2,5,6-Dibenzanthracene	266.5–267		No reaction		++
20-Methylcholanthrene 	178.4–179.4			0.22	+++++
6,20-Dimethylcholanthrene	176–177			.16	+[15]
20-Methyl-1,2,3,4,11,14-hexahydrocholanthrene	160.5–161	0.3	1.3	2.6	–
Aceanthrene	112.5–114			0.27	–
Acenaphthene	93.8–94.4		No reaction		–
3,4-Benzpyrene 	178.2–179.2		0.4	1.5	++++
2'-Methyl-3,4-benzpyrene	138.4–139			0.36	–[14]
3'-Methyl-3,4-benzpyrene	143–149			.57	–[14]
1',2',3',4'-Tetrahydro-3,4-benzpyrene	113.5–114	0.88	4.4	14	+
Pyrene	150.8–151.3	25			–

carbon carcinogens, biological potency parallels chemical reactivity if the molecule is of adequate size (four or five aromatic rings) and is free from appended groups that somehow interfere with biological functioning (alkoxyl, higher alkyls, sometimes methyl).

Experimental Part

Reagents.—The lead **tetraacetate**,[9] found by titration analysis to be 98.9% pure, was employed in most instances in approximately 0.05 *N* solutions in 99 or 99.9% acetic acid. **Acetic acid,** 99%, was prepared from commercial acid refluxed with 2% potassium permanganate for two hours; the liquid was decanted and distilled and the fraction boiling above 116° adjusted to a melting point of 14.8 ± 0.05°[16] by the addition of distilled water.

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(13) Unless otherwise stated, the citations of relative carcinogenic activity (+) or lack of activity (–) given in this paper are taken from the compilation of J. L. Hartwell, "Survey of Compounds Which Have Been Tested for Carcinogenic Activity," U. S. Public Health Service, 1941.

(14) Badger, Goulden and Warren, *J. Chem. Soc.*, 18 (1941); Cook and Kennaway, *Am. J. Cancer*, **39**, 381 (1940).

(15) Dunlap and Warren, *Cancer Research*, **3**, 606 (1943): **6**, 454 (1946).

(16) Harvey, *Analyst*, **51**, 238 (1926).

TABLE III

RATE OF OXIDATION BY LEAD TETRAACETATE IN 99% ACETIC ACID (25°)

(Moles consumed per mole of hydrocarbon)

9,10-Dimethyl-anthracene		1,2-Benz-anthracene		9,10-Dimethyl-1,2-benzanthracene		10-Methyl-1,2-benzanthracene		9-Methyl-1,2-benzanthracene		7-Methyl-1,2-benzanthracene	
Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$
0.17	0.60	1	0.00	0.17	0.08	1	0.04, 0.07	1	0.03	1	0.01
.33	.81	3	.03	.67	.27	3	.14, .18	3	.06	3	.03
.50	.91	5	.02	1	.35	5	.21, .24	5	.11	5	.05
1	1.06	8	.05	2	.52	8	.31, .31	8	.16	8	.05
3	1.23	12	.05	3	.64	11	.36	12	.23	14	.07
7	1.37	16	.05	6	.86	12	.40	16	.31	24	.13
12	1.51	24	.05	10	1.04	14	.42	24	.41	39	.16
25	1.79	36	.10	24	1.29	16	.47	36	.57	54	.21
52	2.11	50	.14	51	1.47	21	.56	50	.72	77	.37
						24	.61				
						36	.79, .77				

10-Ethyl-1,2-benzanthracene		10-*n*-Propyl-1,2-benzanthracene		10-*n*-Butyl-1,2-benzanthracene		10-*n*-Amyl-1,2-benzanthracene		6-Methyl-10-ethyl-1,2-benzanthracene		3-Methoxy-10-methyl-1,2-benzanthracene	
Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	Pb(OAc)
1	0.04	1	0.09	1	0.04	1	0.05	1	0.01	1	1.12
3	.11	3	.17	3	.14	3	.13	3	.05	2	1.31
5	.19	5	.24	8	.23	5	.17	5	.04	3	1.41
8	.25	8	.26	12	.28	8	.26	8	.07	5	1.47
11	.30	12	.34	16	.34	12	.32	14	.10	8	1.52
14	.37	24	.46	24	.43	16	.38	24	.11	12	1.59
21	.45	36	.54	36	.51	24	.46	39	.17	16	1.61
36	.60	50	.62	51	.55	36	.55	54	.23	25	1.67
48	.66					50	.65	77	.32	50	1.81

3-Methoxy-10-ethyl-1,2-benzanthracene		3-Methoxy-10-*n*-propyl-1,2-benzanthracene		20-Methyl-cholanthrene		6,20-Dimethyl-cholanthrene		20-Methyl-1,2,3,4,11,14-hexahydrocholanthrene	
Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$
1	0.69	1	0.63	0.17	0.97	0.17	1.03	0.17	0.05
2	.95	2	.90	.33	1.07	.33	1.09	1	.34
3	1.15	3	1.07	1	1.15	.1	1.18	1.5	.61
5	1.37	5	1.32	2	1.20	2	1.30	2	.76
8	1.58	8	1.57	7	1.36	7	1.63	3	1.16
12	1.80	12	1.75	13	1.50	13	1.89	4	1.53
16	1.88	16	1.85	26	1.75	26	2.20	7	2.28
25	2.04	25	1.97	37	1.89	37	2.37	12	2.94
50	2.23	50	2.16	49	2.01	49	2.49	23	3.83

Aceanthrene		3,4-Benzpyrene		2'-Methyl-3,4-benzpyrene		3'-Methyl-3,4-benzpyrene		1',2',3',4'-Tetrahydro-3,4-benzpyrene		Pyrene	
Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$	Hr.	$Pb(OAc)_4$
0.17	0.95	0.17	0.27	0.17	0.69	0.17	0.52	0.17	0.01	1	−0.03
.33	1.04	.33	.45	.33	.97	.33	.78	.33	.02	3	+0.01
.50	1.07	.67	.70	.67	1.20	.67	1.08	1	.12	5	.01
1	1.11	1	.87	1	1.30	1	1.15	3	.35	8	.03
2	1.15	2	1.13	2	1.50	2	1.32	5	.56	12	.03
5	1.25	6	1.43	12	2.48	7	1.84	8	.75	16	.07
13	1.44	10	1.66	22	2.78	14	2.29	16	1.09	25	.10
24	1.64	20	2.14	34	2.93	24	2.59	25	1.24	38	.17
49	1.92	32	2.40			36	2.79	38	1.43	54	.26

Acetic acid, 99.9%, was prepared by refluxing permanganate-purified acid with triacetyl borate[17] and slowly distilling the product in an all-glass apparatus; the acid melted at 16.45°. **Sodium thiosulfate**, 0.01 *N*, was prepared and standardized (frequently) according to Kolthoff and Sandell.[18]

Procedure.—A sample of purified hydrocarbon that had been dried in vacuum was weighed on a microbalance to 0.05 mg. (approximately 0.00015 mole) and transferred with 49 cc. of solvent to a calibrated 100-cc. flask, dissolved by shaking or heating, and the flask placed in a thermostat at 25 ± 0.1°. After suitable time for the adjustment of temperature, 50 cc. of standardized lead tetraacetate solution (about 9 mole equiv.) was transferred from a flask immersed in the thermostat; the flask was quickly filled to the calibration mark, shaken thoroughly, and returned to the thermostat. Samples were withdrawn by suction

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[17] Eichelberger and La Mer, THIS JOURNAL, **55**, 3633 (1933); Pictet and Geleznoff, *Ber.*, **36**, 2219 (1903).

[18] Kolthoff and Sandell, "Textbook of Qualitative Inorganic Analysis," The Macmillan Company, New York, N. Y., 1937.

with a 10-cc. calibrated pipet and decomposed with 20 cc. of sodium acetate–potassium iodide buffer (250 g. of acetate and 20 g. of iodide in 1 liter of water) and the iodine titrated with thiosulfate with starch as indicator. A blank determination in which the hydrocarbon was omitted was conducted simultaneously with every oxidation experiment and a correction applied for any lead tetraacetate consumed by the solvent.

Summary of Results.—The results are reported in terms of the moles of lead tetraacetate consumed per mole of hydrocarbon. The results of the experiments with anthracene in different solvents are recorded only in the graphs of Fig. 1. The results for the other hydrocarbons are given in Table III. In the case of the hydrocarbons listed in Table II as showing "no reaction," the observation extended over periods of fifty to sixty hours.

Summary

The oxidation of anthracene by lead tetraacetate in acetic acid solution is accelerated enormously by water, methanol or potassium acetate, but is retarded by benzene. A study has been made of the rate of oxidation of several polynuclear aromatic hydrocarbons by excess lead tetraacetate in 99% acetic acid. Some correlation between rate of oxidation and carcinogenic activity is discernible in specific, limited series of compounds, but no general correlation exists.

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A New Method of Esterification[1]

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Carre and Libermann reported the formation of butyl benzoate by pyrolysis of an intermediate formed from the reaction of butyl chlorosulfite with benzoic acid in the presence of pyridine.[2] We became interested in exploring the potentialities of this little known reaction. A few experiments showed that this scheme was not very promising because the yields were mediocre. However, we found that sodium benzoate reacts readily with butyl chlorosulfite to produce an intermediate which produced butyl benzoate in good yield on pyrolysis. This method likewise gave good yields when applied to butyric, tributylacetic, 2,4,6-trimethylbenzoic and 2,4,6-triethylbenzoic acids, but failed with 2,4,6-tribromobenzoic acid. It is thus a valuable new method for the esterification of aliphatic, aromatic and certain sterically hindered acids. It should prove useful in the esterification of acids containing an acid-unstable function.

This method failed to give appreciable amounts of the desired butyl ester when applied to α-hydroxy-*i*-butyric and *p*-acetylaminobenzoic acids. Quantities of *n*-butyl sulfite were isolated from these reaction mixtures but no attempts to secure maximum yields of this by-product were made.

One attempt to use a secondary alkyl chlorosulfite, namely, *i*-propyl chlorosulfite, resulted in the formation of a much smaller yield of desired ester. Accordingly no further work was done in this direction.

Experimental[3]

Alkyl Chlorosulfites.—To 280 g. (2.34 moles) of purified thionyl chloride, cooled to 0°, was added dropwise with stirring 148 g. (2.0 moles) of anhydrous *n*-butyl alcohol, the temperature being maintained below 15°. The solution was then allowed to stand at room temperature for three days (we did not investigate the effect of time and temperature on yield). The excess thionyl chloride was removed under reduced pressure and the residue on distillation yielded 295 g. (94%) of butyl chlorosulfite, b. p. 72–74° at 28 mm.[2] In a similar way, *i*-propyl chlorosulfite, b. p. 63–65° at 80 mm., was obtained in 28% yield. No attempt to find better conditions was made.

General Procedure.—To 0.1 mole of the dried sodium salt of the acid with or without benzene as a solvent was added 30 g. (0.19 mole) of butyl chlorosulfite. A vigorous exothermic reaction always occurred, even in those cases where the desired ester was not obtained. After a few minutes the reaction mixture was slowly heated until pyrolytic decomposition set in as indicated by the evolution of sulfur dioxide. The pyrolysis usually took place in the range of 100–150° and was maintained as long as any appreciable gas evolution took place. This usually required one to two hours. The mixture was then treated with water and the organic product isolated by suitable means. There was usually from 10 to 20% of unreacted acid which was recovered. By this procedure pure butyl benzoate and butyl butyrate were prepared in 81 and 61% yields.

Butyl 2,4,6-Trimethylbenzoate.—This compound, reported previously[4] but not analyzed, was prepared in 71% yield by the above method. The reaction was carried out on a 0.01 molar scale and the ester boiled at 147.5–149° at 12 mm.

Anal.[3] Calcd. for $C_{14}H_{20}O_2$: C, 76.3; H, 9.1. Found: C, 76.1, 76.3; H, 9.2, 9.5.

Butyl 2,4,6-Triethylbenzoate.—From 2.57 g. of 2,4,6-triethylbenzoic acid[5] there was obtained 2.41 g. (74%) of butyl 2,4,6-triethylbenzoate, b. p. 136–140° at 3 mm.

Anal.[3] Calcd. for $C_{17}H_{26}O_2$: C, 77.8; H, 10.0. Found: C, 77.6, 77.4; H, 10.2, 9.8.

Butyl Tributylacetate.—A sample of 11.2 g. of tributylacetic acid, prepared by alkylation of acetonitrile[6] followed by hydrolysis, was converted into the sodium salt and gave in 82% yield the butyl ester, b. p. 148–153° at 9 mm., by the above method.

Anal.[3] Calcd. for $C_{18}H_{36}O_2$: C, 76.0; H, 12.7. Found: C, 76.5, 76.3; H, 12.6, 12.7.

Isolation and Identification of Butyl Sulfite.—The dry salt obtained by the saponification of 13.2 g. of ethyl α-hydroxy-*i*-butyrate was treated as above with 45 g. of

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(1) The material herein reported is from the thesis presented by W. S. Fones to the Graduate School in partial fulfillment of the requirements for the Ph.D. degree, December, 1946.

(2) Carre and Libermann, *Bull. soc. chim.*, [4] **53**, 1062 (1933).

(3) All microanalyses by the Arlington Laboratories, Fairfax, Va.

(4) Fuson and Bottorf, THIS JOURNAL, **64**, 1451 (1942).

(5) We wish to thank Prof. R. C. Fuson, University of Illinois, for the sample of 2,4,6-triethylbenzoic acid.

(6) Ziegler and Ohlinger, *Ann.*, **495**, 84 (1932).