and the filtrate was concentrated. The product was recrystallized from cyclohexane, affording 40 g (79%) of thick, colorless prisms, mp $120-121^{\circ}$.

Anal. Calcd for C₁₁H₇Br₂F: C, 41.5; H, 2.2; F, 6.0. Found: C, 41.7; H, 2.3; F, 6.4.

1,2-Di(1-bromo-4-fluoro-2-naphthyl)ethane (XII).—To the Grignard reagent prepared from 1.59 g of 1-bromo-4-fluoronaphthalene, 0.122 g of magnesium and 50 ml of ether, 1.59 g of VII in 100 ml of benzene was added. The ether was removed by distillation and the solution was refluxed for 20 hr. Dilute hydrochloric acid was added and the organic layer was concentrated. The sparingly soluble solid that separated was triturated with cold benzene and recrystallized from xylene, yielding 0.219 g (9%) of XII as shiny, colorless needles, mp 221.5-222.5°.

g (9%) of XII as shiny, colorless needles, mp 221.5-222.5°. Anal. Calcd for $C_{22}H_{14}Br_{2}F_{2}$: C, 55.5; H, 2.9; F, 8.0. Found: C, 55.5; H, 3.1; F, 8.0. The remaining material, *i.e.*, that which dissolved in cold

The remaining material, *i.e.*, that which dissolved in cold benzene during the trituration, was separated by fractional crystallization from cyclohexane into 1.21 g of starting material VII and 0.83 g of X.

Attempted Coupling of 4-Fluoro-1-naphthylmagnesium Bromide and VII.—In analogy with the previous experiment, 28 g of 1-bromo-4-fluoronaphthalene in 75 ml of ether was treated with 3 g of magnesium. Benzene (75 ml) was added and the ether was distilled off. Powdered VII (17.5 g) was then added and the mixture was refluxed for 6 hr. Decomposition of excess Grignard reagent with 10% hydrochloric acid, followed by removal of half of the organic solvents, caused fluffy, white needles to separate. Upon recrystallization from xylene 9.0 g (69%) of XII was obtained, mp and mmp 221.5–222 5°. The benzene-soluble material was fractionated at 0.5 mm. The fraction boiling at 180–230° was triturated with hexane and recrystallized from toluene (carbon), yielding 6.5 g of 4,4'-diffuoro-1,1'-binaphthyl, mp 177–177.5° (lit.4 mp 176–177°). Under analogous conditions, phenylmagnesium bromide failed equally to couple with VII. Together with much starting material, a 2% yield of XII was obtained.

1-(o-Bromobenzyl)-4-fluoronaphthalene (XIII).—A quantity of 22.5 g of 1-bromo-4-fluoronaphthalene was treated with 2.43 g of magnesium in 150 ml of ether. After addition of 150 ml of benzene the ether was distilled off and 12.5 g of o-bromobenzyl bromide in 100 ml of benzene was added. The mixture was refluxed for 6 hr with agitation, decomposed with ice and dilute hydrochloric acid, and worked up in the usual manner. The residue was fractionated at 0.5 mm and the oil boiling at 182–200° was chromatographed on alumina (hexane serving as eluent). Recrystallization of the first fraction from ethanol and then from hexane afforded 11.9 g (76%) of XIII as colorless cubes, mp 44.0–44.5°.

Anal. Calcd for C₁₇H₁₂BrF: C, 64.8; H, 3.8; Br, 25.4; F, 6.0. Found: C, 64.5; H, 3.7; Br, 25.4; F, 6.3.

Its structure was proved by carbonation of the corresponding magnesium compound, giving a 84% yield of o-(4-fluoro-1-naphthylmethyl)benzoic acid (XIV), mp 180–181° (from nitromethane) (lit.⁴ mp 176–177°). The product did not depress the melting point of an authentic sample.

4-Fluorobenzo[a]pyrene and 8-Fluorobenz[l]aceanthrylene

JOCHANAN BLUM AND ERNST D. BERGMANN

Department of Organic Chemistry, Hebrew University, Jerusalem, Israel

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Starting from 12-cyanomethyl-5-fluorobenz[a]anthracene (I), (5-fluoro-12-benz[a]anthryl)acetaldehyde (V) has been prepared. Its cyclodehydration gave 4-fluorobenz[a]pyrene (VI) and 8-fluorobenz[l]aceanthrylene (VII).

Several fluorine derivatives of carcinogenic polycyclic hydrocarbons have been described.¹

In the present paper the 4-fluoro derivative of the powerful carcinogen benzo [a] pyrene has been added to this list. A suitable starting point appeared to be the 12-cyanomethyl-5-fluorobenz [a] anthracene (I), which has been prepared before in this laboratory.¹ At that time it had already been pointed out that alkaline hydrolysis of nitrile I was practically impossible—probably for steric reasons. In repeated experiments traces (less than 1%) of an acidic material have been obtained, mp 274–275°, which is not the desired acid (II), although it has the same elementary analysis. Its structure has not been elucidated.

The hydrolysis of I to acid II has been accomplished in 88% yield by prolonged (150 hr) heating with boiling saturated alcoholic hydrogen chloride solution and saponification of the crude ester. The acid gave, with diazomethane, the methyl ester III in quantitative yield.

This ester was reduced with lithium aluminum hydride to the corresponding primary alcohol (IV) and the latter oxidized to the aldehyde V by the chromic acid anhydride-pyridine complex. No other method gave us V; the Stephen reduction of I and the reduction of the chloride of II with lithium tri(t-butoxy)aluminum hydride² failed. From the aldehyde V, a very simple reaction led directly to the desired 4-fluorobenzo[a]pyrene (VI), viz. the treatment of the (crude) aldehyde with polyphosphoric acid. This is a novel application of Bradsher's synthesis of 9-alkylphenanthrenes from (2biphenylyl)alkylacetaldehydes³ to the transformation of the benz[a]anthracene into the benzo[a]pyrene system and opens many interesting possibilities.

In fact, two isomeric fluorinated hydrocarbons have been formed in this reaction: 4-fluorobenzo[a]pyrene (VI) in 25% yield and 8-fluorobenz[l]aceanthrylene (VII); both gave well-defined trinitrofluorenone complexes.

The structure of VI was easily established by comparison of its electronic spectrum with that of benzo-[a] pyrene:⁴ the two are practically identical (Table I).

As to the isomeric fluoro compound VII, the orange color already led us to assume that by a very obvious reaction a derivative of acenaphthylene had been formed. Here again, proof was obtained by comparison of the spectrum of VII with that of benz[l]aceanthrylene (VIII) (Table I). The hydrocarbon VIII which had not been described before, was obtained by dehydrogenation, with chloranil, of its dihydro derivative (IX).⁵

(2) H. C. Brown and R. F. McFarlin, J. Am. Chem. Soc., 80, 5372 (1958);
 H. C. Brown and B. C. Subba Rao, *ibid.*, 80, 5377 (1958).

(3) C. K. Bradsher and W. J. Jackson, ibid., 76, 734 (1954).

(4) E. Clar, "Polycyclic Hydrocarbons," Vol. 2, Academic Press Inc., New York, N. Y., 1964, p 135.

(5) L. F. Fieser and A. M. Seligman, J. Am. Chem. Soc., 57, 2174 (1935).

⁽¹⁾ See, for further references, E. D. Bergmann and J. Blum, J. Org. Chem., **27**, 527 (1962); and M. S. Newman and S. Blum, *ibid.*, **29**, 1414 (1964).

 TABLE I

 Electronic Spectra in Chloroform Solution

Compd															
Benzo[a]-	254	266	274	284	297	330	347	364	385	403					
pyrene	(4.60)	(4.66)	(4.50)	(4.66)	(4.76)	(3.76)	(4.10)	(4.36)	(4.44)	(3.60)					
VI	257	267		286	299	333	350	369	390	405					
	(4.64)	(4.72)		(4.65)	(4.71)	(3.76)	(4.11)	(4.34)	(4.40)	(4.54)					
VIII	263	272	284	295	311	322	343	360	379	392	399 s	414 s	445 s	503 s	540 s
	(4.50)	(4.52)	(4.65)	(4.72)	(4.40)	(4.04)	(3.67)	(3.82)	(3.85)	(3.70)	(3.64)	(3.28)	(2.78)	(2.20)	(1.62)
VII	262 s	270	283	293	303 s		340	362	381	390	401	417 s		510 s	545 s
	(4.54)	(4.58)	(4.52)	(4.59)	(4.48)		(3.73)	(3.94)	(4.10)	(4.04)	(4.06)	(3.70)		(2.20)	(1.62)

So far as we know, the Bradscher reaction has not been used before for the synthesis of a five-membered ring system.



Another approach to the synthesis of fluorinated benzo[a] pyrenes failed; however, the experiments appear sufficiently interesting to be reported briefly here. 2-Fluoro-9-anthrone $(X)^6$ underwent smoothly the Michael reaction with ethyl crotonate to give XI in 56% yield (after hydrolysis). It is noteworthy that ethyl *acrylate* gave a very much lower yield under these conditions, owing to extensive polymerization.

The keto acid XI was not isolated but directly reduced (and dehydrated) to β -(3-fluoro-9-anthryl)-

(6) E. D. Bergmann, J. Blum, and S. Butanaro, J. Org. Chem., 26, 3211 (1961).

butyric acid (XII). Its dihydro derivative XIII was obtained with metallic sodium in amyl alcohol. When the reaction mixture was acidified without removing first the solvent, the amyl ester of XIII and, unexpectedly, 2-fluoroanthracene were obtained. Such reductive removal of side chains from the 9 position of anthracene has to the best of our knowledge only been observed by Rona and Feldman.⁷ Cyclization of acid XIII could lead to two ketones (XIV and XV). In fact, the treatment of XIII with anhydrous hydrofluoric acid gave one ketone only to which we ascribe formula XIV on the strength of its dipole moment, which is much too small for XV (calcd for XIV, μ = 1.1 D.; calcd for XV, $\mu = 2.7$ D.; found, 0.97 D.).⁸ Ketone XIV proved useless for further syntheses as it was refractory to diethyl succinate (Stobbe reaction),⁹ to vinylmagnesium bromide, and to methoxymethylenetriphenylphosphorane.

Experimental Section

(5-Fluoro-12-benz[a]anthryl)acetic Acid (II).—A solution of 3.0 g of 12-cyanomethyl-5-fluorobenz[a]anthracene (I) in 150 ml of absolute ethanol, saturated with hydrogen chloride, was refluxed for 150 hr. On dilution with 1 l. of water, a brown semisolid product separated; it was dissolved in hot ethanol and heated on the steam bath with 150 ml of 15% ethanolic potassium hydroxide solution for 30 min. After removal of some neutral material by filtration and extraction of the solution with ether, the potassium salt of II was dissolved in 1 l. of boiling water and acidified, and the acid recrystallized from benzene, yielding 2.8 g (88%) of pale yellow crystals, mp 213-216° dec.

Anal. Calcd for $C_{20}H_{13}FO_2$: C, 79.0; H, 4.3; F, 6.2. Found: C, 79.0; H, 4.2; F, 6.5.

The methyl ester (III) was obtained in quantitative yield with an excess of ethereal diazomethane; it crystallized from ethanol as faintly colored, fluffy needles, mp 126.5–127.5°.

Anal. Calcd for $C_{21}H_{15}FO_2$: C, 79.2; H, 4.7; F, 6.0. Found: 78.9; H, 4.6; F, 6.4.

 β -(5-Fluoro-12 benz[a] anthryl) ethanol (1V).—To a stirred suspension of 0.5 g of lithium aluminum hydride in 50 ml of ether a solution of 1.59 g of III in 20 ml of benzene and 20 ml of ether was added and the mixture was refluxed for 3 hr, cooled, and treated with ethyl acetate and dilute hydrochloric acid. The organic layer was separated, washed with warm 10% sodium carbonate solution and water, dried, and concentrated. The residue was recrystallized from benzene. Thus was obtained 1.26 g (87%) of IV as pale yellow needles, mp 143.5-144°.

Anal. Calcd for $C_{20}H_{13}FO$: C, 82.7; H, 5.2; F, 6.6. Found: C, 82.4; H, 5.3; F, 7.0.

4-Fluorobenz[a]**pyrene** (VI) and **8-Fluorobenz**[l]**aceanthrylene** (VII).—A solution of 1.00 g of IV in 10 ml of pyridine was added with external cooling (ice water) and vigorous agitation to a solution of 1.0 g of chromic acid in 10 ml of pyridine. The mixture was stirred for 3 hr at room temperature and poured on ice and hydrochloric acid. The neutral material was extracted with benzene and washed successively with 18% hydro-

⁽⁷⁾ P. Rona and U. Feldman, Bull. Res. Council Israel, 7A, 89 (1958); J. Chem. Soc., 1737 (1958).

⁽⁸⁾ The calculations were made with the simplifying assumption that the whole system of XIV and XV is planar.

⁽⁹⁾ Cf., e.g., J. W. Cook, R. S. Ludwiczak, and R. Schoental, J. Chem. Soc., 1112 (1950).

heated at 100° for 15 min. Addition of water caused a brown semisolid material to separate, which was dissolved in benzene and chromatographed on alumina. First, 0.23 g (25%) of the pale yellow plates of 4-fluorobenzo[a] pyrene (VI) was eluted with hexane, mp 145.5-146.5°. Recrystallization from ethanol did not change the melting point. The analytical sample was dried at 100° (20 mm); less stringent drying conditions led to high C and H values.

Anal. Calcd for C₂₀H₁₁F: C, 88.9; H, 4.1; F, 7.0. Found: C, 88.9; H, 4.0; F, 6.9.

The 2,4,7-trinitrofluorenone complex was prepared in benzene and recrystallized from a mixture of benzene and ethyl acetate as yellow-brown needles, mp 248° dec. Anal. Calcd for C₃₃H₁₆FN₃O₇: C, 67.7; H, 2.7; F, 3.3; N,

7.2. Found: C, 67.3; H, 2.7; F, 3.7; N, 7.3.

The more strongly adsorbed VII was eluted from the alumina column with benzene, yielding 0.135 g (14%) of orange crystals, mp 147-149° (from ethanol-benzene).

Anal. Calcd for C₂₀H₁₁F: C, 88.9; H, 4.1; F, 7.0. Found: C, 88.8; H, 4.0; F, 7.2.

The 2,4,7-trinitrofluorenone derivative crystallized from benzene as red-brown needles, mp 230-231°

Anal. Calcd for $C_{33}H_{16}FN_{3}O_{7}$: C, 67.7; H, 2.7; F, 3.3; N, 7.2. Found: C, 67.4; H, 2.4; F, 3.8; N, 7.3.

1,2-Dihydrobenz[l]aceanthrylene (IX) was prepared essentially by the method of Fieser and Seligman,⁵ mp 173-174°. The yield of 4-indanyl 2-naphthyl ketone was increased to 80% and the time of reaction was shortened to 2 hr when the ether used for the preparation of 4-indanylmagnesium bromide was freshly distilled over lithium aluminum hydride and a threefold] amount of 2-naphthoyl chloride was employed: λ_{max}^{CHCls} 265 s m μ (log ϵ 4.54), 273 (4.60), 283 (4.79), 295 (3.92), 327 (3.66), 343 (3.83), 0514 (2.01) 2027 (2.01) 20 354 s (3.81), 359 (3.91), 377 (3.76), and 392 (3.40).

The 2,4,7-trinitrofluorenone complex of IX was prepared in, and recrystallized from, benzene as olive-green needles (black

when dissolved in benzene), mp 234-236°. Anal. Calcd for $C_{33}H_{19}N_3O_7$: C, 69.6; H, 3.3; N, 7.4. Found: C, 69.9; H, 3.2; N, 7.6. **Benz**[l]aceanthrylene (VII).—A mixture of 500 mg of IX, 30 h (a) C_{33} (b) C_{33} (b) C_{33} (c) C_{33

ml of dry xylene, and 500 mg of chloranil was refluxed for 20 hr. The cooled solution was washed with 10% sodium hydroxide solution and water and dried, and the solvent was removed in vacuo. The residue was chromatographed on alumina, benzenehexane (1:2) serving as eluent, and the first fraction (orange-red) was recrystallized from benzene and ethanol. Thus was obtained 345 mg (70%) of brick-red, shiny crystals of the desired hydrocarbon VIII, mp 161.5-163°

Anal. Calcd for C₂₀H₁₂: C, 95.2; H, 4.8. Found: C, 95.1; H, 5.1.

The 2,4,7-trinitrofluorenone derivative crystallized from benzene as tan needles (changing into orange-brown on heating), mp 241-143°.

Anal. Calcd for C33H17N3O7: C, 69.8; H, 3.0; N, 7.4. Found: C, 69.9; H, 3.1; N, 7.2.

β-(3-Fluoro-9-anthryl) butyric Acid (XII).-To a stirred suspension of sodium t-amylate in t-amyl alcohol (prepared from 2 g of sodium hydride and 200 ml of the alcohol), 12 g of 2-fluoro-9anthrone (X) was added in portions within 30 min, to keep the mixture boiling gently. To the hot, green solution, 11.5 g of ethyl crotonate in 20 ml of t-amyl alcohol was added dropwise (90 min) and the cooled mixture was acidified with 20 ml of concentrated hydrochloric acid in 100 ml of water. The organic layer was separated and the t-amyl alcohol was removed with steam. The resulting brown semisolid ester was refluxed with 50 ml of concentrated hydrochloric acid for 10 hr. Upon dilution with water, the brown keto acid (XI) separated; it was reduced

immediately with 50 g of zinc powder (activated with 1 g of copper sulfate) in 500 ml of concentrated ammonia and 200 ml of water. After refluxing for 10 hr, the excess zinc was filtered off and the filtrate was acidified. Thus was obtained 9 g (55% over-all yield) of XII as pale yellow crystals, mp 137-138° (from nitromethane)

Anal. Calcd for C₁₈H₁₈FO₂: C, 76.6; H, 5.3; F, 6.7. Found: C, 76.6; H, 5.3; F, 7.2.

 β -(3-Fluoro-9-anthryl) propionic Acid.—In the same manner, 12 g of I was condensed with 15 g of ethyl acrylate. Because of extensive polymerization, only 3 g (19%) of the condensation product was obtained. The acid crystallized from nitromethane as a pale yellow powder, mp 200-201°.

Anal. Calcd for C₁₇H₁₃FO₂: C, 76.1; H, 4.8; F, 7.1. Found: C, 76.3; H, 4.8; F, 7.7.

β-(9,10-Dihydro-3-fluoro-9-anthryl)butyric Acid (XIII).-Small pieces of sodium (6 g) were added within 90 min to a solution of 8 g of XII in 200 ml of hot n-amyl alcohol. The solvent was steam-distilled and the resulting sodium salts were dissolved in hot water and acidified with 18% hydrochloric acid. The semisolid product crystallized from a mixture of ethyl acetate and cyclohexane (1:1) as colorless needles (6 g, 74%), mp 125-127°. The analytical sample was recrystallized from the same mixture of solvents and showed mp 127

Anal. Calcd for C₁₈H₁₇FO₂: C, 76.0; H, 6.0; F, 6.7. Found: C, 76.0; H, 5.7; F, 7.2.

When the reaction mixture from 28 g of XII was treated with concentrated hydrochloric acid before removal of the n-amyl alcohol, an extremely lively reaction occurred. Steam distillation of the amyl alcohol and the usual work-up led to two neutral products which were separated by distillation at 0.5 mm. The first fraction, boiling at 185–187°, was identified as 2-fluoro-anthracene (mp and mmp 212°, with an authentic sample), yield 0.7 g (3.5%).

Anal. Calcd for C14H9F: C, 85.7; H, 4.5; F, 9.8. Found: C, 86.1; H, 4.9; F, 9.5.

The second fraction, bp $199-200^{\circ}$, proved to be the *n*-amyl ester of XIII, a yellow, viscous liquid showing the characteristic ester carbonyl peak in the infrared spectrum (KBr) at 1730 cm^{-1} , yield 25 g (75%).

Anal. Calcd for C23H27FO2: C, 78.0; H, 7.6; F, 5.4. Found: C, 78.2; H, 7.8; F, 4.9.

The structure of the compound follows from the hydrolysis which was effected by refluxing 1 g with 1 g of potassium hydroxide in 20 ml of ethanol for 1 hr and gave the acid XIII, mp and mmp 127°

9-Fluoro-1-methyl-1,2,7,11b-tetrahydro-3H-benz[d,e]anthracen-3-one (XIV).—The foregoing acid (XIII, 4.5 g) was covered with 150 ml of anhydrous hydrofluoric acid and the acid was left to evaporate (15 hr). Water was added and the yellow precipitate was extracted with hot benzene and washed with 10%sodium carbonate solution and water. On concentration of the solution and addition of ethanol, yellow crystals, mp 97–99° separated. Chromatography on alumina (benzene as eluent) yielded 3 g (71%) of greenish yellow needles, 145-146°. Thin layer chromatography indicated that a single ketone had formed. The ketone possessed a dipole moment of 0.97 D., which is far too low for the expected 5-fluoro-1-methyl-1,2,7,11b-tetrahydro-3H-benz[d,e] anthracen-3-one (XV), but in fair accordance with the formula of the isomeric ketone (XIV): $\lambda_{\text{max}}^{\text{CHOI3}}$ 247 m μ (log ϵ 4.66), 255 (4.76), 303 (3.29), 352 s (3.39), 358 (3.43), 369 (3.65), 399 (3.80), 414 (3.80), and 420 (3.76).

Anal. Caled for C₁₈H₁₅FO: C, 81.2; H, 5.6; F, 7.1. Found: C, 81.7; H, 5.3; F, 7.4.

The 2,4-dinitrophenylhydrazone crystallized from xylene, mp 265° dec.

Anal. Calcd for C24H19FN4O4: C, 64.6; H, 4.3; F, 4.3. Found: C, 64.7; H, 4.3; F, 4.8.