this on recrystallization from chloroform–petroleum ether gave 28% of *N*-methylphthalimidine, m.p. 114–116°, undepressed on admixture with an authentic sample,[10] m.p. 115–118°. The infrared spectra of the two samples were identical.

***N*-Ethylphthalimidine.**—Ten grams (0.057 mole) of *N*-ethylphthalimide[10,24] was mixed with 40 ml. of water, 50 ml. of conc. hydrochloric acid, and 25 g. (0.38 g.-atom) of amalgamated zinc. The mixture was boiled under reflux for 2 hr. The hot solution was decanted and diluted with an equal volume of water; the mixture deposited a colorless oil upon standing overnight. The mixture was extracted with chloroform; the chloroform solution was dried and evaporated. The residue was distilled to give 5.4 g. (59%) of *N*-ethylphthalimidine, b.p. 120–121°/2 mm. When chilled in an icebox this material crystallized, m.p. 44–45° (lit.,[10] 45°).

***N*-Benzylphthalimidine.**—Under similar conditions there was obtained, from 20 g. of *N*-benzylphthalimide,[24,27] 12.4 g. (66%) of *N*-benzylphthalimidine, m.p. 88–90° (lit.,[28] 90–91°).

Acknowledgment.—We wish to thank the Continental Oil Company for a free-grant fellowship given to L.E.C. and the Purdue Research Foundation for additional financial support of this work.

[27] S. Gabriel, *Ber.*, **20**, 2224 (1887).

[28] S. Gabriel, *ibid.*, **45**, 724 (1912).

Steric Effect in the Reduction of *N*-Methyl-1,2-naphthalimide with Zinc[1]

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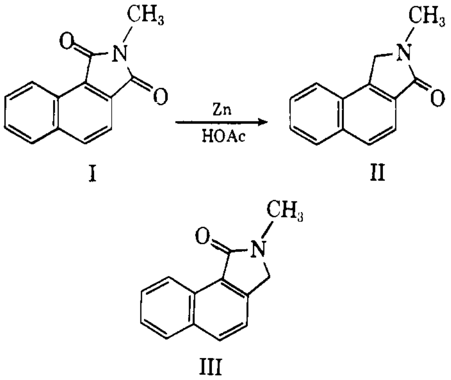
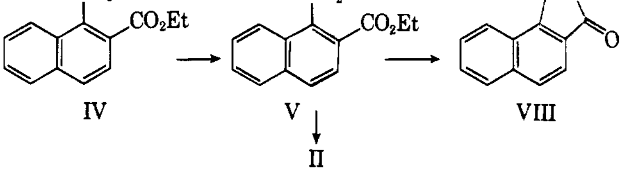
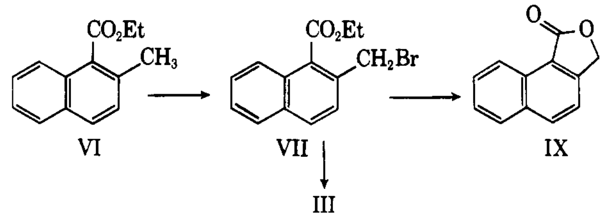
The more hindered carbonyl group of *N*-methyl-1,2-naphthalimide is selectively reduced by zinc and acetic acid. The *N*-methylated 4,5- and 6,7-benzophthalimidines have been prepared by independent syntheses. The reduction of 1,2-naphthalic anhydride under similar conditions gives both of the possible benzophthalides.

It seemed important to determine whether an unsymmetrical phthalimide such as I would be reduced by zinc and acetic acid at the less hindered carbonyl group (as might be expected if the reaction is analogous to the Clemmensen reduction of ketones[2]) or at the more hindered group (as would be possible under the mechanism considered in part IV[1]). Reduction of I gave a 79% yield of a single compound having the composition of an *N*-methyl-1,2-naphthalimidine. The two possible products (II and III) were prepared by independent methods; direct comparisons showed the reduction product to have structure II.



Ethyl 1-methyl-2-naphthoate[3] (IV) was photobrominated[4] in carbon tetrachloride. The product (V) was added to liquid methylamine to give the phthalimidine II[5]; this substance produced no melting point depression on admixture with the reduction product and had a superimposable infrared spectrum. The other phthalimidine (III) was similarly prepared by photobromination[4] of ethyl 2-methyl-1-naphthoate[6] (VI) followed by reaction with methylamine. This substance depressed the melting point of the reduction product; its infrared spectrum differed in the "fingerprint" region and showed a small shift (*ca.* 5 cm.$^{-1}$) of the carbonyl band to lower wave numbers.





In the course of this work the two benzophthalides (VIII and IX) were also prepared. The second of these (IX) had previously been prepared by reduction of 1,2-naphthalic anhydride with lithium aluminum hydride[7] and also by heating the methyl ester analog of VII.[8] The isomeric bromo ester (V) failed to give the latter reaction, perhaps because the *peri* hydrogen atom prevents the necessary alignment of the bromine atom for internal displacement. It could, however, be hydrolyzed by base to a product which lactonized to VIII on treatment with acid. A mixture from which each of these lactones could be isolated was obtained in 82% yield by reduction of 1,2-naphthalic anhydride with zinc and acetic acid; it is hoped that the precise composition of this mixture can be established in future work.

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[1] Reductions at Metal Surfaces, V. Preceding paper, J. H. Brewster, A. M. Fusco, L. E. Carosino, and B. G. Corman, *J. Org. Chem.*, **28**, 498 (1963).

[2] (a) J. H. Brewster, *J. Am. Chem. Soc.*, **76**, 6364 (1954); J. H. Brewster, J. Patterson, and D. A. Fidler, *ibid.*, **76**, 6368 (1954). (b) T. Nakabayashi, *ibid.*, **82**, 3900, 3906, 3909 (1960).

[3] H. Gilman and J. E. Kirby, *ibid.*, **51**, 3475 (1929).

[4] See E. L. Eliel and D. E. Rivard, *J. Org. Chem.*, **17**, 1252 (1952).

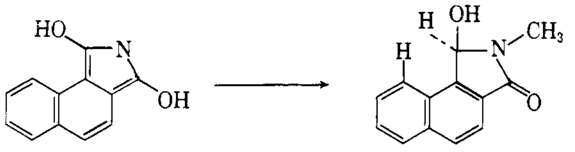
[5] Phthalimidine itself has been prepared by reaction of ethyl *o*-bromomethylbenzoate with aqueous alcoholic ammonia. The bromo ester gives phthalide on heating. W. Davies and W. H. Perkin, Jr., *J. Chem. Soc.*, **121**, 2202 (1922).

[6] Acid prepared by R. Adams and L. O. Binder, *J. Am. Chem. Soc.*, **63**, 2773 (1941); acid and ester prepared by F. Mayer and A. Sieglitz, *Ber.*, **55**, 1851 (1922).

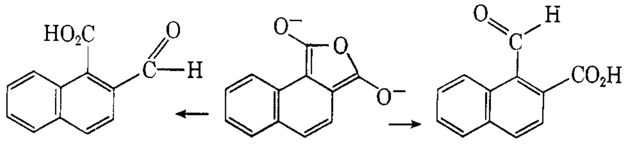
[7] F. Weygand, K. G. Kinkel, and D. Tietjen, *Chem. Ber.*, **83**, 394 (1950).

[8] Y. Hirshberg, D. Lavie, and E. D. Bergmann, *J. Chem. Soc.*, 1030 (1951).

This work indicates that the reduction of phthalimides does not involve attack of the metal surface on a carbonyl carbon atom. Our results are most simply accounted for by the postulate that there is appreciable steric interaction between the *peri* hydrogen atom and the nearby oxygen atom of the postulated isoindole intermediate[1] (X). Protonation to form XI would relieve this strain and give a product reducible to that actually isolated (II). Here, as in simpler phthalimides,[1] ring opening would appear not to occur rapidly under acidic conditions. The fact that the corresponding anhydride gives both of the possible lactones (VIII, IX) suggests that the isobenzofuran (XII) is less selectively protonated and achieves relief of steric strain by ring opening to give the aldehydo acids (XIII, XIV). These products could be reduced to the hydroxy acids, which, under our conditions would be recovered as the lactones (VIII, IX).



X XI



XIII XII XIV

Experimental[9]

1,2-Naphthalic Anhydride.—1,2-Naphthalic anhydride, m.p. 165.5–167°, (lit.,[10] m.p. 166–167°) was prepared by the dehydrogenation of 3,4-dihydro-1,2-naphthalic anhydride with sulfur.[10] The infrared spectrum showed bands at 1770 and 1830 cm.$^{-1}$ as expected for an anhydride.

Reduction of 1,2-Naphthalic Anhydride.—Ten grams (0.0505 mole) of 1,2-naphthalic anhydride and 210 ml. of glacial acetic acid were placed in a flask fitted with a reflux condenser and a mechanical stirrer with a Teflon paddle. Twenty-five grams (0.38 g.-atom) of zinc dust was added all at once with stirring and the reaction mixture was heated at reflux for 6.5 hr. The hot reaction mixture was filtered on a sintered glass Büchner-type funnel with suction and the residue was washed on the funnel with three 25-ml. portions of glacial acetic acid. The yellow filtrate, which had a greenish fluorescence, was evaporated to a small volume under vacuum with gentle heating on a steam cone. Saturated sodium bicarbonate solution (200 ml.) was added and the mixture was extracted four times with 100-ml. portions of chloroform; the combined chloroform extract was washed once with cold water prior to drying over anhydrous magnesium sulfate. The yellow chloroform solution was evaporated to a small volume and the remaining solvent was stripped off under vacuum; the residue was distilled through a 10-cm. Vigreux column under vacuum to give 7.65 g. (82.3% yield) of a light yellow solid, collected at 180–183°/2 mm. Fractional crystallization of the distillate from chloroform–petroleum ether (60–79°) to constant melting points gave 0.65 g. of 6,7-benzophthalide (IX), m.p., 153–154.5° (lit. m.p., 154°,[7] 157°[8]) and 0.50 g. of 4,5-benzophthalide (VIII), m.p., 117.5°. The higher melting compound crystallized from the chloroform–petroleum ether solution first and the lower melting compound was obtained from the filtrates. The yields of the pure products were low due to the difficulty in the separation.

Anal. Calcd. for $C_{12}H_8O_2$: C, 78.25; H, 4.38. Found for 6,7-benzophthalide: C, 78.11; H, 4.62. Found for 4,5-benzophthalide: C, 78.02; H, 4.58.

The infrared spectra of these compounds were not superimposable but both showed a single carbonyl band at 1730 cm.$^{-1}$.

6,7-Benzophthalide (IX).—In a 300-ml. round-bottomed three-necked flask equipped with a dropping funnel, mechanical stirrer, and a reflux condenser fitted with a calcium chloride drying tube were placed 20 g. (0.0935 mole) of ethyl 2-methyl-1-naphthoate[6] and 100 ml. of dry carbon tetrachloride. The funnel was filled with a solution of 14.9 g. (0.0935 mole) of bromine in 50 ml. of dry carbon tetrachloride. The flask was illuminated by a General Electric 275W RS reflector floodlamp and the bromine solution was added in small portions over a period of 45 min. The bromine color in the reaction mixture was allowed to discharge before each succeeding portion of the bromine solution was added. After all of the bromine solution had been added, the reaction mixture was illuminated for an additional 30 min. and then concentrated by heating on the steam plate. The oily residue of crude 2-bromomethyl 1-naphthoate was heated in an oil bath at 150–160° for 2 hr., then cooled to room temperature; the residue, which solidified on cooling, was taken up in 50 ml. of chloroform. Upon adding petroleum ether (30–60°) to the boiling chloroform solution until a slight turbidity resulted and cooling, a colorless precipitate was obtained. Five more recrystallizations from chloroform–petroleum ether (30–60°) gave 7.9 g. (42.9% yield) of 6,7-benzophthalide, m.p., 154.5–155°; m.m.p. with the product from the reduction of 1,2-naphthalic anhydride, 154–154.5°.

The infrared spectrum of this product was superimposable on that of the reaction product obtained from the reduction of 1,2-naphthalic anhydride.

Ethyl 1-Bromomethyl-2-Naphthoate (V).—A solution of 16.5 g. (0.0773 mole) of ethyl 1-methyl-2-naphthoate[3] in 100 ml. of dry carbon tetrachloride was photobrominated in generally the same manner using 12.3 g. (0.0773 mole) of bromine in 50 ml. of carbon tetrachloride. The reaction proceeded slowly, however, and it proved useful to place the floodlamp under the flask and close to the bottom so that its heat kept the reaction mixture refluxing. Illumination was continued, with stirring, for 30 min. after the bromine solution had been added. The excess solvent was evaporated and the semisolid residue was heated first to 150–160° (2 hr.) and then to 189–190° in an effort to achieve cyclization. Heating was discontinued since no ethyl bromide appeared to be forming and as the material began to darken. The dark material was taken up in chloroform, treated thrice with charcoal, and crystallized twice from chloroform–petroleum ether (30–60°) to give 6.4 g. (28%) of fine colorless needles, m.p. 78°. The product gave a positive halogen test with silver nitrate and showed a carbonyl band at 1700 cm.$^{-1}$ in the infrared.

4,5-Benzophthalide (VIII).—The above product (2.5 g.) was heated under reflux for 18 hr. with a mixture of 30 ml. of 20% sodium hydroxide solution and 5 ml. of ethanol. The reaction mixture was cooled in ice and then acidified with 3 *N* hydrochloric acid solution to give a colorless precipitate. This was collected, washed with water, dried in air, and crystallized twice from chloroform–petroleum ether (30–60°) to give 0.8 g. (51%) of 4,5-benzophthalide, m.p. 116.5–117°; m.m.p. with product from the reduction of 1,2-naphthalic anhydride, 117–118°.

Infrared spectrum of this product was superimposable on that of product obtained from reduction of 1,2-naphthalic anhydride.

Benz[*g*]dihydro-1,3-isoindoledione (1,2-naphthalimide) was prepared in 75% yield from the dicarboxylic acid essentially by the method of Noyes and Porter for the preparation of phthalimide.[11] The product was crystallized from acetic acid and had m.p. 226–227 (lit.,[12] m.p. 224°).

***N*-Methyl-1,2-naphthalimide (I).**—The potassium salt of 1,2-naphthalimide was prepared in 65% yield from the imide essentially by the method of Salzberg and Supniewski for the preparation of potassium phthalimide.[13] This was methylated with methyl iodide in dimethylformamide by the method of

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[9] Microanalyses by Mrs. C. S. Yeh and Mrs. D. W. Margerum; infrared spectra were determined by Miss M. M. Haley. All melting points were measured in soft glass capillaries and are corrected.

[10] E. B. Hershberg and L. F. Fieser, "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N.Y., 1943, p. 423.

[11] W. A. Noyes and P. K. Porter, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N.Y., 1941, p. 457.

[12] P. T. Cleve, *Ber.*, **25**, 2475 (1892).

[13] P. L. Salzberg and J. V. Supniewski, "Organic Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., New York, N.Y., 1941, p.119.

Sheehan and Bolhofer.[14] The product was obtained in 85% yield after crystallization from chloroform as canary yellow needles, m.p. 166–167°.

Anal. Calcd. for $C_{13}H_9NO_2$: C, 73.92; H, 4.30; N, 6.64. Found: C, 73.88; H, 4.10; N, 6.86.

The infrared spectrum showed carbonyl bands at 1705 and 1760 cm.$^{-1}$.

Reduction of *N*-Methyl-1,2-naphthalimide.—*N*-Methyl-1,2-naphthalimide (I) (8 g.) and 150 ml. of glacial acetic acid were placed in a flask equipped with a reflux condenser and a mechanical stirrer with a Teflon paddle and warmed slightly to dissolve solid material; then 16.3 g. (0.25 g.-atom) of zinc dust was added all at once with stirring. The reaction mixture was heated as reflux for 12 hr. and then filtered while hot on a sintered glass Büchner-type funnel with suction. The residue was washed on the funnel with three 50-ml. portions of glacial acetic acid. The filtrate was evaporated to a volume of approximately 56 ml. under vacuum with gentle heating on a steam cone. Excess saturated sodium bicarbonate solution was added to neutralize the remaining glacial acetic acid and the mixture was extracted with four 50-ml. portions of chloroform. The combined chloroform extract was washed with 50 ml. of saturated sodium bicarbonate solution and 50 ml. of water, dried over anhydrous magnesium sulfate, and evaporated to a volume of approximately 30 ml. The remaining solvent was removed under vacuum and the product was distilled at reduced pressure, the fraction distilling at 210–212°/2 mm. being collected. Crystallization from chloroform–petroleum ether (30–60°) gave 5.95 g. (79.3% yield) of 2-methylbenz[*g*]dihydro-3-isoindolone (II) m.p., 133.5–134°, as fine colorless needles.

Anal. Calcd. for $C_{13}H_{11}NO$: C, 79.16; H, 5.62; N, 7.10. Found: C, 78.95; H, 5.58; N, 7.16.

The infrared spectrum of this compound showed the presence of a carbonyl band at 1670 cm.$^{-1}$.

Attempted Hydrolysis of 2-Methylbenz[*g*]dihydro-3-isoindolone (II).—2-Methylbenz[*g*]dihydro-3-isoindolone (2 g.) and 30 ml. of 20% sodium hydroxide solution were heated at reflux for 72 hr. The cooled reaction mixture was diluted to a volume of 100 ml. with water and neutralized (hydrion paper) with 6 *N* hydrochloric acid solution. The neutral mixture, which contained some crystalline material, was extracted with four 25-ml. portions of chloroform. The combined chloroform extract was washed once with 25 ml. of water, dried over anhydrous magnesium sulfate, and evaporated to a volume of approximately 25 ml. Colorless crystals formed on adding petroleum ether (30–60°) to turbidity and cooling in the cold room overnight. The product was collected with suction and washed on the funnel with petroleum ether (30–60°). After air drying there was recovered 1.74 g. (89.9% recovery) of 2-methylbenz[*g*]dihydro-3-isoindolone, m.p., 134–134.2°; m.m.p. with starting material, 134–134.5°.

2-Methylbenz[*g*]dihydro-3-isoindolone (II).—Ethyl 1-methyl-2-naphthoate (15 g., 0.0702 mole) in 100 ml. of dry carbon tetrachloride was photobrominated as before, using 11.2 g. (0.0702 mole) of bromine in 25 ml. of dry carbon tetrachloride. The dropping funnel was removed and the reaction mixture was swept free of hydrogen bromide by bubbling nitrogen through a gas dispersion tube for 3 hr. The solvent was then evaporated by directing a stream of nitrogen over the surface of the solution. The semisolid residue of crude ethyl 1-bromomethyl-2-naphthoate was taken up in 10 ml. of anhydrous diethyl ether and the ether solution was carefully poured in small portions into approximately 100 ml. of liquid methyl amine which had been collected in a 12-inch test tube immersed in a Dry Ice bath. A vigorous reaction resulted as each succeeding portion of the ether solution was added. After all of the ether solution had been added, the reaction mixture was allowed to remain in the Dry Ice bath overnight. Boiling chips were added to the reaction mixture and the excess methylamine was allowed to evaporate at room temperature in the hood. The residue was taken up in 150 ml. of chloroform and the solution was washed with three 50-ml. portions of 6 *N* hydrochloric acid solution and three 50-ml. portions of water. The chloroform solution was dried over magnesium sulfate, treated with activated charcoal, and evaporated to a small volume. Petroleum ether (60–70°) was added to turbidity and, upon cooling, crystals of 2-methylbenz[*g*]dihydro-3-isoindolone (II) formed. After crystallizing five times from chloroform–petroleum ether (60–70°) there was obtained 3.72 g. (26.9% yield), m.p. 131.5–132°; m.m.p. with the reduction product from I, 132–132.5°.

The infrared spectrum of this product was superimposable with the infrared spectrum of the product obtained from the reduction.

2-Methylbenz[*g*]dihydro-1-isoindolone (III).—In a similar way, 20 g. (0.0935 mole) of ethyl 2-methyl-1-naphthoate was photobrominated with 14.95 g. (0.0935 mole) of bromine in carbon tetrachloride and added to liquid methylamine. The product was worked up as before. After five additional crystallizations from chloroform–petroleum ether (30–60°), 5.69 g. (30.8% yield) of 2-methylbenz[*g*]dihydro-1-isoindolone (III), m.p., 130–130.5°, was obtained. A mixture melting point of this product and that obtained from the reduction of I was depressed and the respective infrared spectra were not superimposable.

Anal. Calcd. for $C_{13}H_{11}NO$: C, 79.16; H, 5.62; N, 7.10. Found: C, 79.29; H, 5.88; N, 7.12.

The infrared spectrum of this compound showed the presence of a single carbonyl band at 1665 cm.$^{-1}$.

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(14) J. C. Sheehan and W. A. Bolhofer, *J. Am. Chem. Soc.*, **72**, 2786 (1950).