Cyclization of Aromatic Aldehyde and Ketone Phenylhydrazones with Carbon Monoxide to Yield Substituted Phthalimidines. Study of the Mechanism of the Reaction[1]

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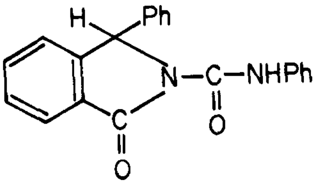
Benzaldehyde phenylhydrazone reacted with carbon monoxide in the presence of dicobalt octacarbonyl at 230° and 3540 p.s.i. to give mainly N-phenylphthalimidine. At 200° the yield of the major product was greatly decreased, whereas that of an organocobalt complex was increased. Tracer studies using benzaldehyde 1-phenylhydrazone-1-N^{15} established that the 2-N of the hydrazone was eliminated in the cyclization. Benzaldehyde *m*-tolylhydrazone at 230° gave the new compound, N-*m*-tolylphthalimidine. An independent synthesis of the latter compound is described. Under the same conditions, 1-naphthaldehyde phenylhydrazone afforded mainly 2-phenylbenz[*e*]isoindolin-1-one. Acetophenone phenylhydrazone yielded the new compounds N-phenyl-3-methylphthalimidine and 3-methylphthalimidine-N-carboxyanilide. In a crossed-over experiment using 1-naphthaldehyde phenylhydrazone and benzaldehyde *m*-tolylhydrazone, the fact that no crossed-over products were obtained showed that the rearrangement proceeded by an intramolecular mechanism. The infrared spectra of the N^{15} tracer compounds are described.

It recently has been shown[3] that benzophenone phenylhydrazone cyclized with carbon monoxide at 230° and 3800 p.s.i. to give 3-phenylphthalimidine-N-carboxyanilide (**1**), and at 190–220° to give a mixture of the same compound and 3-phenylphthalimidine (**2**). Because the number of carbon monoxide entities incorporated into the product was temperature dependent and scission of the N–N bond had occurred, we decided to study further the cyclization of aromatic phenylhydrazones in order to determine the generality and mechanism of this reaction.



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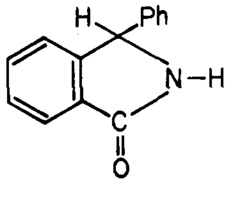

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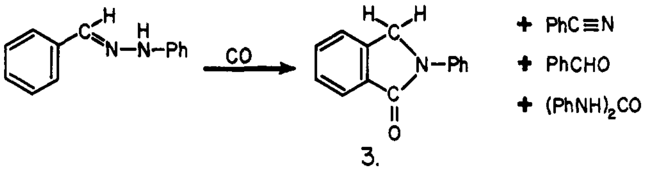
The aromatic aldehyde or ketone phenylhydrazone, dissolved in benzene as solvent, reacted with commercial high purity carbon monoxide in the presence of preformed dicobalt octacarbonyl as catalyst in a 300-ml. rocker bomb fitted with a glass liner. After the carbon monoxide was vented, only that portion of the reaction mixture which was still in the glass liner was freed of catalyst, either by chromatography or by heating it at 70°. The per cent yields of products reported in the experiments involving less than 1 g. of substrate were always less than those in which about 10 g. of starting material were used because of greater mechanical losses in the former than in the latter. Since about 10% of the substrate escaped through the hole of the liner (material outside of the liner was not recovered because of possible contamination), the reported yields of products are correspondingly lower than they actually were. In general, the aromatic aldehyde phenylhydrazones gave more complex product mixtures with lower yields of cyclic products (these were N-substituted phthalimidines) than did the aromatic ketone phenylhydrazones. In contrast to our findings, Murahashi and Horiie[4] reported recently that benzaldehyde phenylhydrazone did not give any definite result when treated with synthesis gas.

Benzaldehyde phenylhydrazone reacted with carbon monoxide at 230° and 3540 p.s.i. to give N-phenylphthalimidine (**3**) in 50% yield. It is interesting to note that one nitrogen has been eliminated from the phenylhydrazone in this reaction. The structure of compound **3** was confirmed by direct comparison (mixture melting point and infrared analysis) with an authentic sample of N-phenylphthalimidine, prepared by the reduction of phthalanil as described by Graebe.[5] In addition to the N-phenylphthalimidine, the reaction mixture also contained small amounts of benzonitrile, benzaldehyde, N,N′-diphenylurea, and a blue-black solid which appeared to be an organometallic complex. Treatment of the last substance with sodium hydroxide yielded ammonia and aniline.



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On lowering the carbonylation temperature to 200°, benzaldehyde phenylhydrazone gave only 5% of N-phenylphthalimidine in the product mixture. This reduction of the yield of cyclized product by lowering the reaction temperature is in accord with similar observations previously reported on the carbonylation of benzophenone phenylhydrazone.[3] In the 200° experiment a higher yield of the organocobalt complex was obtained as well as 3% of a yellow crystalline compound of empirical formula C_7H_6N. The remainder of the product mixture was again a complex mixture of oils.

In order to determine which nitrogen atom was eliminated from benzaldehyde phenylhydrazone during its conversion to N-phenylphthalimidine, labeled benzaldehyde 1-phenylhydrazone-1-N^{15} was treated with carbon monoxide under the same conditions as those used for the carbonylation of the normal phenylhydra-

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(1) Presented before the XIX International Congress of Pure and Applied Chemistry, London, England, July, 1963.

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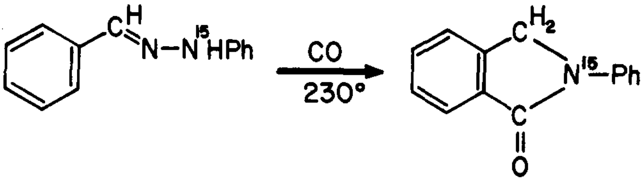
(3) A. Rosenthal and Mary R. S. Weir, *Can. J. Chem.*, **40**, 610 (1962).

(4) S. Murahashi and S. Horiie, *Bull. Chem. Soc. Japan*, **33**, 78 (1959).

(5) C. Graebe, *Ann.*, **247**, 288 (1888).

zone. Alumina chromatography of the products from the labeled phenylhydrazone gave N-phenylphthalimidine-N^{15} (4). Infrared and mass spectrometric analyses showed conclusively that compound **4** was the



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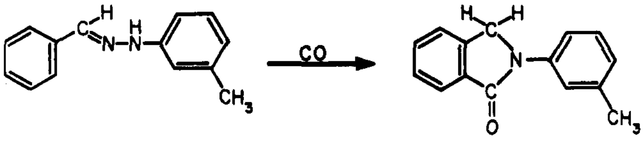
essentially pure N^{15} labeled compound. As shown in the Experimental section, the only peaks which were displaced (displacement of the N^{15} N-phenylphthalimidine shown in brackets) occurred at 1390 [10], 1372 [2], 1264 [4], 1149 [14], 1061 [6], and 877 cm.$^{-1}$ [4]. Since the labeled N-phenylphthalimidine did not exhibit any trace of peaks which would arise from N^{14}–C groups, it was tentatively surmised that the labeled compound was essentially pure. Unequivocal proof of the purity of the labeled N-phenylphthalimidine was provided by mass spectrometric analysis which showed that the labeled N-phenylphthalimidine contained 97.5% enriched nitrogen. Since the benzaldehyde 1-phenylhydrazone-1-N^{15} contained at least 95% enriched nitrogen (analysis supplied by Merck Sharp and Dohme of Canada), it was definitely concluded that the labeled N-phenylphthalimidine was essentially pure and that 2-N of the phenylhydrazone was completely eliminated during the reaction.

With reference to the infrared spectra (shown in the Experimental) of the normal and labeled benzaldehyde phenylhydrazones and N-phenylphthalimidines, the peaks at 1132 and 1149 cm.$^{-1}$ in the normal compounds were assigned to the N–Ph stretch of the hydrazone and the phthalimidine, respectively (or probably the C–N bond participated in ring vibration). Confirmation of this assignment is provided by the recent work of Kübler and co-workers.[6]

Although it appeared that the phenyl group attached to the nitrogen of the phthalimidine originated from the phenylhydrazone, it was conceivable that it also might have been produced by the solvent benzene. Since previous workers[7] have shown that the yield of ureas obtained from the carbonylation of azo compounds varied with the solvent used, it might be concluded that the solvent furnished the hydrogen which was necessary for the reduction of the azo compound to the hydrazo form and the latter was then carbonylated to yield the urea. On the basis of this assumption it might be expected that the solvent benzene could also supply phenyl groups in addition to hydrogen. In order to test this hypothesis a phenylhydrazone was chosen that contained a methyl "tagged" phenyl group on the nitrogen. Thus, when *m*-tolylhydrazone was carbonylated using benzene as solvent at 230°, N-*m*-tolylphthalimidine (**5**) was the sole cyclized product obtained. This "tagged" methyl group was shown to be in the *meta* position of the tagged substituted phthalimidine by comparing compound **5** with an authentic sample of N-*m*-tolylphthalimidine prepared by the condensation of phthalic anhydride with *m*-toluidine and subsequent reduction of the N-*m*-tolylphthalimide with tin and hydrochloric acid (each phthalimidine had the same melting point and infrared spectrum). Therefore, the group on the nitrogen of the N-phenylphthalimidine was a moiety of benzaldehyde phenylhydrazone and did not arise from the solvent. In addition, the *m*-tolyl group must not have come free during the rearrangement since the structural purity of the *m*-tolyl group had been retained. Further additional convincing proof that the reaction must have proceeded *via* an intramolecular mechanism was provided by carrying out a crossed-over carbonylation experiment involving two different phenylhydrazones having approximately the same rates of reaction. Thus, when an equimolar mixture of 1-naphthaldehyde phenylhydrazone and benzaldehyde *m*-tolylphenylhydrazone was carbonylated at 230°, the only cyclized products were N-*m*-tolylphthalimidine (**5**) and 2-phenylbenz[*e*]isoindolin-1-one (**6**).



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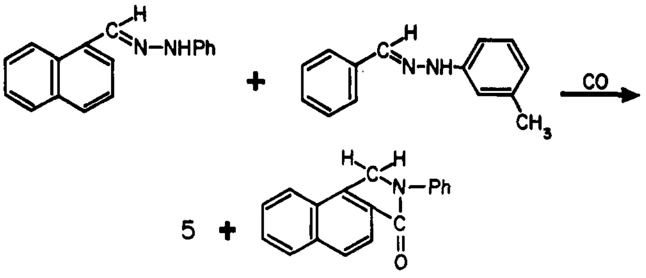

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Because the aromatic aldehyde phenylhydrazones cyclized with carbon monoxide to yield a product in which one nitrogen was eliminated from the starting material whereas the diaryl ketone phenylhydrazones cyclized under similar conditions to give a product containing both nitrogens, it appeared of interest to carbonylate an alkyl aryl ketone phenylhydrazone. Carbonylation of acetophenone phenylhydrazone afforded 3-methylphthalimidine-N-carboxyanilide and 3-methyl-N-phenylphthalimidine. It would, therefore, appear that the substituents, other than hydrogen, attached to the carbon of the imino group have little effect on the cyclization. In this connection it is interesting to note that Murahashi and Horiie[8] recently reported that substituents on the carbon of C=N group of anils had no discernible steric effect on the velocity of the cyclization with carbon monoxide.

Although the complete mechanism for the unusual rearrangement of the aromatic aldehyde phenylhydrazones is unknown, the following postulations may be of interest since evidence for some of the proposed steps exist in the literature. Based on the fact that the phenylhydrazones of aldehydes and ketones rapidly tautomerize to benzene azoalkanes,[9] the assumption can be made that the azo tautomer **7** (Chart I) of benzaldehyde phenylhydrazone reacts with the metal carbonyl to give a nitrogen–metal Σ bond as shown in structure **8**.

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(6) R. Kübler, W. Lüttke, and S. Weckberlin, *Z. Eleckt.*, **64**, 650 (1960).

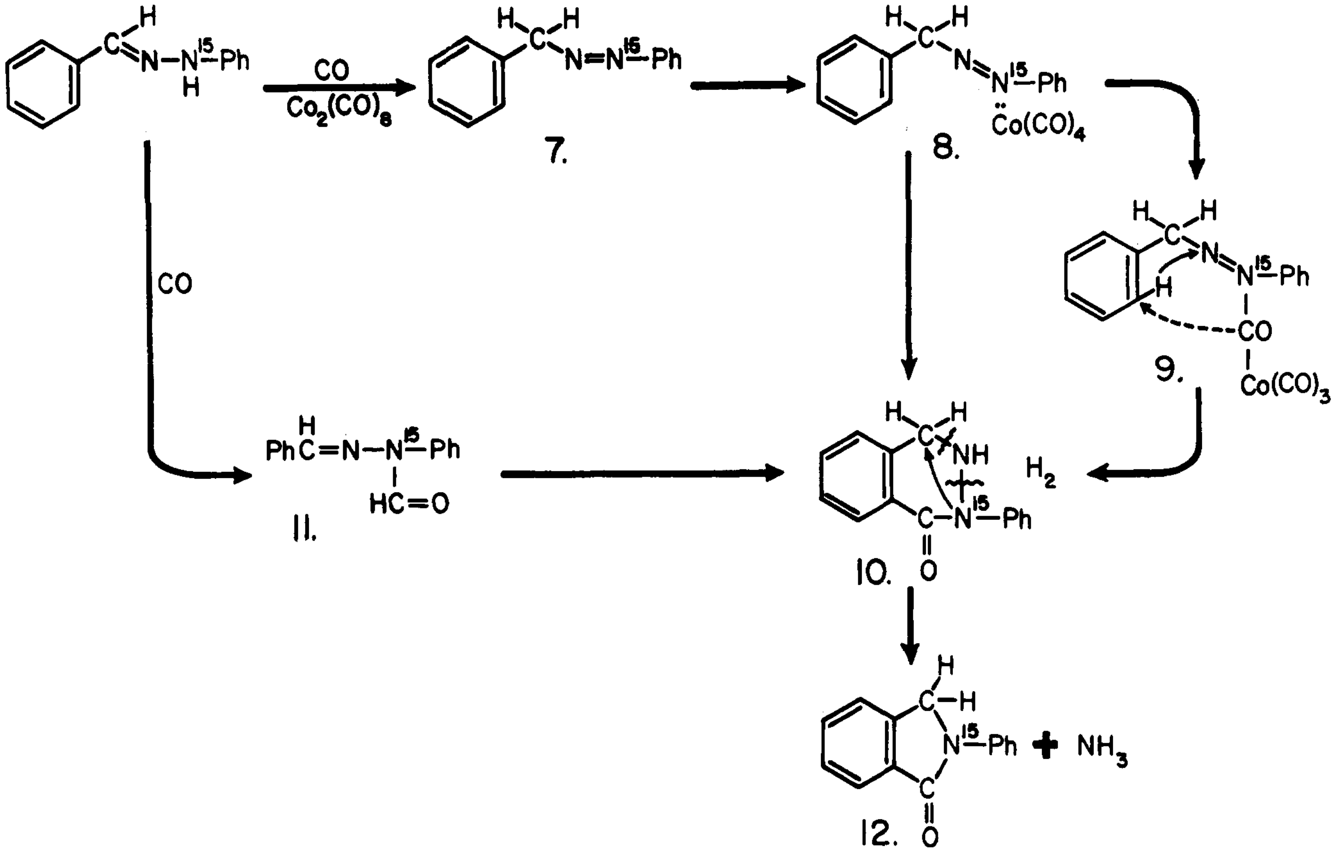
(7) S. Horiie and S. Murahashi, *Bull. Chem. Soc. Japan*, **33**, 88 (1959).

(8) S. Horiie and S. Murahashi, *ibid.*, **33**, 247 (1960).

(9) R. O'Connor, *J. Org. Chem.*, **26**, 4375 (1961).

CHART I

MECHANISM OF CARBONYLATION OF BENZALDEHYDE 1-PHENYLHYDRAZONE-1-N^{15}



After CO from the metal carbonyl is inserted between the nitrogen and the cobalt atom[10] to give intermediate **9**, cyclization of the CO to the aromatic ring occurs to yield intermediate **10**. Alternatively, the assumption that the attack of dicobalt octacarbonyl on the phenylhydrazone gives the N-formyl compound **11** which undergoes cyclization to yield labeled N-phenylphthalimidine **12**, is based on the facts that amines gave formamides with dicobalt octacarbonyl,[11] and aniline yields formanilide, and N,N'-diphenylurea with nickel carbonyl.[12] Hydrogenolysis of the C–N bond might be expected to take place easily because of the activating effect of the benzylic group. The hydrogen must be furnished by the reactants in some type of transfer process, possibly *via* the formation and decomposition of cobalt hydrocarbonyl as envisaged by Natta, Pino, and Ercoli.[13] The apparent analogy between the rearrangement of benzaldehyde phenylhydrazone to yield N-phenylphthalimidine in the research described herein and the Fischer indole synthesis,[14] which also involves elimination of 2-N of the phenylhydrazone, is misleading, we believe, since the former reaction involves cyclization with carbon monoxide, whereas the latter does not.

Experimental

General Considerations.—The high pressure equipment has been described previously.[15] After each experiment, only the product inside the glass liner was utilized (part of the reaction mixture leaked through the hole of the glass liner into the metal reaction vessel). High purity carbon monoxide was obtained from the Matheson Co., East Rutherford, N. J. All melting points were obtained on a Leitz heating stage. The infrared analyses were done on a Perkin-Elmer Model 21 instrument using sodium chloride optics. The mass spectrometric analysis was done on an A. E. I. instrument with heated inlet.

Benzaldehyde 1-Phenylhydrazone-1-N^{15}.—To 0.75 g. of benzaldehyde was added with stirring 0.75 g. of 1-phenylhydrazine-1-N^{15},[16] and the hydrazone kept at 75° for 10 min. Anhydrous ethanol (50 ml.) was added and the hydrazone heated at reflux for 10 min. Removal of the solvent under reduced pressure was followed by recrystallization of the residue from 90% ethanol' m.p. 159–160°.

Infrared (KBr) (peaks given in brackets are for normal benzaldehyde phenylhydrazone): 3288 [3292] [w], 1588 (s), 1562 (m), 1509 [1516], 1488 (s), 1442 (m), 1356 (m), 1312 (m), 1298 (m), 1285 (m), 1255 (s), 1162 (w), 1122 [1132] (s), 1063 (s), 1025 (w), 926 (s), 900 (907) (w), 880 (m), 750 (s), 640 (s) cm.$^{-1}$.

Reaction of Benzaldehyde Phenylhydrazone with Carbon Monoxide to Yield N-Phenylphthalimidine. Procedure A (at 230–240°). Carbonylation of Normal Benzaldehyde Phenylhydrazone.—Benzaldehyde phenylhydrazone (8 g.) was carbonylated at 230–240° and at 3540 p.s.i. for 2.2 hr. as described previously.[3] The recorded pressure drop at 20° was 90 p.s.i. After the reaction mixture was filtered to remove the blue-black organocobalt complex (1.0 g.), the catalyst was destroyed by heating at 70°. The solution was again filtered, evaporated to dryness under vacuum, and the residue recrystallized twice from ethanol; yield, 4.2 g. (50%); m.p. 166.5–167.5°. Chromatography of this substance on alumina using benzene–chloroform (1:1) as developer showed one zone. The mixture melting point of the product with an authentic sample of N-phenylphthalimidine[5] was 166–167°.

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[10] I. Wender, private communication.

[11] H. W. Sternberg, I. Wender, R. A. Friedel, and M. Orchin, *J. Am. Chem. Soc.*, **75**, 3148 (1953).

[12] W. Reppe, *Ann.*, **582**, 1 (1953).

[13] G. Natta, P. Pino, and R. Ercoli, *J. Am. Chem. Soc.*, **74**, 4496 (1952).

[14] C. F. H. Allen and C. V. Wilson, *ibid.*, **65**, 611 (1943).

[15] A. Rosenthal, R. F. Astbury, and A. Hubscher, *J. Org. Chem.*, **23**, 1037 (1958).

[16] Products of Merck Sharp and Dohme of Canada Limited, Montreal, Canada. The labeled phenylhydrazine contained at least 95% of N^{15}.

Anal. Calcd. for $C_{14}H_{11}NO$: C, 80.37; H, 5.30; N, 6.70; O, 7.64; mol. wt., 209. Found: C, 80.15; H, 5.44; N, 6.69; O, 7.79; mol. wt. (Rast), 210.

Infrared spectrum of N-phenylphthalimidine in KBr (cm.$^{-1}$): 3030 (w), 1680 (s), 1590 (m), 1495 (s), 1468 (m), 1455 (w), 1439 (s), 1390 (s), 1327 (s), 1305 (s), 1264 (m), 1221 (m), 1200 (w), 1184 (w), 1149 (s), 1090 (m), 1061 (w), 945 (w), 894 (m), 877 (w), 751 (s), 732 (s), 681 (s) (s = strong; m = medium; w = weak).

Anal. of organocobalt complex. Found: C, 31.56; H, 4.13; N, 6.59.

The organocobalt complex was insoluble in ethanol and acetone. Treatment of the complex with hot concentrated sodium hydroxide yielded aniline (isolated and characterized as 2,4,6-tribromoaniline, m.p. 129–130°).

Since less than 1 g. of benzaldehyde 1-phenylhydrazone-1-N^{15} was available for carbonylation, it was decided to carry out an experiment on a like quantity of the normal phenylhydrazone using the same 300-ml. reaction vessel and to separate the products by chromatography. It was believed that the trace of moisture present in the carbon monoxide (the molar concentration remained essentially constant in all experiments) might have a greater hydrolytic effect on a 1-g. than on an 8-g. quantity of benzaldehyde phenylhydrazone.

An amount of 2 g. of the product obtained from the carbonylation of 2 g. of benzaldehyde phenylhydrazone was placed on a column of Florisil[17] and chromatographed with the following results. (i) Benzene eluted 0.35 g. of oil which contained benzaldehyde and benzonitrile (the former was isolated as the 2,4-dinitrophenylhydrazone derivative). A trace of an unstable red oil (no carbonyl) accompanied the first zone. (ii) N-Phenylphthalimidine (0.86 g., 42% yield) was eluted with benzene. (iii) Benzene–chloroform (4:1) eluted 0.05 g. of N,N′-diphenylurea which was recrystallized from chloroform; m.p. 251–252°; m.m.p. 251–252° with an authentic sample. (iv) Benzene–ethanol (9:1) eluted 0.2 g. of an oil (which contained no cyclic carbonyl group as evidenced by the fact that the material did not absorb in the region 1630 to 1750 cm.$^{-1}$).

Carbonylation of Benzaldehyde 1-Phenylhydrazone-1-N^{15} (1-Benzylidene-2-phenylhydrazine-2-N^{15}).—An amount of 0.80 g. of benzaldehyde 1-phenylhydrazone-1-N^{15} was carbonylated at 230–240° as described previously. The organocobalt complex (0.02 g.) was removed by filtration.

Anal. Found: N, 7.12.

The filtrate was then chromatographed as described in the preceding section with the following results. (i) Petroleum ether (b.p. 65–80°) eluted the catalyst. (ii) Benzene eluted a red zone which gave 0.32 g. of sirup. Rechromatography of this red material on alumina yielded 0.11 g. of benzaldehyde which was characterized as benzaldehyde 2,4-dinitrophenylhydrazone, m.p. 239°, m.m.p. with an authentic sample of benzaldehyde 2,4-dinitrophenylhydrazone was 239–240°, the infrared spectra of both substances were identical. Benzonitrile (0.09 g.) was also isolated and characterized by comparison of its infrared spectrum with that of an authentic sample. The red oil, which was present in trace amount, contained no carbonyl group and was not characterized. (iii) After elution of the red zone, N-phenylphthalimidine-N^{15} was eluted with benzene and recrystallized from ethanol; yield, 0.20 g.; m.p. 166–167°; normal and labeled N-phenylphthalimidine had m.m.p. 166–168°; infrared (KBr) of labeled N-phenylphthalimidine was 1380 (s), 1325 (s), 1260 (m), 1135 (s), 1055 (w), 873 (w) cm.$^{-1}$. The remaining peaks of the normal and labeled N-phenylphthalimidine were identical. Analysis of N-phenylphthalimidine-N^{15} by mass spectrometric means showed 97.5% (± 1%) of N^{15} content. (iv) Further elution of the column with benzene–chloroform (4:1 v./v.) yielded 0.026 g. of a solid substance which on recrystallization from chloroform afforded N,N′-diphenylurea. (v) Benzene–ethanol (9:1 v./v.) gave 0.033 g. of an oil. As infrared analysis showed the absence of a cyclic carbonyl group, the material was not characterized.

Procedure B (at 200°.)—Benzaldehyde phenylhydrazone (8 g.) reacted with carbon monoxide at 200° to yield an organocobalt complex (2 g.), N-phenylphthalimidine (5% yield), and a yellow crystalline compound which crystallized from the original benzene solution (3%), m.p. 187–187.5°.

Anal. Calcd. for C_7H_6N: C, 80.76; H, 5.76; N, 13.46. Found: C, 80.49; H, 5.61; N, 13.59.

Infrared (KBr): 1595 (w), 1512 (s), 1492 (s), 1477 (s), 1455 (s), 1300 (m), 1262 (w), 1230 (w), 1185 (w), 1150 (s) cm.$^{-1}$. Ultraviolet: 4000 cm.$^{-1}$.

Anal. (of organocobalt complex). Found: C, 31.56; H, 4.13; N, 6.59.

Treatment of the complex with sodium hydroxide liberated ammonia and aniline (characterized as 2,4,6-tribromoaniline).

Infrared (KBr) of the complex: 3040 (w), 2920 (w), 2290 (w), 1712 (m), 1685 (w), 1600 (s), 1495 (s), 1400 (s), 1350 (m), 1185 (s) cm.$^{-1}$.

Carbonylation of Benzaldehyde *m*-Tolylhydrazone to Yield N-*m*-Tolylphthalimidine.—Benzaldehyde *m*-tolylhydrazone (8 g.) was carbonylated at 230° and the crude product recrystallized several times from ethanol; yield, 1.7 g.; m.p. 147–149°; m.m.p. 147–149° with an authentic sample of N-*m*-tolylphthalimidine. The infrared spectra of both substances were identical.

Anal. Calcd. for $C_{15}H_{13}NO$: C, 80.70; H, 5.84, N, 6.28. Found: C, 80.52; H, 5.89; N, 6.42.

Infrared (KBr): 3080 (w), 2920 (w), 1685 (s), 1600 (s), 1495 (s), 1465 (m), 1448 (s), 1390 (s), 1338 (w), 1300 (s), 1222 (m), 1200 (s), 1182 (w), 1158 (s), 1105 (w), 1092 (m), 1075 (m) cm.$^{-1}$.

Synthesis of N-*m*-Tolylphthalimidine. A. N-*m*-Tolylphthalimide.—N-*m*-Tolylphthalimide was prepared according to a modification of the method used by Graebe.[5] A mixture of 3.2 g. (0.033 mole) of freshly distilled *m*-toluidine and 7.4 g. (0.050 mole) of phthalic anhydride in 60 ml. of acetic acid was heated at reflux for 1 hr. The solution was then poured into 450 ml. of water, boiled, and allowed to stand overnight. The resulting solid was filtered and air-dried, giving 7.3 g. of white powder which on crystallization from 95% ethanol had m.p. 175–178°.

Anal. Calcd. for $C_{15}H_{11}NO_2$: C, 75.90; H, 4.64; N, 5.91. Found: C, 75.74; H, 4.65; N, 5.86.

B. N-*m*-Tolylphthalimidine.—N-*m*-Tolylphthalimide (4 g.) dissolved in ethanol was treated with 4.4 g. of granulated tin. The mixture was warmed on a water bath, and concentrated hydrochloric acid added gradually during the warming till all the tin had dissolved. The white solid, which precipitated on cooling overnight, was filtered, washed, and dried. On crystallization from 95% ethanol, it had m.p. 150–151°.

Anal. Calcd. for $C_{15}H_{13}NO$: C, 80.70; H, 5.84; N, 6.28. Found: C, 80.61; H, 5.72; N, 6.28.

3-Methylphthalimidine-N-carboxyanilide and 3-Methyl-N-phenylphthalimidine from Acetophenone Phenylhydrazone.—Acetophenone phenylhydrazone (8 g.) was cyclized with carbon monoxide at 230° for 2.5 hr.

Chromatography of 2.9 g. of the crude product (first freed of catalyst) on alumina, using benzene as a developer, yielded 3-phenylphthalimidine-N-carboxyanilide, 0.9 g., which was recrystallized from ethanol, m.p. 97–99°.

Anal. Calcd. for $C_{16}H_{14}N_2O_2$: C, 72.25; H, 5.26; N, 10.52. Found: C, 71.98; H, 5.19; N, 10.48.

Infrared (KBr): 3205 (w), 1715 (s), 1685 (m), 1595 (s), 1505 (w), 1490 (w), 1470 (w), 1450 (m), 1355 (s) cm.$^{-1}$.

Further elution of the column with benzene–chloroform (9:1) afforded 3-methyl-N-phenylphthalimidine; yield, 0.52 g.; m.p. 76–78° (from ethanol).

Anal. Calcd. for $C_{15}H_{13}NO$: C, 80.70; H, 5.84; N, 6.28. Found: C, 80.76; H, 5.86; N, 6.05.

Infrared (KBr): 1685 (s), 1595 (s), 1500 (w), 1470 (w), 1455 (m), 1365 (m) cm.$^{-1}$.

Reaction of 1-Naphthaldehyde Phenylhydrazone with Carbon Monoxide to Yield 2-Phenylbenz[*e*]isoindolin-1-one, 1-Naphthonitrile, and Aniline.—Similarly, 1-naphthaldehyde phenylhydrazone (7 g.) was treated with carbon monoxide at 230–235° for 2.5 hr.

After removing the solid organocobalt complex (1.0 g.) from the reaction mixture, the filtrate was added to a column of Florisil. The catalyst was eluted using petroleum ether as developer. Organic material (6.7 g.) was then eluted with benzene-absolute ethanol (9:1). A 3.1-g. portion of the residue was chromatographed on B.D.H. Alumina (80 × 72 mm. diameter) column using benzene–absolute ethanol (99.4:0.6 v./v.) as developer. Four fractions, two of which fluoresced, were collected.

Fraction A (0.6 g.) was separated by vapor phase chromatography to yield aniline and 1-naphthonitrile, m.p. 31–33°. The latter compound was hydrolyzed with ethanolic potassium hydroxide according to the method of Rule and Barnett[18] to give 1-

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[17] Product of Floridin Company, Tallahassee, Fla.

[18] H. G. Rule and A. J. G. Barnett, *J. Chem. Soc.*, **177** (1932).

naphthoic acid, m.p. 161°, m.m.p. 160–161° with an authentic sample. The infrared spectra of both compounds were identical.

Fraction B, which appeared as a brown zone (0.56 g.), was rechromatographed on alumina using benzene–chloroform (6:1 v./v.) as developer. Most of fraction B fluoresced and was identical to fraction C. The slow moving fraction called B (recrystallized from ethanol to yield 0.030 g., m.p. 225–226°) is possibly the N-carboxyanilide derivative of 2-phenylbenz[*e*]isoindolin-1-one.

Anal. Calcd. for $C_{19}H_{14}N_2O_2$: C, 75.52; H, 4.64; N, 9.28. Found: C, 75.77; H, 5.14; N, 8.87.

Infrared spectrum of substance B (KBr): 3200 (w), 3030 (w), 2900 (w), 1700 (s), 1680 (m), 1645 (w), 1590 (s), 1548 (s), 1500 (m), 1447 (s), 1395 (w), 1359 (s), 1310 (w), 1275 (m), 1237 (s), 1178 (w), 1156 (m) cm.$^{-1}$.

Fraction C (0.33 g.) was rechromatographed on alumina according to the same procedure used for fraction B, yield 0.30 g. Recrystallization from ethanol gave pure material, m.p. 177°. The literature melting point of 2-phenylbenz[*e*]isoindolin-1-one[19] is 177°.

Anal. Calcd. for $C_{18}H_{13}NO$: C, 83.20; H, 5.02; N, 5.40. Found: C, 82.89; H, 5.32; N, 5.66.

Infrared spectrum of 2-phenylbenz[*e*] isoindolin-1-one in KBr: 3030 (w), 2900 (w), 1682 (s), 1643 (w), 1593 (m), 1550 (m), 1500 (m), 1444 (m), 1375 (s), 1294 (w), 1273 (w), 1245 (w), 1148 (m) cm.$^{-1}$.

Crossed Carbonylation Experiment of 1-Naphthaldehyde Phenylhydrazone and Benzaldehyde *m*-Tolylhydrazone to Yield 2-Phenylbenz[*e*]isoindolin-1-one and N-*m*-Tolylphthalimidine.—A mixture of 1-naphthaldehyde phenylhydrazone (0.32 g., 0.0013 mole) and benzaldehyde *m*-tolylphenylhydrazone (0.27 g., 0.0013 mole) was carbonylated as described previously in the Experimental section.

The product consisted of an organocobalt complex (0.066 g.) and a mixture of products which were separated by chromatography as described previously.

Benzaldehyde (0.032 g.), benzonitrile (about 0.020 g.), and 1-naphthonitrile were obtained from the first fraction. The second fraction was rechromatographed on alumina using benzene–petroleum ether (b.p. 30–65°) (6:1 v./v.) as developer. The product, 0.24 g., was recrystallized from ethanol, m.p. 177°, m.m.p. 177° with a sample of 2-phenylbenz[*e*]isoindolin-1-one prepared as described in the Experimental. The infrared spectra of both substances were identical.

The third fraction (0.14 g.), rechromatographed on alumina using benzene–chloroform (1:1 v./v.) as developer, was recrystallized from ethanol, m.p. 148–149°, m.m.p. 148–149° with an authentic sample of N-*m*-tolylphthalimidine. The infrared spectra of both compounds were identical.

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Aldehyde Hemihydrates

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A reinvestigation of the dry codistillation of barium *n*-dodecanoate and barium formate has shown that Krafft's *n*-dodecanal, which was first reported in 1880, is *n*-dodecanal hemihydrate. *n*-Dodecanal, *n*-decanal, and *n*-heptanal on treatment with water form isolable hemihydrates in which the carbonyl groups and water are chemically combined. Hemihydrate formation appears to be a general reaction for normal aliphatic aldehydes. The experimental evidence indicates that the structures of the addition products are α,α'-dihydroxy ether derivatives.

In 1880, Krafft reported the synthesis of *n*-dodecanal and other higher aldehydes by the dry codistillation of the barium salts of the corresponding acids and barium formate.[2] The C_{12} aldehyde was characterized as a solid, melting at 44.5°. Subsequent investigators, however, characterized *n*-dodecanal, obtained by numerous synthetic methods[3–8] and from natural products,[9,10] as a high boiling liquid with a melting point of about 11°.

Krafft's *n*-dodecanal has been the subject of periodic conjecture since its isolation. The product has been postulated to be *n*-dodecanal polymer,[11,12] a hydrogen bonded complex of *n*-dodecanal and *n*-dodecanol,[7] the hemiacetal of *n*-dodecanal and *n*-dodecanol,[13] and *n*-dodecanal enol.[5] The polymeric structure does not appear to be the correct structure of Krafft's *n*-dodecanal because polymers of *n*-dodecanal have been prepared, and they have properties inconsistent with the properties of Krafft's material.[8,12] The hydrogen bonded structure and the hemiacetal are not satisfactory because Krafft's *n*-dodecanal has been prepared from liquid *n*-dodecanal purified through the bisulfite addition product[5] and the semicarbazone derivative,[10] thereby precluding the presence of *n*-dodecanol. The enolic structure postulated by Zaar[5] seemed to be the correct structure even though enols of simple aldehydes generally cannot be isolated.[14] This investigation was undertaken to confirm the enolic structure of Krafft's *n*-dodecanal.

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