mixture turned red and warmed up to 50°. After the reaction was complete, the mixture was extracted with aqueous sodium carbonate. Acidification of the extracts gave 2.4 g. of dark red crystals. The infrared spectrum of this acid resembles the spectrum of an authentic sample of mixed ferrocenecarboxylic and 1,1′-ferrocenedicarboxylic acids.

The material which was insoluble in the base gave by sublimation 6.0 g. (16.2%) of ferrocene. In the sublimation residue remained 20.5 g. of red crystalline poly(ferrocenyl ketone). The poly(ferrocenyl ketone) was extracted with benzene and then with chloroform.

The benzene-soluble poly(ferrocenyl ketone), 10 g., decomposes above 200°, av. mol. wt. 1114, has infrared and ultraviolet spectra very similar to the spectra of an authentic sample of diferrocenylketone.[24] The infrared spectrum (Nujol) has strong bands at 1625, 1290, 1110, 1065, 1000, 850–810, 807, and 772 cm.$^{-1}$. Weaker bands are at 3120, 1200, 1050, 1025, 900, and 700 cm.$^{-1}$. The ultraviolet spectrum (in $CHCl_3$) has a wide absorption maximum between 250 and 280 mμ ($E^{1\%}_{1\,\mathrm{cm}}$ 4.18 × 10^2) and an absorption maximum at 365 mμ ($E^{1\%}_{1\,\mathrm{cm}}$ 89.5). Low voltage mass spectrometry gave only a mass peak corresponding to the molecular ion of diferrocenyl ketone (*m/e* 398).

The 70-e.v. mass spectrum has additional peaks which correspond to the following fragment ions: $C_5H_5Fe^{56}$ (*m/e* 121), C_5H_4-C_5H_4 (*m/e* 128), C_5H_4–C_5H_5 (*m/e* 129), $Fe^{56}C_5H_3CO$ (*m/e* 147), $C_5H_5Fe^{56}C_5H_4CO$ (*m/e* 213), $C_5H_5FeC_5H_4COC_5H_4$ (*m/e* 277), $C_5H_4Fe^{56}C_5H_4C_5H_4Fe^{56}$ or $C_5H_5Fe^{56}C_5H_4COC_5H_3CO$ (*m/e* 304), $C_5H_5Fe^{56}C_5H_4C_5H_4Fe$ (*m/e* 305), and $C_5H_4Fe^{56}C_5H_4COC_5H_4Fe^{56}$-$C_5H_4CO$ (*m/e* 424). Analysis showed that the carbon–hydrogen–oxygen–iron ratio is 11.0:10.5:0.8:0.8.

The chloroform-soluble portion (7 g., decomposes above 200°) has an infrared spectrum (Nujol) similar to that for the benzene-soluble ketone, except that the 1110- and 1000-cm.$^{-1}$ bands are weaker. Analysis showed that carbon–hydrogen–oxygen–iron ratio is 11.0:10.2:1.4:0.9.

In the insoluble residue remained 3.5 g. of the polyketone.

Acknowledgment.—The authors are indebted to Drs. B. A. King and J. G. Larson for the mass spectrometry and Dr. J. C. Schug for the n.m.r. analyses.

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[24] An authentic sample of diferrocenyl ketone was prepared by reacting ferrocene with phosgene and aluminum chloride.

Synthetic Utility of Alkali Metal Adducts of Diaryl Ketones

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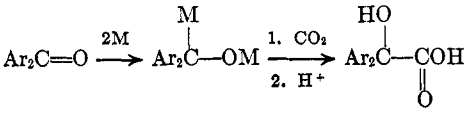
Reaction conditions for the preparation and use of dimetallo adducts (II) of benzophenones have been investigated. Two solvents (ammonia and dimethoxyethane), the three common alkali metals, and several substituted ketones were employed to prepare these organometallic reagents (II). Included in the discussion of uses of these reagents are new preparations of benzoins and benzilic acid esters, further studied preparations of glycols and benzilic acids, and a brief summary of other preparations previously reported.

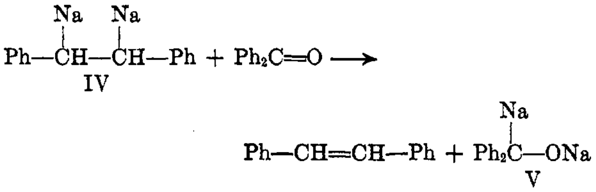
For an investigation[2] of the benzilic ester rearrangement a synthesis of this type of ester labeled with C^{14} was needed. One possibility (which could utilize readily available C^{14}-labeled carbon dioxide) conceived for synthesis (1) of the corresponding benzilic acid (III) involved carbonation of the dimetallo adduct II produced by reaction of a diaryl ketone (I) with alkali metal (M). To evaluate this possibility a fairly extensive study was made of the optimum conditions



$$\underset{\mathrm{I}}{\mathrm{Ar_2C{=}O}} \xrightarrow{2\mathrm{M}} \underset{\mathrm{II}}{\mathrm{Ar_2}\overset{\mathrm{M}}{\overset{|}{\mathrm{C}}}\mathrm{{-}OM}} \xrightarrow[2.\ \mathrm{H^+}]{1.\ \mathrm{CO_2}} \underset{\mathrm{III}}{\mathrm{Ar_2}\overset{\mathrm{HO}}{\overset{|}{\mathrm{C}}}\mathrm{{-}}\underset{\mathrm{O}}{\underset{\|}{\mathrm{C}}}\mathrm{OH}} \qquad (1)$$

for preparation of, and the various possible reactions of, these metallo adducts (II). While our investigation of the benzilic ester rearrangement was in progress, Hamrick and Hauser reported certain other synthetic utilizations of adducts like II.[3] Our study, which complements that of Hamrick and Hauser, and a brief summation of earlier studies are recorded here to indicate that these adducts are conveniently accessible reagents of utility in several types of preparations.[4]

The disodio adducts (II, M = Na) were first formed by Schlenk and co-workers[5] using ether as solvent and later by Wooster[6] using liquid ammonia. Brook, Cohen, and Wright[7] effected a novel preparation of the disodio adduct of benzophenone (V) by transfer of sodium from the analogous adduct of stilbene (IV).



$$\underset{\mathrm{IV}}{\mathrm{Ph{-}}\overset{\mathrm{Na}}{\overset{|}{\mathrm{C}}}\mathrm{H{-}}\overset{\mathrm{Na}}{\overset{|}{\mathrm{C}}}\mathrm{H{-}Ph}} + \mathrm{Ph_2C{=}O} \longrightarrow \mathrm{Ph{-}CH{=}CH{-}Ph} + \underset{\mathrm{V}}{\mathrm{Ph_2}\overset{\mathrm{Na}}{\overset{|}{\mathrm{C}}}\mathrm{{-}ONa}} \qquad (2)$$

Benzilic Acid Synthesis.—The usual time required for adduct II formation in ether was reported to be several days.[5] Since facile formation of other types of organometallics by direct reaction of sodium metal in 1,2-dimethoxyethane has been reported,[7,8] this was the first solvent we evaluated as a medium for reaction of alkali metals and diaryl ketones. In exploratory experiments, mixtures of benzophenone and 2 equiv. of alkali metal in dimethoxyethane were allowed to react and then treated with carbon dioxide (eq. 1). Some of the results are summarized in Table I.

When sodium was employed as a suspension, the densely colored (purple) adduct formed rapidly and, after carbonation, a 60–65% yield of benzilic acid was obtained. The adduct formed rapidly even when the metal was present in small chunks; the yield of benzilic acid was approximately the same (45–60%)

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[1] Union Carbide Nuclear Corp. Fellow, 1958–1959.

[2] J. F. Eastham and S. Selman, *J. Org. Chem.*, **26**, 293 (1961).

[3] P. J. Hamrick, Jr., and C. R. Hauser, *J. Am. Chem. Soc.*, **81**, 493 (1959).

[4] Accessibility of adducts II stems from the variety of syntheses available for preparation of diaryl ketones, *e.g.*, Friedel–Craft reactions, polyphosphoric acid and hydrogen fluoride acylations.

[5] W. Schlenk and T. Weickel, *Ber.*, **44**, 1183 (1911); W. Schlenk and A. Thal, *ibid.*, **46**, 2840 (1913); W. Schlenk, J. Appenrodt, A. Michael, and A. Thal, *ibid.*, **47**, 473 (1914); W. Schlenk and E. Bergmann, *Ann.*, **464**, 26 (1928).

[6] C. B. Wooster, *J. Am. Chem. Soc.*, **50**, 1388 (1928); see also C. A. Kraus and G. F. White, *ibid.*, **45**, 771 (1923).

[7] A. G. Brook, H. L. Cohen, and G. F. Wright, *J. Org. Chem.*, **18**, 447 (1953).

[8] N. D. Scott, J. F. Walker, and V. L. Hansley, *J. Am. Chem. Soc.*, **58**, 2442 (1936).

TABLE I

SYNTHESIS OF BENZILIC ACIDS FROM ALKALI METAL ADDUCTS OF DIARYL KETONES PREPARED IN DIMETHOXYETHANE

Ar groups of starting ketone (I)	Metal and its state	Metal–ketone reaction		Yield of acid (III), %
		Temp.	Time, hr.	
$(Ph)_2$	Na suspension	Room temp.	4	64
$(Ph)_2$	Na chunks	Reflux	2	45
$(Ph)_2$	Na chunks	Room temp.	72	50
$(Ph)_2$	Li chunks	Room temp.	48	26
$(Ph)_2$	Li adduct IV	Room temp.	2	57
Ph, 2-PhC_6H_4	Li adduct IV	Room temp.	2	21
Ph, 4-$CH_3OC_6H_4$	Li adduct IV	Room temp.	2	6
Ph, 4-$CH_3OC_6H_4$	Na chunks	Room temp.	4	0
Ph, 4-$CH_3C_6H_4$	Na chunks	Room temp.	4	41
3-$CH_3C_6H_4$, 4-$CH_3C_6H_4$	Na chunks	Room temp.	4	55
(4-$CH_3OC_6H_4)_2$	Na chunks	Room temp.	4	0

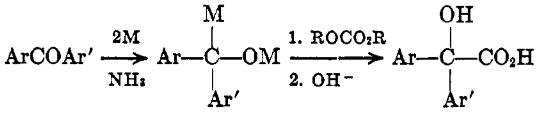
whether the mixture of benzophenone, sodium, and 1,2-dimethoxyethane was refluxed for 2 hr. or stirred for 4 hr. or 3 days prior to carbonation. The method of carbonation, *i.e.*, passing in gaseous carbon dioxide or pouring the reaction mixture into Dry Ice, had no effect on the yield of acid. The presence of sodium in excess of the theoretically required amount also had no effect. As an alternative to carbonation, treatment of disodiobenzophenone with ethyl chloroformate in dimethoxyethane gave, after saponification, only 14% yield of benzilic acid.

Yields of benzilic acid were not so good with the other alkali metals as with sodium; *e.g.*, reaction of benzophenone with lithium and then with carbon dioxide gave only 26% acid. However, when dilithiobenzophenone was prepared by the treatment of benzophenone with stilbene–dilithium adduct in 1,2-dimethoxyethane, *cf.* eq. 2, the yield of benzilic acid upon carbonation was 57%.

The utility of reaction of diaryl ketones with sodium and then carbon dioxide in dimethoxyethane has been demonstrated by the synthesis of 4-methylbenzilic acid, 3,4′-dimethylbenzilic acid, and 2-phenylbenzilic acid. The synthesis of 3,4′-dimethylbenzilic acid or any benzilic acid with substituents in different positions in each ring would be a tedious procedure by other methods. A previously reported method of synthesis of 2-phenylbenzilic acid was from 2-phenylphenylmagnesium iodide and ethyl phenylglyoxylate,[9] but subsequent difficulty was encountered in the synthesis of this acid by this Grignard method and by two other methods.[10]

Method of synthesis 1 was not satisfactory for methoxy-substituted benzilic acids. Carbonation of the purple solution produced from stilbene–disodium adduct and 4-methoxybenzophenone in 1,2-dimethoxyethane produced only a 6% yield of 4-methoxybenzilic acid. When 4-methoxybenzophenone was treated with sodium directly, no acid was obtained. Several attempts were made to prepare anisilic acid from 4,4′-dimethoxybenzophenone and each of the alkali metals (or their stilbene adducts), but none was successful.

The other solvent of apparent utility for this study, liquid ammonia, reacts with carbon dioxide and prevents its use for direct carbonation of the dimetallo adducts. Diethyl carbonate, though, can be added directly to the liquid ammonia solution, and the organic product then can be saponified. This technique, illustrated in eq. 3, effected the synthesis of benzilic



$$\underset{\text{I}}{ArCOAr'} \xrightarrow[NH_3]{2M} \underset{\text{II}}{Ar\text{—}\overset{M}{\underset{Ar'}{C}}\text{—}OM} \xrightarrow[2.\ OH^-]{1.\ ROCO_2R} \underset{\text{III}}{Ar\text{—}\overset{OH}{\underset{Ar'}{C}}\text{—}CO_2H} \quad (3)$$

acid, 4-methylbenzilic acid, and 4,4′-dimethylbenzilic acid from the corresponding ketones in yields of 50–70%. 4,4′-Dimethoxybenzophenone yielded no acid by this technique. Results are summarized in Table II.

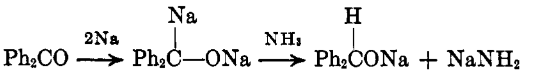
TABLE II

SYNTHESIS OF BENZILIC ACIDS FROM ALKALI METAL ADDUCTS OF DIARYL KETONES PREPARED IN LIQUID AMMONIA

Ar groups of starting ketone I	Metal in NH_3 soln.	Metal–ketone reaction time, min.	Yield of acid (III), %
$(Ph)_2$	Na	10	67
$(Ph)_2$	Na	60	25
Ph, 4-$CH_3C_6H_4$	Na	10	70
Ph, 4-$CH_3C_6H_4$	K	10	49
Ph, 4-$CH_3C_6H_4$	Li	10	0[a]
Ph, 4-$CH_3C_6H_4$	Li	120	0[b]
(4-$CH_3C_6H_4)_2$	Na	10	51
(4-$CH_3OC_6H_4)_2$	Na	10	0[c]

[a] A 60% yield of 4-methylbenzhydrol was isolated. [b] An 80% yield of 4-methylbenzhydrol was isolated. [c] A 44% yield of 4,4′-dimethoxybenzhydrol was isolated.

It was found that the nature of the alkali metal employed has a profound effect upon the yield of the benzilic acid obtained in accordance with eq. 3. The use of potassium in place of sodium in the transformation of 4-methylbenzophenone into 4-methylbenzilic acid decreased the yield from 70 to 49%. When lithium was used, no 4-methylbenzilic acid was found, but there was obtained considerable 4-methylbenzhydrol, a reduction product. This type of reduction product was found to some extent in almost all reactions involving an alkali metal and a benzophenone in liquid ammonia. The yield of this reduction product was found to increase as the time between the addition of the ketone and the addition of the alkyl carbonate to the alkali metal–ammonia solution was increased. Almost surely, reduction occurred as shown in eq. 4. Thus it is logical that of the three alkali



$$Ph_2CO \xrightarrow{2Na} Ph_2\overset{Na}{C}\text{—}ONa \xrightarrow{NH_3} Ph_2\overset{H}{C}ONa + NaNH_2 \quad (4)$$

metals used, the least effective for benzilic acid synthesis, lithium, possesses the largest reduction potential while the most effective, sodium, possesses the smallest reduction potential.

Ester Synthesis.—Esters themselves may be isolated in good yield from reactions of sodium and benzophenone in ammonia with carbonates. The reaction of disodiobenzophenone with dimethyl carbonate gave methyl benzilate in 70% yield. Preparations of multifunctional esters in an analogous manner constitute the most striking illustrations of the utility of the dimetallo adducts. Thus, 2-diethylaminoethyl benzilate was isolated in 77% yield from reaction of sodium and benzophenone in ammonia with bis-2-diethylamino-

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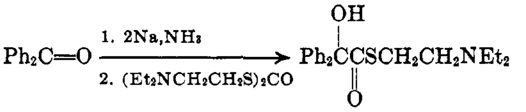
(9) C. F. Koelsch, *J. Am. Chem. Soc.*, **56**, 480 (1934).

(10) C. A. Buehler, H. A. Smith, D. M. Glenn, and K. V. Nayak, *J. Org. Chem.*, **23**, 1432 (1958).

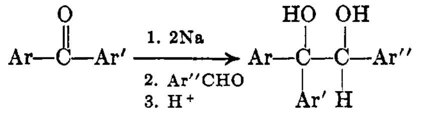
ethyl carbonate. The technique was extended to the use of bis-2-diethylaminoethyl thiocarbonate[11] and disodiobenzophenone for the preparation of diethylaminoethyl thiobenzilate (VI).



$$\mathrm{Ph_2C{=}O \xrightarrow[2.\ (Et_2NCH_2CH_2S)_2CO]{1.\ 2Na,NH_3} Ph_2C(OH)C({=}O)SCH_2CH_2NEt_2}$$

VI

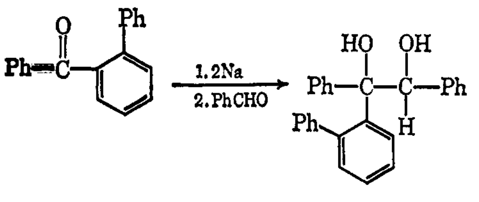
Glycol Synthesis.—Aldehydes react with the disodio adducts to give glycols. Thus we obtained 1,1-diphenyl-2-*p*-anisylethylene glycol (22% yield) from reaction of anisaldehyde with disodiobenzophenone in dimethoxyethane, while Hamrick and Hauser[3] obtained triphenylethylene glycol (91% yield) from the analogous reaction of benzaldehyde in ammonia. In the general case of this triarylethylene glycol synthesis, in which the three aryl groups could be different, eq. 5, two pairs of diastereomers could be produced.



$$\mathrm{Ar{-}C({=}O){-}Ar' \xrightarrow[2.\ Ar''CHO;\ 3.\ H^+]{1.\ 2Na} Ar{-}C(OH)(Ar'){-}C(OH)(H){-}Ar''} \qquad (5)$$

Thus reaction of sodium, 4-methylbenzophenone, and anisaldehyde in ammonia yielded 1-phenyl-1-*p*-tolyl-2-*p*-anisylethylene glycol which has the proper spectral properties and elemental analysis, but which has a 10° melting point range (somewhat variable with recrystallization) and is apparently the expected mixture of diastereoisomers.

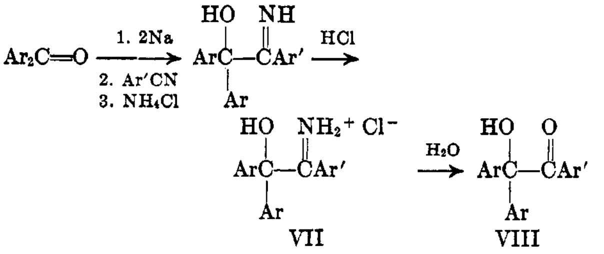
It seemed worthwhile to determine if a bulky group in the 2-position of one of the aryl groups in the organometallic would cause a stereospecific reaction in the synthesis of glycols by eq. 5. The reaction of sodium, 2-methylbenzophenone, and anisaldehyde in ammonia did yield 1-phenyl-1-*o*-tolyl-2-*p*-anisylethylene glycol, but still of melting point characteristics indicative of a mixture of diastereomers. Similar results were obtained from reaction of sodium, 2-phenylbenzophenone, and benzaldehyde in ammonia; *i.e.*, the glycol produced had a melting point range variable with recrystallization. However, this latter reaction, eq. 6, carried out in 1,2-dimethoxyethane gave a sharp melting 1-(2-biphenylyl)-1,2-diphenylethylene glycol (21% yield).



(6)

The possibility suggested by this last result, *i.e.*, that dimethoxyethane as solvent allows a stereospecificity in the synthesis (5) of glycols (while liquid ammonia does not), has not been further investigated, but this possibility would seem to hold promise. Even for the synthesis of glycols with one asymmetric center, though, reaction 5 is more convenient than those formerly used.[12]

Benzoin Synthesis.—The final reaction attempted with the disodio adducts was with nitriles in the α-arylbenzoin (VIII) synthesis outlined below. Unequivocal synthesis of α-arylbenzoins has been difficult to accomplish because these compounds undergo molecular rearrangement in the presence of alkali[13]; the obvious synthesis of this type compound, inverse addition of a Grignard reagent to benzil, also may proceed with rearrangement[14]; and finally, despite their molecular weight and polar functional groups, they are low melting and uncommonly difficult to crystallize.[15] Success in this synthesis (7) was achieved; sodium and benzophenone in ammonia reacted with *p*-tolunitrile to yield the expected ketimine (59% yield) isolated as its crystalline hydrochloride (VII, Ar = phenyl; Ar′ = *p*-tolyl). Hydrolysis of the latter gave α-phenyl-4-methylbenzoin. Use of anisonitrile in the synthesis gave α-phenyl-4-methoxybenzoin (VIII, Ar = phenyl; Ar′ = *p*-anisyl). These new benzoins were obtained crystalline and had the proper spectroscopic properties and reasonable elemental analyses, but they showed the previously noted[15] puzzling resistance to recrystallization.

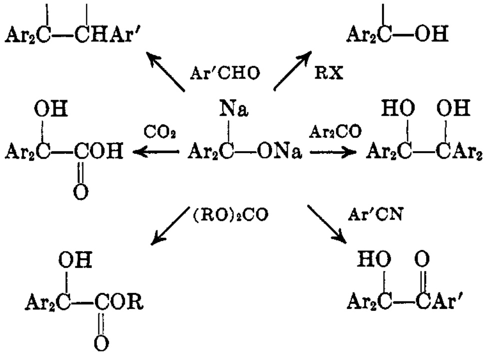


$$\mathrm{Ar_2C{=}O \xrightarrow[2.\ Ar'CN;\ 3.\ NH_4Cl]{1.\ 2Na} ArC(OH)(Ar){-}C({=}NH)Ar' \xrightarrow{HCl} \underset{VII}{ArC(OH)(Ar){-}C({=}NH_2^+\,Cl^-)Ar'} \xrightarrow{H_2O} \underset{VIII}{ArC(OH)(Ar){-}C({=}O)Ar'}} \qquad (7)$$

α-Phenylbenzoin itself was prepared in an analogous manner, but an attempt to obtain α-anisyl-4-methoxybenzoin was unsuccessful. Our uniform lack of success in all syntheses attempted with the methoxy-substituted sodio adducts is not easily rationalized.

Summary.—The number of successful reactions now known for the disodio adducts of diaryl ketones (and the ready availability of the latter) indicates a potential utility for this type of organometallic compound in selected preparative problems. Products available from reaction of these organometallic compounds are summarized in Chart I. The solvent of choice for most preparations is ammonia, in which the metallo adduct forms essentially instantaneously, but the less reactive solvent dimethoxyethane allows the adduct to form in a reasonable time and is superior to ammonia

CHART I



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[11] R. L. Wells, Jr., M.S. Thesis, University of Tennessee, 1961.

[12] J. F. Eastham and D. J. Feeney, *J. Org. Chem.*, **23**, 1826 (1958).

[13] S. Selman and J. F. Eastham, *Quart. Rev.* (London), **14**, 221 (1960).

[14] J. F. Eastham, J. E. Huffaker, V. F. Raaen, and C. J. Collins, *J. Am. Chem. Soc.*, **78**, 4323 (1956).

[15] This synthetic difficulty is briefly discussed in ref. 12, footnotes 3 and 5. In the present synthesis (7), it is felt that success was facilitated by the ability to isolate and purify the intermediate ketimine through its salt VII.

for carbonation. In ammonia the coreactant for the organometallic compound should be added immediately after mixing metal and ketone to minimize reduction reactions. In Chart I, new products of the metallo adducts found in this work were esters and benzoins (also ketimines) and known products further studied were acids and glycols. The alkylation with an organic halide shown in the chart was studied by Hamrick and Hauser.[3]

Experimental Section

Unless otherwise specified in the following, alkali metals were added to reaction mixtures in small pieces, *ca.* 0.25 cm.^{3}; in some cases sodium was prepared as a suspension, each time as described in the next paragraph. To ensure that it was anhydrous, just before its use, 1,2-dimethoxyethane was redistilled from a mixture of sodium and benzophenone. Ammonia was distilled from its storage tank through a column of anhydrous barium oxide and into one neck of a three-neck reaction flask; to the other two necks of this flask were attached, respectively, a pressure-equalizing dropping funnel and a Dry Ice filled cold finger, which condensed the ammonia into the flask and which in turn was attached to a manostat. Elemental analyses were performed by Weiler and Strauss Microanalytical Laboratory, Oxford, England.

Synthesis of Benzilic Acids in 1,2-Dimethoxyethane.—A mixture of sodium (1.84 g., 0.080 g.-atom) and 50 ml. of anhydrous toluene contained in a 100-ml., nitrogen-filled flask equipped with a reflux condenser and a magnetic stirrer was heated to reflux. The mixture was vigorously stirred and allowed to cool to room temperature. The toluene was decanted from the finely divided sodium, which was washed twice with anhydrous ether, and to it was added 50 ml. of anhydrous 1,2-dimethoxyethane and benzophenone (3.64 g., 0.020 mole). The resulting mixture was stirred for 4 hr. under nitrogen and the resulting purple solution was decanted onto an excess of Dry Ice. (There remained in the flask about 1 g. of sodium metal.) The solvent was evaporated and the residue was diluted with 100 ml. of water. The aqueous solution was washed with ether and acidified with hydrochloric acid. **Benzilic acid**, 2.83 g. (64% yield), m.p. 146–148°, crystallized directly from the solution.

In another run similar to this one, a mixture of sodium (1.44 g., 0.063 g.-atom) cut into small pieces, and benzophenone (5.47 g., 0.030 mole) in 100 ml. of dimethoxyethane was refluxed for 2 hr. Carbon dioxide was passed through the cooled purple reaction mixture and decolorization occurred within 3 min. Evaporization of the solvent, dilution with water, and work-up as before gave 3.0 g. (45%) of benzilic acid. In another run the sodium and benzophenone were stirred together 3 days at room temperature before carbonation and a 50% yield of benzilic acid was obtained. In another run, after 4-hr. reflux of sodium (0.76 g., 0.033 g.-atom) and benzophenone (3.0 g., 0.016 mole), ethyl chloroformate (2.0 g., 0.018 mole) was added to the dimethoxyethane; the aqueous solution obtained in the work-up of this run was made 5% in sodium hydroxide and refluxed before continuing the usual work-up, which then yielded 0.5 g. (14%) of benzilic acid. In a run involving lithium (in place of sodium), the metal (0.30, 0.043 g.-atom) and benzophenone (1.82 g., 0.01 mole) were stirred together 48 hr. before the resulting purple solution was poured onto Dry Ice and worked up as before, to yield 0.6 g. of benzilic acid (26%).

In another variation involving lithium, the metal (0.5 g., 0.072 g.-atom) and stilbene (1.8 g., 0.01 mole) were stirred in 59 ml. of dimethoxyethane for 24 hr. under nitrogen. To this mixture was added a solution of benzophenone (1.82 g., 0.010 mole) in 10 ml. of 1,2-dimethoxyethane and the resulting purple mixture was stirred for 2 hr. The nitrogen atmosphere was replaced by a carbon dioxide atmosphere and decolorization of the mixture occurred in a few minutes. The mixture was diluted with water, acidified with hydrochloric acid, and extracted with ether. The combined ethereal extract was extracted with 10% sodium carbonate until no more solid appeared upon acidification of the basic extract. The acidified basic extracts were combined and filtered and the product crystallized to give 1.3 g. of benzilic acid (57%).

Preparation of **4-methylbenzilic acid** was effected by the general procedure outlined above using a suspension of sodium. A mixture of sodium (0.71 g., 0.031 g.-atom), 4-methylbenzophenone (3.0 g., 0.015 mole), and 50 ml. of dimethoxyethane was stirred and refluxed for 4 hr. under nitrogen. The resulting purple mixture was cooled and poured onto excess Dry Ice and allowed to come to room temperature. The solvent was evaporated and the residue was diluted with water. The aqueous mixture was washed with ether and acidified with hydrochloric acid and cooled. The crystals were collected and recrystallized from benzene–hexane to yield 1.5 g. (41%) of 4-methylbenzilic acid, m.p. 132–133° (lit.[16] m.p. 132°) with or without admixture of an authentic sample.

Preparation of **3,4′-dimethylbenzilic acid** was effected in an exactly analogous manner from 3,4′-dimethylbenzophenone (prepared from reaction of *m*-toluic acid with toluene in polyphosphoric acid) in 55% yield, m.p. 132.0–132.5°.

Anal. Calcd. for $C_{16}H_{13}O_3$: C, 74.98; H, 6.29. Found: C, 75.0; H, 6.38.

Preparation of **2-phenylbenzilic acid** was effected from a mixture of lithium (0.14 g., 0.020 g.-atom), 25 ml. of 1,2-dimethoxyethane, and stilbene (1.39 g., 0.0077 mole), which was stirred for 7 hr. under nitrogen and added to a solution of 2-phenylbenzophenone (2.00 g., 0.0077 mole) in 15 ml. of 1,2-dimethoxyethane. The resulting blue mixture was poured onto excess Dry Ice and worked up in the usual manner to give 0.50 g. (21%) of 2-phenylbenzilic acid, m.p. 188–190° dec. (lit.[17] m.p. 189–191° dec). Because an authentic sample of this acid was not available for comparison, a sample of it was decarboxylated by heating with chromium trioxide in acetic acid to give the known 2-phenylbenzophenone, m.p. 86.5–88.0° with or without admixture of an authentic sample.

Preparation of **4-methoxybenzilic acid** was effected, but in only 6% yield, in an exactly analogous manner from 4-methoxybenzophenone. When the preparation was attempted through direct reaction of this ketone with sodium (*i.e.*, no stilbene adduct intermediate), no 4-methoxybenzilic acid resulted. Attempts to prepare 4,4′-dimethoxybenzilic acid from 4,4′-dimethoxybenzophenone were unsuccessful under a variety of reaction conditions analogous to those just outlined.

Synthesis of Benzilic Acids Using Liquid Ammonia.—To a stirred solution of sodium (1.17 g., 0.051 g.-atom) in 200 ml. of liquid ammonia there was added dropwise during *ca.* 10 min. a solution of 4-methylbenzophenone (5.00 g., 0.025 mole) in 50 ml. of anhydrous ether. Immediately upon completion of the addition of the 4-methylbenzophenone solution there was added dropwise to the deep purple reaction mixture a solution of diethyl carbonate (3.01 g., 0.025 mole) in 50 ml. of anhydrous ether. The resulting light blue solution was refluxed for 1 hr. and cautiously treated with solid ammonium chloride (2.73 g., 0.051 mole). The ammonia was evaporated and anhydrous ether was added to the residue. The ethereal mixture was filtered and the ether was evaporated to leave an oil which was taken up in 25 ml. of ethanol and mixed with 2.5 g. of potassium hydroxide in 25 ml. of water. The resulting solution was refluxed for 90 min., cooled, diluted with 50 ml. of water, washed with ether, acidified with hydrochloric acid, and cooled. The crystals which appeared were recrystallized from benzene–hexane to give 4.3 g. (70%) of **4-methylbenzilic acid**, m.p. 133–134°, undepressed by admixture of an authentic sample.

The preceding reaction was repeated using potassium metal (1.99 g., 0.051 g.-atom) instead of sodium. The yield was 3.0 g. (49%) of 4-methylbenzilic acid.

The preceding reaction was repeated using lithium metal (0.35 g., 0.051 mole). In the work up, the aqueous–alcoholic saponification solution of product was refluxed 90 min., cooled, extracted with ether, and acidified in the usual manner, but no acid crystallized. The ethereal extract was dried over magnesium sulfate and evaporated to an oil which solidified when stirred. The solid was recrystallized from hexane to give 3.0 g. (60%) of 4-methylbenzhydrol, m.p. 49–51° (lit.[18] m.p. 52–53°), undepressed by admixture of an authentic sample. This reaction was repeated with the exception that the ammoniacal solution of lithium and 4-methylbenzophenone was refluxed for 2 hr. prior to the addition of the diethyl carbonate solution. During this reflux period, the color of the solution turned from the deep purple to light blue and a white precipitate appeared. In the work-up

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(16) A. H. Ford-Moore, *J. Chem. Soc.*, 952 (1947).

(17) C. F. Koelsch, *J. Am. Chem. Soc.*, **56**, 480 (1934).

(18) E. Fischer and O. Fischer, *Ann.*, **194**, 265 (1878).

saponification was not even attempted and 4-methylbenzhydrol, 4.0 g., m.p. 51.0–52.5°, was isolated in 80% yield.

Preparation of **4,4′-dimethylbenzilic acid**, m.p. 132–133° (lit.[19] m.p. 131–132°), was effected in 51% yield from 4,4′-dimethylbenzophenone by a procedure exactly analogous to that described above using sodium in liquid ammonia. **Benzilic acid** itself was obtained by this procedure from benzophenone in 67% yield. **4,4′-Dimethoxybenzilic acid** preparation was attempted by this procedure from 4,4′-dimethoxybenzophenone, but the only isolable product was 4,4′-dimethoxybenzhydrol, m.p. 70–71° (lit.[20] m.p. 72°), in 44% yield.

Synthesis of Benzilic Esters Using Liquid Ammonia.—To a stirred solution of sodium (2.3 g., 0.10 g.-atom) in 200 ml. of liquid ammonia there was added dropwise a solution of benzophenone (9.1 g., 0.05 mole) in 50 ml. of ether. Immediately upon completion of the addition of the benzophenone solution, there was added to the purple reaction mixture a solution of dimethyl carbonate (4.51 g., 0.050 mole) in 50 ml. of ether. After the resulting blue solution was refluxed for 1 hr., solid ammonium chloride (5.35 g., 0.10 mole) was cautiously added to it. The ammonia was evaporated and anhydrous ether was added to the residue. The ethereal mixture was filtered and the ether was evaporated from the filtrate leaving 11 g. of solid yellowish residue which was recrystallized from hexane to give 8.40 g. (70%) of **methyl benzilate**, m.p. 69.5–71.0° with or without admixture of an authentic sample.

Preparation of **2-diethylaminoethyl benzilate** was effected in an exactly analogous manner from a solution of sodium (0.88 g., 0.038 g.-atom), benzophenone (3.50 g., 0.019 mole), and 50 ml. of ether, in 200 ml. of ammonia, to which was added 2-diethylaminoethyl carbonate (5.0 g., 0.019 mole) in 50 ml. of ether. Work-up as before yielded from the usual ether solution an oil, from which ammonia, alcohol, and unreacted carbonate were evaporated under vacuum. This oil was redissolved in anhydrous ether and cooled to 0° while anhydrous hydrochloric acid was bubbled through it. A dense white precipitate was collected and washed several times with anhydrous ether to yield 2.70 g. (77%) of 2-diethylaminoethyl benzilate hydrochloride, m.p. 173–175° with or without admixture of an authentic sample.

Synthesis of Triarylethylene Glycols in 1,2-Dimethoxyethane.—A mixture of lithium (0.28 g., 0.040 g.-atom), 2-phenylbenzophenone (4.00 g., 0.0155 mole), and 50 ml. of 1,2-dimethoxyethane contained in a 100-ml., nitrogen-filled flask was stirred for 29 hr. To this mixture was added dropwise a solution of benzaldehyde (1.64 g., 0.0155 mole) in 10 ml. of 1,2-dimethoxyethane. The resulting mixture was refluxed for 6 hr. under nitrogen, cooled, poured onto excess Dry Ice, and allowed to come to room temperature. The solvent was evaporated and the residue was diluted with 100 ml. of water and extracted twice with ether. The combined ethereal extract was dried and evaporated to leave an oil which was recrystallized from methanol to give 1.2 g. (21% yield) of **1-(2-biphenyl)-1,2-diphenylethylene glycol**, m.p. 176–177°.

Anal. Calcd. for $C_{26}H_{22}O_2$: C, 85.21; H, 6.05. Found: C, 85.32; H, 5.71.

For proof of structure, a solution of 1-(2-biphenylyl)-1,2-diphenylethylene glycol (100 mg., 0.27 mmole) in 3 ml. of warm glacial acetic acid was added to a solution of chromium trioxide (64 mg., 0.64 mmole) in 2 ml. of glacial acetic acid containing 2 drops of water. The resulting solution was heated on a steam bath for 1 hr. and diluted with 15 ml. of water. The aqueous mixture was extracted with two 20-ml. portions of ether. The combined ethereal extract was washed with water, extracted several times with aqueous potassium hydroxide, washed again with water, dried, and evaporated. The solid residue was recrystallized from methanol to give 30 mg. (43%) of 2-phenylbenzophenone, m.p. 86–87° with or without admixture of an authentic sample. The combined basic aqueous extract was acidified with hydrochloric acid, cooled, and extracted twice with ether. The combined ethereal extract was dried and evaporated to leave a solid which was vacuum sublimed (100° and 1 mm.) to give 20 mg. (60%) of benzoic acid, m.p. 118–120° with or without admixture of an authentic sample.

Preparation of **1,1-diphenyl-2-*p*-anisylethylene glycol** was effected in an analogous manner except that a suspension of sodium (rather than lithium) was allowed to react with the benzophenone (1.82 g., 0.01 mole) in dimethoxyethane. After 24 hr., anisaldehyde (1.45 g., 0.01 mole) was added to the mixture. Solvent was evaporated by a stream of dry air (in contrast to the usual evaporation under vacuum); the residue was diluted with 50 ml. of water. The aqueous mixture was extracted twice with benzene–ether, acidified with hydrochloric acid, cooled, and filtered to give 0.7 g. of crude anisic acid, m.p. 177° with or without admixture of an authentic sample. The combined benzene–ether extract was filtered and partially evaporated to crystallize 0.70 g. (22%) of 1,1-diphenyl-2-anisylethylene glycol, m.p. 203.5–204.0°, undepressed by admixture of an authentic sample.[12]

Synthesis of Triarylethylene Glycols in Liquid Ammonia.—To the purple solution of 4-methylbenzophenone (7.84 g., 0.040 mole) and sodium (1.84 g., 0.080 g.-atom) in 250 ml. of ammonia and 50 ml. of ether there was added a solution of anisaldehyde (5.44 g., 0.040 mole) in 50 ml. of ether. The resulting light blue solution was refluxed for 1 hr., treated with solid ammonium chloride (4.28 g., 0.080 mole), and evaporated. Ether was added to the residue, which was then filtered, and the ether was evaporated from the filtrate until only 30 ml. remained. The solution was cooled and filtered to yield 3.0 g. of material with m.p. 148–158°, which melting point varied when recrystallized from benzene, but did not sharpen. Ultraviolet, infrared, and n.m.r. spectra and elemental analysis agreed with this material being *dl-threo-* and ***dl-erythro*-1-phenyl-1-*p*-tolyl-2-*p*-anisylethylene glycol**.

Anal. Calcd. for $C_{22}H_{22}O_3$: C, 79.01; H, 6.63. Found: C, 78.74; H, 6.55.

A mixture of the diastereoisomers of **1-phenyl-1-*o*-tolyl-2-*p*-anisylethylene glycol** was prepared in an exactly analogous manner starting with 2-methylbenzophenone (5.0 g., 0.025 mole), rather than the 4-methyl isomer. There was obtained 2.0 g. of the glycol, m.p. 183–188°, variable with repeated recrystallization.

Anal. Calcd. for $C_{22}H_{22}O_3$: C, 79.01; H, 6.63. Found: C, 79.26; H, 6.42.

Preparation of **1-(2-biphenylyl)-1,2-diphenylethylene glycol** was attempted by this procedure from 2-phenylbenzophenone, but the only isolable crystalline product melted over a range (121–124°) below the melting point already found (176–177°) for this glycol prepared in dimethoxyethane, although the elemental analyses of the two agreed.

Synthesis of α-Arylbenzoins Using Liquid Ammonia.—To a stirred solution of benzophenone (3.64 g., 0.020 mole) and sodium metal (0.90 g., 0.039 g.-atom) in 250 ml. of liquid ammonia, there was added *p*-tolunitrile (2.34 g., 0.020 mole). The resulting solution was refluxed for 6 hr. and treated with ammonium chloride (2.14 g., 0.040 mole). The ammonia was evaporated and the residue was refluxed with ether, which was then cooled and filtered. The filtrate was cooled to 0° and kept at this temperature while anhydrous hydrochloric acid was passed through it. The dense white precipitate which appeared (4 g.) was filtered and washed with ether. One gram of this precipitate was dissolved in ethanol and recrystallized by the addition of anhydrous ether to give **α-phenyl-4-methylbenzoin ketimine hydrochloride**, m.p. 170–174°.

Anal. Calcd. for $C_{21}H_{20}ClNO$: C, 74.66; H, 5.97; Cl, 10.50; N, 4.15. Found: C, 74.61; H, 6.16; Cl, 11.4; N, 4.87.

To 1.0 g. of the unrecrystallized hydrochloride was added 35 ml. of 20% hydrochloric acid and the resulting solution was refluxed for 30 min., during which time oil separated. The mixture was cooled and extracted twice with ether. The combined ethereal extract was dried and evaporated to an oil. The oil was dissolved in benzene–hexane and stored for 2 weeks at room temperature in such a manner as to allow very slow evaporation. The crystals which appeared under these circumstances could not be recrystallized in a conventional manner directly from a solution; the oil obtained when the solvent was evaporated in these attempted recrystallizations would crystallize when seeded. These crystals were collected, washed with hexane, and dried to give **α-phenyl-4-methylbenzoin**, m.p. 57.0–59.5°.

Anal. Calcd. for $C_{21}H_{18}O_2$: C, 83.42; H, 6.00. Found: C, 83.60; H, 6.18.

When vigorously oxidized (for technique see preparation of 1-(2-biphenylyl)-1,2-diphenylethylene glycol above), this benzoin yielded benzophenone and terephthalic acid.

In order to prepare α-phenyl-4-methoxybenzoin, the above procedure was repeated on a somewhat larger scale and with

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[19] V. Grignard, *Compt. rend.*, **135**, 1201 (1903).

[20] H. Schnackenberg and R. Scholl, *Ber.*, **36**, 655 (1903).

the addition of *p*-anisonitrile (6.65 g., 0.05 mole), instead of *p*-toluonitrile. The **α-phenyl-4-methoxybenzoin ketimine hydrochloride** (10 g.), precipitated in the indicated work-up, was recrystallized from ethanol–ether–chloroform and melted at 205–210° dec.

Anal. Calcd. for $C_{21}H_{20}ClNO_2$: C, 71.28; H, 5.70; Cl, 10.02; N, 3.96. Found: C, 70.75; H, 5.81; Cl, 9.51; N, 3.62.

To 5.0 g. of the precipitated hydrochloride was added 50 ml. of 18% hydrochloric acid and the resulting solution was refluxed for 6 hr. Upon cooling the aqueous acid was decanted from a crystalline mass which had formed. This solid was ground in a mortar and pestle, washed with water, and dried. The yield was 4.1 g. of product, m.p. 58–63°, which could not be crystallized from a variety of solvents, although the oil which separated from mixed solvents containing water would always eventually crystallize upon standing. Elemental analysis indicated that the material obtained this way is a hydrate of **α-phenyl-4-methoxybenzoin**.

Anal. Calcd. for $C_{21}H_{18}O_3 \cdot H_2O$: C, 74.98; H, 5.99. Found: C, 74.02; H, 5.99.

Preparation of the known **α-phenylbenzoin** and its ketimine were accomplished in an exactly analogous manner from benzophenone and benzonitrile. Attempts to prepare **α-anisyl-4-methoxybenzoin** in an analogous manner from *p*-methoxybenzophenone and anisonitrile were not successful.

Reductions with Metal Hydrides. XVIII. Reductions of Ketones with Lithium Aluminum Hydride–Aluminum Chloride and Hydride Transfer from the Resulting Alcohol Complexes[1]

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This paper is concerned with two types of reduction: (1) application of the previously described "mixed hydride" (probably $HAlCl_2$) reduction under conditions of kinetic and thermodynamic control to camphor and norcamphor (bicyclo[2.2.1]heptan-2-one), and (2) reductions with alkoxyaluminum dichlorides, $RR'CHOAlCl_2$, by hydride transfer. (1) In the mixed hydride reduction, under kinetic control, norcamphor gives 95–96% of the less stable *endo*-norborneol (rest *exo*) and camphor gives 66–71% of the less stable isoborneol (rest 10–11% borneol and 2–8% camphene), hydride approaching from the less hindered side in both cases. Equilibration of norborneols with excess ketone leads to 89–90% of the more stable *exo* isomer (rest *endo*), but fails in the case of isoborneol where dehydration to camphene occurs instead. An improved method of mixed hydride equilibration is described. (2) The alkoxyaluminum dichlorides formed from ketone (or alcohol) and mixed hydride in turn function as reducing agents. In $RR'CHOAlCl_2$ reduction, an I-strain series is observed in that the isobornyloxy derivative is a better reducing agent than cyclopentyloxy which, in turn, is better than cyclohexyloxyaluminum dichloride. Conversely, 4-*t*-butylcyclohexanone was reduced more readily than cyclopentanone or norcamphor; camphor was least readily reduced by alkoxyaluminum dichlorides. Isobornyloxyaluminum dichloride is a fairly stereoselective reducing agent in that it produces largely axial alcohols in the reduction of cyclohexanones. The reaction is synthetically useful for the stereoselective reduction of higher ketones, such as 3-cholestanone (whose reduction products can be readily freed of residual isoborneol).

Reductions and Equilibrations with Mixed Hydride.—In a previous publication[1] we have described the reduction of various cyclohexanones with lithium aluminum hydride–aluminum chloride ("mixed hydride", probably[2b,c] effectively $AlHCl_2$). Under conditions of kinetic control, mixtures are produced which are ordinarily richer in the less stable (axial) alcohol than those obtained with $LiAlH_4$ alone. Under conditions of thermodynamic control, *i.e.*, in the presence of a small excess of ketone (which provokes a reversible hydride transfer), the more stable (equatorial) alcohol results almost to the exclusion of its epimer.

We have now applied the reaction to camphor and norcamphor. Our results and those of the earlier work[2a] are summarized in Table I which, for the sake of comparison, also contains results of reduction with lithium aluminum hydride alone and of equilibration with aluminum alkoxide (Meerwein–Ponndorf–Oppenauer), the latter at slightly higher temperatures.

Table I

Ketone reduced	Stable alcohol	% equatorial or stable alcohol in product obtained by			
			$LiAlH_4$–$AlCl_3$		
		$LiAlH_4$	Kinetic	Thermodynamic	M-P-O[a]
4-*t*-Butylcyclohexanone	*trans*	89[b]	80[b]	99.5[b]	79[c]
4-Methylcyclohexanone	*trans*	81[c]	77[b]	92[b]	70[c]
4-Phenylcyclohexanone	*trans*	91[b]	86[b]	99[b]	79[b]
3-Cholestanone	β	91[d]	83[d]	100[d]	84[e]
3,3,5-Trimethylcyclohexanone	*cis*	45[f]	15[f]	100[f]	94[g]
Norcamphor	*exo*	9[h,i]	4[j]	89[j]	80[h]
Camphor	Borneol (*endo*)	10[k]	27[j]	*l*	71[h]

[a] Meerwein–Ponndorf–Oppenauer equilibration with aluminum isopropoxide–isopropyl alcohol–acetone. [b] Reference 2a. [c] E. L. Eliel and R. S. Ro, *J. Am. Chem. Soc.*, **79**, 5992 (1957). [d] Reference 3. [e] H. R. Nace and G. L. O'Connor, *J. Am. Chem. Soc.*, **73**, 5824 (1951). [f] Reference 4. [g] E. L. Eliel and H. Haubenstock, *J. Org. Chem.*, **26**, 3504 (1961). [h] C. F. Wilcox, M. Sexton, and M. F. Wilcox, *ibid.*, **28**, 1079 (1963). [i] R. Howe, E. C. Friedrich, and S. Winstein, *J. Am. Chem. Soc.*, **87**, 379 (1965). [j] This work. [k] D. S. Noyce and D. B. Denney, *J. Am. Chem. Soc.*, **72**, 5743 (1950). [l] Equilibration does not occur; isoborneol is destroyed and forms camphene.

The reduction of norcamphor proceeds normally. As in the instances earlier described[2a,3,4] mixed hydride gives less of the stable (*exo*) isomer under conditions of kinetic control than does $LiAlH_4$ (Chart I). Apparently steric hindrance to approach from the *endo* side (to give *exo* alcohol) is more severe for mixed hydride than for $LiAlH_4$. Equilibration of the nor-

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(1) Paper XVII: E. L. Eliel and J. Roy, *J. Org. Chem.*, **30**, 3092 (1965).

(2) (a) E. L. Eliel and M. N. Rerick, *J. Am. Chem. Soc.*, **82**, 1367 (1960); (b) E. L. Eliel, *Record Chem. Progr.* (Kresge-Hooker Sci. Lib.), **22**, 129 (1961); (c) see also E. L. Eliel and T. J. Brett, *J. Org. Chem.*, **28**, 1923 (1963).

(3) J.-C. Richer and E. L. Eliel, *ibid.*, **26**, 972 (1961).

(4) E. L. Eliel and H. Haubenstock, *ibid.*, **26**, 3504 (1961).