[Contribution from the Department of Chemistry, University of Oregon]

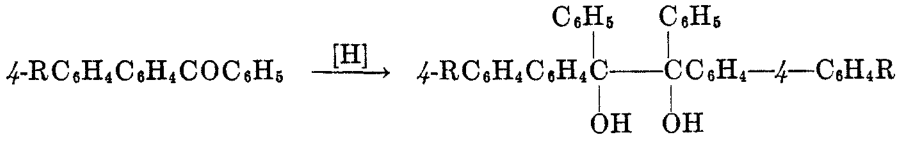
THE REDUCTION OF DIARYL KETONES TO STEREOISOMERIC BENZOPINACOLS

RUSSELL GAERTNER

Received March 13, 1950

In this report we wish to describe the isolation of a pair of stereoisomeric benzopinacols from each of two diaryl ketones, *p*-phenylbenzophenone (I) and 4-(*p*-anisyl)benzophenone (II), by the action of phenylmagnesium bromide containing unchanged magnesium. Some reactions of the products are considered.

p-Phenylbenzophenone (I) was added to a phenyl Grignard reagent which contained some unconverted metal, and two isomeric benzopinacols were easily isolated from the hydrolyzed reaction mixture. The more insoluble compound (IIIb), identified by analysis and thermal dismutation to the starting ketone, melted in thirty seconds at 206–207° (dec.) when placed in the bath at 205°. It should be mentioned that melting points of these compounds may vary considerably depending on the rate of heating and the temperature at which they are placed in the bath.



$$4\text{-}RC_6H_4C_6H_4COC_6H_5 \xrightarrow{[H]} 4\text{-}RC_6H_4C_6H_4\underset{OH}{\overset{C_6H_5}{C}}-\underset{OH}{\overset{C_6H_5}{C}}C_6H_4-4-C_6H_4R$$

I. R = H

II. R = p-CH_3O

III. R = H. *a.* m.p. 190°; *b.* m.p. 207°

IV. R = p-CH_3O. *a.* m.p. 177°; *b.* m.p. 206°.

The second isomer (IIIa), when heated slowly from room temperature, appeared to sinter slightly over a wide temperature range, finally melting at 188.5–190° (dec.). It is completely soluble in cold acetone and may be separated by virtue of this fact. If a sample is placed in the bath at 172°, liquefaction occurs (presumably with loss of benzene of solvation), the sample resolidifies, and then remelts at 188.5–190° as before, *p*-phenylbenzophenone being one of the products of decomposition.

Reduction of diaryl ketones or their precursors with a number of reagents has led to the isolation of presumably stereoisomeric benzopinacols. Among these are: sodium with 2,2′-dibenzoylbiphenyl (1) and *o*-phenylbenzophenone (2); the magnesium iodide-magnesium couple with the former ketone and *o*-chlorobenzophenone (3); the zinc-acetic acid couple with the latter compound (3) and *o*-phenylbenzophenone (2); and Grignard reagents (containing unchanged magnesium) with methyl *o*-phenylbenzoate (2) and ethyl *o*-chlorobenzoate (3).

There are many reports of the isolation of a single benzopinacol from the reaction of Grignard reagents with ketones (4–8); in some of these cases a pair of stereoisomers was theoretically possible. Besides the esters listed above, a single pinacol has been obtained in several instances by treatment of compounds of this class with Grignard reagents (9, 10).

The literature concerning the reduction of I is confusing. A single benzopinacol melting at 198° has been reported to be the product of the reaction of magnesium iodide and magnesium (7, 2) or with sodium (1). A form melting at 212° was obtained by Bergmann and Fujise (11), using *bis*-(*p*-dimethylaminophenyl)methane as the reducing agent. Later, Bergmann and Wolff (12) isolated still another substance, m.p. 181°, suggested as a possible stereoisomer, by subjecting α,β-epoxy-β,p-diphenylpropiophenone to the action of phenylmagnesium bromide. This work was repeated by Bachmann and Wiselogle (13) with entirely different results. From the epoxide, in the absence of magnesium, these authors were able to isolate either *p*-phenylbenzophenone in 60% yield or, with an excess of the reagent, *p*-phenyltriphenylcarbinol in 51% yield. In the presence of magnesium and magnesium bromide, there was obtained a 45% yield of the benzopinacol (m.p. 198°) previously reported from their laboratory. It should be pointed out that Bergmann and Wolff used one of a pair of stereoisomeric epoxides in their work while Bachmann and Wiselogle were able to obtain only a single product following the former authors' directions for the epoxidation of the corresponding chalcone. We believe that our high-melting pinacol (IIIb) is undoubtedly the 198° compound of Bachmann and Wiselogle (13) and probably is identical with the 212° isomer of Bergmann and Fujise (11). Furthermore, it seems likely that IIIa is the 181° compound of Bergmann and Wolff (12). These suppositions are strongly supported by the equilibration experiments to be described presently.

Details of the reduction of 4-(*p*-anisyl)benzophenone (II) to pinacols, a reaction which appears not to be recorded elsewhere, were quite analogous to those relating to the work with I. In this case, the less soluble isomer (IVb), m.p. 205–206°, was also characterized by analysis and by isolation of the starting ketone among its decomposition products, as was the lower-melting compound (IVa), m.p. 176–177.5°.

In view of the conflicting reports concerning the first pair of isomers, it seemed of interest to study the reduction of both ketones by the magnesium bromide-magnesium couple, both alone and followed by treatment of the mixture with phenyl Grignard reagent. The isomerization of a pinacol obtained by reduction of α-benzoylnaphthalene to a lower-melting isomer by ethylmagnesium bromide (14) and similar results with *sym*-di-*o*-chlorobenzopinacol by the action of phenyl Grignard reagent (3) have been reported.

Reduction of I with magnesium bromide and magnesium gave only the high-melting pinacol (IIIb), previously reported to be the sole product of reduction with the iodide reagent (7). However, on similar treatment, the anisyl compound (II) yielded a mixture of the two pinacols (IVb and IVa) in a weight ratio of 5.4:1. When phenylmagnesium bromide was formed in the reaction mixture after the ketone had been reduced, IIIa was obtained in greater amount than IIIb (2.4:1). Conversely, II formed largely IVb (6:1 of IVa).

Finally, each of the high-melting pinacols was equilibrated using phenylmagnesium bromide. IIIb was partially isomerized to give about an equal amount of IIIa. IVb was incompletely converted to IVa (2.4 IVb recovered to 1 IVa isolated). Although it appears that these data indicate that equilibration was not consistently complete, they explain qualitatively the mode of formation of stereoisomers, and appear to offer a means of reconciling the previously-discussed disagreement in the literature on this subject. It was early recognized that pinacolates dissociate to ketyls (7); it seems but a step to suppose that this radical may invert and reassociate.

In the course of characterization of these two pairs of isomeric compounds, the ultraviolet absorption spectra were determined. They are presented in Figure 1. It is to be noted that in both cases there is a consistent bathochromic shift in passing from the lower- to the higher-melting isomer, obscured in the low wave-length region by a similar shift in the maxima and a slightly greater general absorption by the latter. This is additional evidence that these compounds are indeed stereoisomeric in nature. Although *d*, *l*, and *dl* modifications of the same compound exhibit identical spectra, such differences between the spectra of *dl* and *meso* forms have been reported previously with tartaric acid (15), various tartrates (16), and a series of several arylated compounds similar to

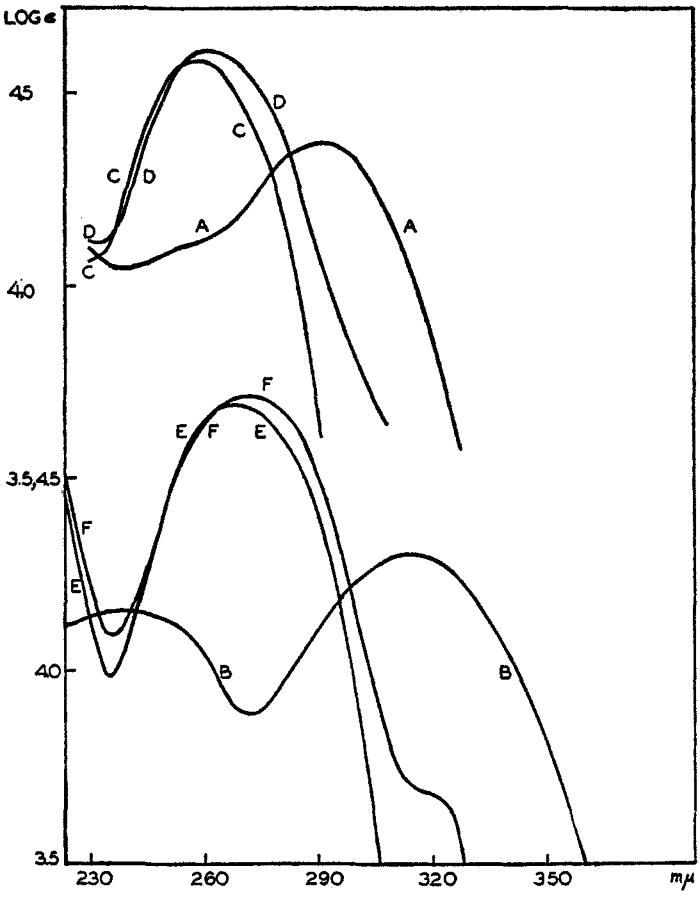


FIGURE 1. ULTRAVIOLET ABSORPTION SPECTRA OF KETONES AND BENZOPINACOLS

Curve A—I; curve B—II; curve C—IIIa; curve D—IIIb; curve E—IVa; curve F—IVb.

benzopinacols (17), the *meso* forms possessing the higher general absorptions. Spectra of the original ketones, of which that of *p*-phenylbenzophenone had been determined by Anderson and Gooding (18), are included for comparison.

In view of the shifts observed in the absorption maxima for the two series of pinacols, suggesting considerable interaction of the methoxyl substituent with the biphenyl nucleus, it seemed that this effect might be manifested in the 'migration aptitude' of these groups. Differences due to stereoisomerism would also be of interest. The rearrangement of each of the four pinacols by acetyl chloride in benzene-acetic acid (completed with iodine), followed by cleavage of the pinacolones with alkali, has been carried out by methods somewhat similar to those of Bachmann and Moser (19), and the mixtures of acids so obtained analyzed by isolation of *p*-phenylbenzoic or *p*-anisylbenzoic acid, respectively. The results are summarized in Table I.

TABLE I

REARRANGEMENT OF THE BENZOPINACOLS

PINACOL	SAMPLE, G.	METHANES, G. (%)	ARYLBENZOIC ACID, G.[f]	MIGRATION APTITUDE, ARYLPHENYL[g]
IIIa	1.19	—[c]	0.108	3.2
IIIb	2.00	1.49 (105)	.161	3.6
IVa	1.82[a]	1.21 (98)[d]	.069	8.2
IVb	2.00[b]	1.31 (99)[e]	.108	5.3

[a] Contains one mole of benzene of solvation. [b] Contains two moles of ethanol of solvation. [c] Loss of methanes by sublimation. [d] Includes 0.051 g. of phenolic methanes. [e] Includes 0.016 g. of phenolic methanes. [f] These values were calculated from solubilities of the acids under the conditions of the isolations: *p*-phenylbenzoic acid, 0.02 g./100 ml. of water; *p*-anisylbenzoic acid, 0.033 g./100 ml. of water. The latter is a composite value inasmuch as it was determined on the actual acid mixture produced; this undoubtedly contains phenolic acid produced in both acid-rearrangement and alkaline-cleavage steps. [g] Relative to phenyl as unity.

The value of 3.6 agrees well with that (3.75) of Hatt, Pilgrim, and Stephenson (2) for the migration aptitude of the biphenylyl group in the same compound. However, these authors reported this value using perchloric acid for the rearrangement, and stated that the use of acetyl chloride-benzene-acetic acid mixtures led to a value of 1.87. They have criticized the use of this reagent on the apparently valid grounds that the long heating might cause dismutation to ketones and incomplete rearrangement was their experience. They showed that the presence of ketones during cleavages led to invalid equivalent weights for the acids obtained. They were also unable to duplicate the original value (11.5) of Gomberg and Bachmann (7).

It is of interest then that the acetyl chloride method was brought into agreement with the perchloric acid results by completing the rearrangement with iodine and the cleavage of pinacolones by fusion with sodium and potassium hydroxides (2), at least in this example. It also seemed desirable to have migration aptitudes which were at least somewhat comparable to those of Bachmann and his coworkers (20).

Migration aptitudes for the 4-(*p*-anisyl)phenyl group in the low-melting (IVa, 8.2) and high-melting isomers (IVb, 5.3) seem to indicate a genuinely higher tendency for this group to wander, compared to the unsubstituted group. However, in view of the possibilities for cleavage of the methoxyl group, etc., these values are less certain. Since heating solutions of the low-melting isomer for some hours resulted in formation of some of the high-melting form with loss of pinacol presumably due to pyrolysis, the lower value of 5.3 is regarded as the most reliable for the migration aptitude of the 4-(*p*-anisyl)phenyl group, having been obtained with the more stable high-melting form. The differences in the values obtained for stereoisomers in both cases are thought to be insufficient, in view of the difficulties involved, to support a claim that stereoisomerism is an important factor in the rearrangement of benzopinacols. It is interesting to compare these values with that which has been reported for *p*-anisyl [70 or more (19)].

Acknowledgment: We wish to express our indebtedness to the Graduate School for a research grant made in support of this work.

EXPERIMENTAL PART[1,2]

Isolation of the pinacols. The Grignard reagents were prepared in the usual way and always contained some unchanged metal. Since one experiment carried out under an atmosphere of nitrogen gave similar results to those obtained without this precaution, it was not used routinely.

From 4-(p-anisyl)benzophenone. To the reagent prepared from 39 g. of bromobenzene and 6.07 g. of magnesium in 200 ml. of ether was added the solid ketone (12 g.) in 3–4-g. portions over a period of 30 minutes. A vigorous reaction occurred; the solution became purple and then yellow during a two-hour heating period. The mixture was poured into ice and saturated ammonium chloride solution. The high-melting insoluble pinacol was removed by filtration, washed, and dried. The crude product weighed 2.85 g.; m. p. 197–200° (placed in the bath at 195°). After recrystallization by solution in hot dioxane followed by the addition of several volumes of ethanol, it melted at 205–206° (204°) with evolution of a gas. Drying *in vacuo* for 17 hours at 56° did not remove two moles of ethanol of crystallization.

Anal. Calc'd for $C_{44}H_{46}O_6$: C, 78.76; H, 6.92.
Found: C, 78.76; H, 6.16.

Concentration of the above solvent layer, addition of benzene, distillation to a residue of about 50 ml., and addition of three volumes of Skellysolve B (60–70°) gave 1.6 g. of white crystals of the lower-melting isomer of the pinacol. From the mother liquors 6.3 g. (m.p. 95–98°) of crude 4-(*p*-anisyl)triphenylcarbinol was isolated (21). This form was completely soluble in cold acetone (the high-melting pinacol is quite insoluble) and was recrystallized by addition of benzene to this solution, followed by distillation to remove most of the acetone. A sample melted at 160–165° (160°), resolidified, and remelted at 181–183° (dec.). Drying *in vacuo* at 56° for 16 hours gave crystals containing one mole of benzene of crystallization.

Anal. Calc'd for $C_{46}H_{40}O_4$: C, 84.12; H, 6.13.
Found: C, 83.84, 84.25; H, 6.00, 5.92.

The isomeric pinacols were also characterized by thermal dismutation to the original

---

[1] Microanalyses were carried out by the Clark Microanalytical Laboratory, Urbana, Illinois.

[2] All melting points are corrected. The temperature in parentheses is that at which the sample was placed in the bath, at least 30 seconds being allowed for the attainment of thermal equilibrium.

ketone, among other products. Thus from the pyrolysis at 160–240° of 0.55 g. of lower-melting isomer was isolated 0.31 g. of 4-(*p*-anisyl)benzophenone; m.p. 166–168° alone or mixed with the authentic material. Similar results were obtained using the high-melting pinacol.

From p-phenylbenzophenone. The procedure and course of the reaction of this ketone with phenylmagnesium bromide were quite similar to those described for 4-(*p*-anisyl) benzophenone. From 10 g. of the ketone were obtained by identical methods 1.15 g. of the high-melting pinacol and 1.62 g. of its low-melting isomer. The former, purified by recrystallization from dioxane-ethanol, melted at 206–207° (205°). It is undoubtedly the 198° compound of Bachmann and Wiselogle (13) and probably the 212° compound of Bergmann and Fujise (11).

Anal. Calc'd for $C_{38}H_{30}O_2$: C, 88.01; H, 5.82.
Found: C, 87.59; H, 5.92.

After being purified by recrystallization from acetone-benzene, the low-melting isomer melted, before drying, at 170° (170°) (dec.) almost completely, resolidified rapidly and then melted at 188.5–190° (dec.). The last value refers to the unsolvated crystals.

Anal. Calc'd for $C_{38}H_{30}O_2$: C, 88.01; H, 5.82.
Found: C, 88.30, 88.41; H, 5.93, 6.15.

The latter isomer is believed to be that (m.p. 181°) reported by Bergmann and Wolff (12). Both forms were pyrolyzed to *p*-phenylbenzophenone. The high-melting form (0.25 g.) yielded 0.11 g.; m.p. 98.5–100.5°, when heated briefly at 220–230°. From 0.20 g. of the low-melting isomer was obtained by similar treatment 0.09 g.; m.p. 100.5–102°. Neither product depressed the melting point (100.5–102°) of an authentic sample of the ketone.

No attempt was made to isolate the *p*-phenyltriphenylcarbinol formed in this Grignard reaction. The use of ethylmagnesium bromide in place of the phenyl reagent gave only traces of the impure pinacols; again the carbinol was not isolated.

Reduction of the ketones by magnesium bromide and magnesium. Magnesium bromide in ether-benzene over amalgamated magnesium was prepared by reaction of magnesium powder with anhydrous mercuric bromide according to the method of Gomberg and Bachmann (7). From 1.9 g. of magnesium, 4.27 g. of anhydrous mercuric bromide, and 3 g. of *p*-phenylbenzophenone, after heating in ether-benzene for 14 hours, was obtained 2.75 g. (92%) of the high-melting pinacol; none of the low-melting isomer could be detected.

However, reduction of 3 g. of the *p*-anisyl compound in the same manner gave a mixture of both the high- and low-melting compounds described previously. The former (2.55 g.) predominated over the latter (0.47 g.).

These reductions were repeated with the formation of phenylmagnesium bromide in the reaction mixture after the reduction of the ketone was complete. Thus, 5.2 g. of *p*-phenylbenzophenone, reduced as above, followed by the addition of 0.5 g. of magnesium and 6.6 g. of bromobenzene in that order, after a further heating period of 12 hours, gave 1.15 g. of the high-melting form and 2.75 g. of the low-melting isomer. Similarly, 6 g. of the anisyl ketone yielded 0.80 g. of low-melting pinacol and 4.78 g. of the high-melting form.

Equilibration of the pinacols by phenylmagnesium bromide. Finally the two high-melting pinacols were added to a five- to ten-fold excess of the Grignard reagent. From 1 g. of *sym*-di-*p*-phenylbenzopinacol (IIIb) were obtained 0.45 g. of unchanged material and 0.50 g. of the low-melting isomer. Of three grams of the methoxypinacol, 1.55 g. was recovered and 0.65 g. was isomerized.

Ultraviolet absorption spectra. The spectra of the two pinacols in each series and the parent ketone were determined in direct comparison with one another and with the solvent using a Beckman Model DU Spectrophotometer. Ethanol was a satisfactory solvent for the two low-melting isomers but it was found that the high-melting isomers were quite insoluble in this medium. *n*-Butanol proved more useful for these compounds; therefore all of the curves reported here were obtained with solutions in a solvent mixture consisting of 12.5 parts by volume of ethanol (95%) and one part of *n*-butanol and were compared to a mixture of the same composition. These curves did not differ noticeably from those obtained in ethanol or in dioxane-ethanol mixtures which were also investigated in preliminary runs. The concentrations of the anisyl pinacols are corrected for the solvents of crystallization.

Rearrangement of the pinacols. In preliminary experiments, the two isomeric pinacols from *p*-phenylbenzophenone, when recrystallized from acetic acid containing a crystal of iodine, gave as the only isolated product the pinacolone (m.p. 198°) shown by Gomberg and Bachmann (7) to be that resulting from migration of a biphenylyl group. The methoxy pinacols gave mixtures of pinacolones, which were not resolved.

The results of the quantitative analyses of the pinacolones obtained on rearrangement of the isomeric pinacols have been summarized above in the table. The procedures for rearrangement, cleavage, and analysis were similar to those of Bachmann and Moser (19). Our methods differ from theirs in that the residue from the rearrangement, after distillation of the acetyl chloride and benzene, was routinely heated with 0.05 g. of iodine in acetic acid to complete the reaction. Furthermore, it was found that heating the neutral fraction (triarylmethanes) from the alkaline cleavage (in methanol) of the pinacolones with a mixture of 3 g. each of potassium and sodium hydroxides and a few drops of methanol and water at 200–250° for a short time gave a small additional amount of arylbenzoic acid (2), production of which was taken as the principal basis for the calculations. This procedure was therefore also included routinely.

SUMMARY

Using methods involving essentially reduction with magnesium bromide, magnesium, and phenylmagnesium bromide, both *p*-phenylbenzophenone and 4-(*p*-anisyl)benzophenone have been converted to separable mixtures of stereoisomeric benzopinacols. Isomerization of the pinacols by the phenyl Grignard reagent has been studied.

Ultraviolet absorption spectra for both ketones and the four pinacols have been determined.

A value of 5.3 has been found for the migration aptitude of the 4-(*p*-anisyl)phenyl group.

EUGENE, OREGON

REFERENCES

(1) BACHMANN, *J. Am. Chem. Soc.*, **55,** 1179 (1933).
(2) HATT, PILGRIM, AND STEPHENSON, *J. Chem. Soc.*, 478 (1941).
(3) HATT, *J. Chem. Soc.*, 1623 (1929).
(4) BERGMANN, *J. Org. Chem.*, **4,** 1 (1939).
(5) SCHMIDLIN, *Ber.*, **39,** 4202 (1906).
(6) GILMAN AND FOTHERGILL, *J. Am. Chem. Soc.*, **51,** 3149 (1929).
(7) GOMBERG AND BACHMANN, *J. Am. Chem. Soc.*, **49,** 236 (1927).
(8) KHARASCH, MORRISON, AND URRY, *J. Am. Chem. Soc.*, **66,** 368 (1944).
(9) BOYD AND HATT, *J. Chem. Soc.*, 898 (1927).
(10) BARNETT, COOK, AND NIXON, *J. Chem. Soc.*, 504 (1927).
(11) BERGMANN AND FUJISE, *Ann.*, **483,** 65 (1930).
(12) BERGMANN AND WOLFF, *J. Am. Chem. Soc.*, **54,** 1644 (1932).
(13) BACHMANN AND WISELOGLE, *J. Am. Chem. Soc.*, **56,** 1559 (1934).
(14) BACHMANN AND SHANKLAND, *J. Am. Chem. Soc.*, **51,** 306 (1929).
(15) STEWART, *J. Chem. Soc.*, **91,** 1537 (1907).
(16) DUVAL AND LECOMTE, *Bull. soc. chim. France*, 477 (1946).
(17) RAMART-LUCAS AND BIQUARD, *Compt. rend.*, **194,** 187 (1932).
(18) ANDERSON AND GOODING, *J. Am. Chem. Soc.*, **57,** 999 (1935).
(19) BACHMANN AND MOSER, *J. Am. Chem. Soc.*, **54,** 1124 (1932).
(20) BACHMANN AND FERGUSON, *J. Am. Chem. Soc.*, **56,** 2081 (1934).
(21) ANDERSON AND FISHER, *J. Am. Chem. Soc.*, **66,** 594 (1944).