[Contribution from the George Herbert Jones Laboratory of the University of Chicago]

Factors Influencing the Course and Mechanism of Grignard Reactions. XXII. The Reaction of Grignard Reagents with Alkyl Halides and Ketones in the Presence of Manganous Salts

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Received November 19, 1955

Manganous salts have no effect on the course of the reaction of methylmagnesium bromide, phenylmagnesium bromide, or benzylmagnesium bromide with alkyl halides and with ketones. Alkyl and cycloalkyl Grignard reagents (except methylmagnesium bromide) react by a chain mechanism with other alkyl or cycloalkyl halides (or with ketones) in the presence of manganous chloride. A hypothesis is suggested for these observations.

A satisfactory method is described for the preparation of hexamethylethane (40%) from ethylmagnesium bromide and *tert*-butyl bromide in the presence of manganous chloride.

Manganese salts have no effect on the course of reaction of methylmagnesium bromide with alkyl halides. Thus, whereas methylmagnesium bromide reacts with methyl bromide in the presence of small amounts of a cobaltous halide (2–5 mole-%) to give methane (80 ± 5%), ethane (10 ± 2%), and ethylene (10 ± 2%), no reaction takes place in the presence of manganous halides (5 mole-%). Neither does methylmagnesium bromide react with ethyl bromide in the presence of manganous salts (Table I). Furthermore, whereas benzophenone[2] and isophorone[3] react with methylmagnesium bromide in the presence of cobalt halides (2–5 mole-%) to give benzopinacol and 1,1,3,3,3′,3′-hexamethyl-bicyclohexyl-5,5′-dione,[4] respectively, only the normal addition products (diphenylmethyl carbinol and Δ^1-1,3,5,5-tetramethylcyclohexene-3-ol, respectively) are formed in the presence of manganous salts.

Thus, manganous salts have no effect on the course of the reaction of methylmagnesium halides with alkyl halides or with ketones. On the other hand, small amounts of manganous salts (2 mole-%) altered completely the course of the reaction when a different Grignard, namely isobutylmagnesium bromide, was used. Thus, while isobutylmagnesium bromide reacts with benzophenone to give a high yield (90%) of benzhydrol, an equally high yield (90%) of benzopinacol is obtained in the presence of small amounts (2 mole-%) of manganous salts.[5]

The present work was undertaken in an effort to elucidate the effect of manganous salt in the reaction of Grignard reagents with alkyl halides and with ketones.

Reaction of Grignard reagents with organic halides and with ketones in the presence of manganous salts. The results cited in Table I indicate that although methylmagnesium bromide does not react with ethyl bromide in the presence of manganous chloride (5 mole-%), a wide variety of other Grignard reagents do react, under these conditions, by a chain mechanism. Schematically, this chain reaction may be represented as follows in the case of ethylmagnesium bromide, ethyl bromide and manganous chloride (5 mole-%).

1. $C_2H_5MgBr + MnCl_2 \longrightarrow C_2H_5MnCl + MgBrCl$
2. $C_2H_5MnCl \longrightarrow C_2H_5\cdot + (MnCl)\cdot$
3. $C_2H_5Br + (MnCl)\cdot \longrightarrow C_2H_5\cdot + MnClBr$
4. $2C_2H_5\cdot \longrightarrow C_2H_6 + C_2H_4$

The yield of gas (ethane and ethylene) is almost quantitative on the basis of equations 1 to 4.

The reactions of the other Grignard reagents given in Table I with ethyl bromide and manganous chloride (5 mole-%) follow a course similar to that of ethylmagnesium bromide, except for the tendency of some of the radicals formed as indicated in equation 2 to undergo in part disproportionation, and in part dimerization.

In other words, except for methylmagnesium bromide, arylmagnesium bromides, benzylmagnesium bromide, the other Grignard reagents react with alkyl halides in the presence of small amounts of manganous salts in a manner similar to the reaction of Grignard reagents with alkyl halides in the presence of cobaltous salts. This difference is readily understood on the basis of the reducing power of the organic-anion (R:) in R:MnCl.

Anions of greater reducing power than the methyl

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[1] The effect of cobalt chloride in the reaction between benzylmagnesium bromide and alkyl halide is incorporated in the doctorate dissertation of Mr. Tawney submitted to the faculty of the Division of the Physical Sciences of The University of Chicago in 1942.

[2] Kharasch and Lambert, *J. Am. Chem. Soc.*, **63**, 2315 (1941).

[3] Kharasch and Tawney, *J. Am. Chem. Soc.*, **63**, 2308 (1941).

[4] The structure assigned to this compound by Kharasch and Tawney [*J. Am. Chem. Soc.*, **63**, 2308 (1941)] was based (see discussion in that paper) on the disclosure of Hess and Munderloh [*Ber.*, **51**, 377 (1918)], who prepared the compound by reduction of isophorone with sodium amalgam. Unfortunately, we have overlooked a later paper by Baker [*J. Chem. Soc.*, 663 (1926)] who proved conclusively that the compound prepared by Hess and Munderloh was not 3,3′,5,5,5′,5′-hexamethyldicyclohex-2,2-dien-1,1-diol but was 1,1′,3,3,3′,3′-hexamethyldicyclohexyl-5,5′-dione.

[5] Kharasch, Kleiger, Martin, and Mayo, *J. Am. Chem. Soc.*, **63**, 2305 (1941).

TABLE I

THE REACTION BETWEEN GRIGNARD REAGENT AND ORGANIC HALIDES IN THE PRESENCE OF MANGANOUS CHLORIDE (5 mole-%)

Grignard Reagent	Halide	Yield of Gas, %	Composition of Gas, %	Reaction Products
MeMgBr	EtBr	0	—	No reaction
EtMgBr	EtBr	97	C_2H_6 54 C_2H_4 46	
iso-BuMgCl	EtBr	73	$\left.\begin{matrix}C_2H_6\ 53\\ C_2H_4\ 47\end{matrix}\right\}67$ $\left.\begin{matrix}C_4H_{10}\ 55\\ C_4H_8\ 45\end{matrix}\right\}33$	High-boiling material (not identified)
tert-BuMgBr	EtBr	71	$\left.\begin{matrix}C_2H_6\ 56\\ C_2H_4\ 44\end{matrix}\right\}66$ $\left.\begin{matrix}C_4H_{10}\ 59\\ C_4H_8\ 41\end{matrix}\right\}34$	Hexamethylethane, 43%
Cyclopentyl MgBr	EtBr	92	C_2H_6 52 C_2H_4 48	Cyclopentane, 43.4% Cyclopentene, 30.9% Bicyclopentyl, 9.5%
Cyclohexyl MgBr	EtBr	94	C_2H_6 56 C_2H_4 44	Cyclohexane, 48.6% Cyclohexene, 33.7% Bicyclohexyl, 12.6%
$C_6H_5CH_2MgBr$	EtBr	0	—	No reaction
β-Phenethyl MgBr	EtBr	94	C_2H_6 58 C_2H_4 42	Ethylbenzene, 40.1% Styrene (free and as polymers), 54.6%
EtMgBr	*tert*-BuBr $(CH_3)_3CBr$	76	$\left.\begin{matrix}C_2H_6\ 57\\ C_2H_4\ 43\end{matrix}\right\}65$ $\left.\begin{matrix}C_4H_{10}\ 56\\ C_4H_8\ 44\end{matrix}\right\}35$	Hexamethylethane, 40%
EtMgBr	$C_6H_5CH_2Br$	96	C_2H_6 52 C_2H_4 48	Dibenzyl, 95.0%

or phenyl would reduce the intermediate organomanganous compound and allow the chain reaction to proceed in the manner indicated in equation 5.

5. R:MnCl $\longrightarrow$ R· + (MnCl)·

This hypothesis explains at once why in the presence of manganous salts (2–5 mole-%), methylmagnesium bromide reacts with benzophenone to give the normal addition product (diphenylmethyl carbinol), whereas with isobutylmagnesium bromide almost 90 percent of benzopinacol is obtained.[6] Similarly, whereas methylmagnesium bromide reacts with isophorone in the presence or absence of manganous salts to give the 1,2 adduct (***A***), cyclopentylmagnesium bromide reacts with isophorone in the presence of manganous chloride (5 mole-%) to give 1,1′,3,3,3′,3′-hexamethylbicyclohexyl-5,5′-dione (***B***).[7]

The experiments here cited suggest that in order for a metallic halide to function as an initiator of a free radical chain-reaction when a Grignard reagent

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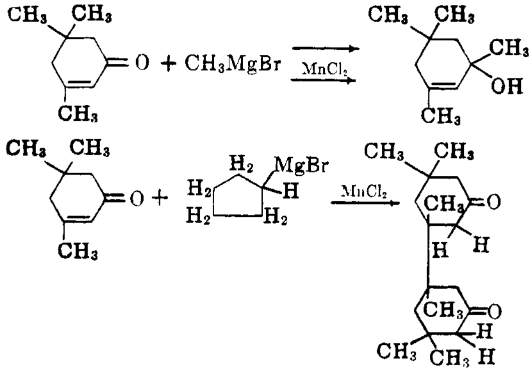
[6] Note that in the absence of manganous salts benzophenone reacts with isobutylmagnesium bromide to give benzohydrol (90%).

[7] No examination was made for the other reaction products, namely cyclopentane, cyclopentene, and bicyclopentyl, since the formation of these products in the reaction of cyclopentylmagnesium bromide with ethyl bromide in the presence of manganous chloride has been demonstrated (Table I).



A

B (89%)

is treated with an alkyl halide (or ketone), the following criteria must be fulfilled:

$$\begin{tikzcd} \text{6. R:MeX} \arrow[r] \arrow[dr, "\text{RMgX}"'] & \text{R}\cdot + (\text{MeX})\cdot \\ & \text{R:R} + (\text{MeX})\cdot + (\text{MgX})\cdot \end{tikzcd}$$

$$\text{7. } (\text{MeX})\cdot + \text{R}'\text{X} \longrightarrow \text{R}'\cdot + \text{MgX}_2$$

The organic-anion must be capable of reducing the metal to a lower oxidation stage, and the (MeX)· radical must be capable of reducing the alkyl halide (or ketone). By the appropriate choice of Grignard reagents, metallic halides and organic halides, it should be possible to arrive at a series of relative reducing powers of the organic anions. This work is now underway.

Of considerable interest is the reaction of *tert*-butylmagnesium bromide with ethyl bromide in the presence of manganous salts. Here a high yield of hexamethylethane[8] is obtained. An equally high yield of hexamethylethane is obtained when ethylmagnesium bromide is treated with *tert*-butyl bromide in the presence of manganous salt.

$$\text{8. } C_2H_5MgBr + MnCl_2 \longrightarrow C_2H_5MnCl + MgBrCl$$

$$\text{9. } C_2H_5MnCl \longrightarrow C_2H_5\cdot + (MnCl)\cdot$$

$$\text{10. } (CH_3)_3CBr + (MnCl)\cdot \longrightarrow (CH_3)_3C\cdot + MnClBr$$

$$\begin{tikzcd} \text{11. } (CH_3)_3C\cdot \arrow[r, "60\%"] \arrow[dr, "40\%"'] & (CH_3)_3CH + (CH_3)_2C{=}CH_2 \\ & (CH_3)_3CC(CH_3)_3 \end{tikzcd}$$

Except for minor differences in the reaction products, the reactions indicated in equations 12 and 13 (Table I) are (in a sense) representative for any given alkyl or cycloalkyl Grignard reagent and an alkyl or cycloalkyl halide.

$$\text{12. } (CH_3)_3CMgBr + C_2H_5Br \xrightarrow[\text{MnCl}_2]{\text{CoBr}_2\text{ or}} (CH_3)_3CC(CH_3)_3 + C_2H_4 + C_2H_6 + C_4H_{10} + C_4H_8$$

$$\text{13. } C_2H_5MgBr + (CH_3)_3CBr \xrightarrow[\text{MnCl}_2]{\text{CoBr}_2\text{ or}} (CH_3)_3CC(CH_3)_3 + C_2H_4 + C_2H_6 + C_4H_{10} + C_4H_8$$

Essentially the same reaction products are formed irrespective whether one proceeds as indicated in equation 12 or 13.

However, different reaction products are formed in equations 12 and 13 when the organic radical is benzyl. Here the reaction indicated in equation 13 proceeds "normally" and a practically quantitative yield of dibenzyl is obtained.[9]

$$\text{14. } C_2H_5MgBr + C_6H_5CH_2Cl \xrightarrow[\text{MnCl}_2]{\text{CoBr}_2\text{ or}} C_6H_5CH_2CH_2C_6H_5 + C_2H_4 + C_2H_6$$

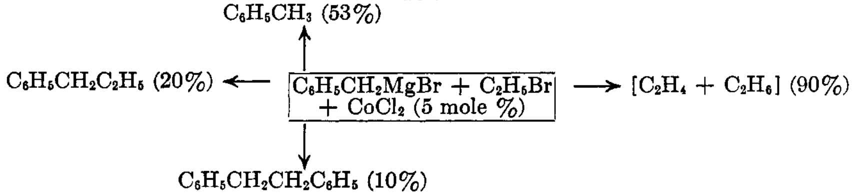
On the other hand, when benzylmagnesium chloride is treated with an alkyl halide and manganous or cobaltous salts strikingly different results are obtained. In the first place, manganous salts (5 mole-%) have no effect on this reaction.[10]

$$\text{15. } C_6H_5CH_2MgBr + C_2H_5Br \xrightarrow{\text{MnCl}_2} \text{No gas evolution (no reaction)}$$

Cobaltous chloride (5 mole-%), on the other hand, induces a free radical reaction and the products formed are indicated in Figure 1.

It would appear, therefore, that the reaction product of benzylmagnesium bromide with manganous salts is stable, whereas the product with cobalt chloride is unstable, and thereby enables the (CoCl)· radical to participate in the chain reaction. Many obvious possibilities suggest themselves which would account for the results cited.[11] Additional work, however, is required for complete elucidation of these interesting observations.[12]

FIGURE 1[a]



[a] Other reaction products: benzyl alcohol (1.5%), probably formed from the Grignard and small amounts of oxygen in the apparatus; stilbene (6.7%); and a very small amount (1 g. from 0.594 mole of the benzylmagnesium chloride) of an unidentified oil.

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(8) The following methods (and the corresponding yields) for preparation of hexamethylethane are cited in the literature: (a) *tert*-butylmagnesium bromide and *tert*-butyl chloride, 4% [Whitmore, Stehman, and Herndon, *J. Am. Chem. Soc.*, **55**, 3807 (1933)]; (b) *tert*-butylmagnesium bromide and silver bromide, 19% (W.S.H.); (c) pentamethylethyl bromide and zinc dimethyl, 50% (W.S.H.); (d) *tert*-butyl chloride and magnesium (under special conditions), 10% [Flood and Calingaert, *J. Am. Chem. Soc.*, **56**, 1211 (1934)].

(9) Except for methylmagnesium halides, the reaction indicated in equation 14 takes place with Grignard reagents of alkyl and cycloalkyl radicals (see previous discussion).

(10) It should be noted that all alkyl Grignard reagents which react with alkyl (or cycloalkyl) halides in the presence of manganous salts have a hydrogen atom on an aliphatic carbon atom *beta* to the carbon atom to which the MgX radical is attached. This is not the case with benzylmagnesium halides.

(11) Kharasch and Reinmuth, *Grignard Reactions of Nonmetallic Substances*, Chapter XVII, Prentice-Hall, Inc., New York, N. Y. (1954).

(12) Note that an excellent yield of free benzyl radicals may be obtained from benzyl halides [*cf.* Kharasch, Holten and Nudenberg, *J. Org. Chem.*, **19**, 1601 (1954); Kharasch, Mulley, and Nudenberg, *J. Org. Chem.*, **19**, 1477 (1954); etc.] but that the yield of free benzyl radical is extremely small when benzylmagnesium chloride is treated with cobalt chloride.

EXPERIMENTAL

Materials. The anhydrous manganous chloride used in these experiments was prepared by heating the hydrated salt *in vacuo.* It was stored in a vacuum desiccator over phosphorus pentoxide.

Grignard reagents were prepared in the usual manner. Excess magnesium (25%) was used in each preparation in order to reduce the amount of unreacted halide to the minimum. In the case of methylmagnesium bromide, at the end of the preparation half of the ether was removed by distillation and replaced by fresh ether so as to ensure complete removal of unreacted methyl bromide. The solutions of the Grignard reagents were filtered (under nitrogen pressure) before use. All analyses and molecular weight determinations of gases were carried out using the apparatus and method described by Kharasch, Lewis and Reynolds.[13]

The reaction between methylmagnesium bromide and ethyl bromide in the presence of manganous chloride. A one-liter three-necked flask, equipped with stirrer, dropping-funnel, and a condenser connected to a gas-collection apparatus was flushed with dry pure nitrogen prior to use. Methylmagnesium bromide (210 ml. of a 0.95 *molar* solution) was introduced and stirring was commenced. Anhydrous manganous chloride (1.26 g.) was added. No visible reaction occurred and no gas was evolved. Ethyl bromide (21.8 g.) dissolved in ether (60 ml.) was added dropwise. The reaction mixture was heated under reflux (1 hr.), but no reaction appeared to take place and no gas was evolved.

The reaction mixture was cooled and water (excess) slowly was added. Gas (assumed to be methane) was evolved and collected (4.4 liters at S.T.P.). This accounts for 98% of the methylmagnesium bromide used.

The reaction between ethylmagnesium bromide and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to ethylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred and the reaction mixture turned black. Gas was evolved and collected (0.5 liter). Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (8.7 liters at S.T.P.). Upon completion of addition, the reaction mixture was heated under reflux (1 hr.). For composition of the gas see Table I.

The reaction between isobutylmagnesium chloride and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to isobutylmagnesium chloride (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred, the reaction mixture turned black, and gas was evolved (0.5 liter). Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (6.8 liters at S.T.P.; for composition of gas see Table I). The reaction mixture became thick due to precipitation of magnesium salts. Upon completion of the addition of the ethyl bromide, the mixture was heated under reflux for one hour.

Water (excess) was added, and the magnesium salts dissolved. The ether layer was separated and the aqueous layer was extracted with ether (3 × 50 ml.). The combined ethereal solutions were dried (sodium sulphate) and ether was removed by fractionation. A dark viscous oil (5.0 g.) remained which could not be crystallized and which would not distill even when heated to 220° at 1 mm. pressure. The oil was considered to be polymeric products derived from isobutene and was not further investigated.

The reaction between tert-butylmagnesium bromide and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to *tert*-butylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred, the reaction mixture turned black, and gas was evolved (0.5 liter). Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (6.4 liters at S.T.P.; for composition of gas see Table I). Upon completion of the addition, the mixture was heated under reflux for one hour.

Water (excess) was added and the organic material was isolated in the usual way. Ether was removed by fractionation and the residue (semi-solid) was distilled. The distillate solidified and was recrystallized from ether. White crystals of strong camphoraceous odor were obtained which melted at 100.5–101°[14] (4.9 g.; 43% of calculated amount).

The reaction between cyclopentylmagnesium bromide and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to cyclopentylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred and the mixture turned black. Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (4.0 liters at S.T.P.; for composition of gas see Table I). Upon completion of the addition of the ethyl bromide, the mixture was heated under reflux for one hour.

Water (excess) was added, and the organic material was isolated in the usual way. Ether was removed by careful fractionation using a Podbielniak column. The remaining liquid was fractionated using a Fenske column: Fraction 1, b.p. 35–41°, n^{20}_{D} 1.3561, 2.0 g.; Fraction 2, b.p. 41–45°, n^{20}_{D} 1.3781, 1.1 g.; Fraction 3, b.p. 45–50°, n^{20}_{D} 1.4110, 10.1 g.; Fraction 4, b.p. 90–91°/20 mm., n^{20}_{D} 1.4631, 1.7 g.

Fractions 1 and 2 were mainly ether and were discarded. Fraction 3 gave a negative test for halogen but readily decolorized potassium permanganate solution and a solution of bromine in carbon tetrachloride. This fraction was accepted as being a mixture of cyclopentane and cyclopentene.[15]

A portion of Fraction 3 was hydrogenated. From the uptake of hydrogen, it was calculated that 42% of the mixture was cyclopentene. Thus, the yield of cyclopentene was 4.2 g. (31% of calculated amount) and that of cyclopentane was 5.9 g. (43% of calculated amount).

Fraction 4 did not decolorize a solution of potassium permanganate or a solution of bromine in carbon tetrachloride. This fraction was assumed to be cyclopentylcyclopentane (10% of calculated amount). When distilled over sodium it had the following constants: b.p. 189–190°, n^{20}_{D} 1.4639).

The molecular weight of this material (cryoscopic in benzene) was 131. Calculated for $C_{10}H_{18}$, 138. The physical constants for cyclopentylcyclopentane given in the literature[16] are as follows: b.p. 190–190.5°, n^{20}_{D} 1.46415.

The reaction between cyclohexylmagnesium bromide and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to cyclohexylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred and the reaction mixture turned black. Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise and with stirring. A steady evolution of gas occurred (4.2 liters at S.T.P.; for composition of gas see Table I). Upon completion of addition, the mixture was heated under reflux for one hour.

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(13) Kharasch, Lewis, and Reynolds, *J. Am. Chem. Soc.*, **65**, 493 (1943).

(14) Flood and Calingaert [*J. Am. Chem. Soc.*, **56**, 1211 (1934)] claim that hexamethylethane melts at 100.7–101.4°.

(15) Smittenberg, Hoog, and Henkes [*J. Am. Chem. Soc.*, **60**, 17 (1938)] give the following physical constants for cyclopentane: b.p. 49.2°, n^{20}_{D} 1.4065. Filipow [*J. Russ. Phys.-Chem. Soc.*, **46**, 1163] gives the following physical constants for cyclopentene: b.p. 44.1–44.6°/752 mm., n^{18}_{D} 1.4218.

(16) Goheen, *J. Am. Chem. Soc.*, **63**, 744 (1941).

Water (excess) was added and the organic material was isolated in the usual way. Ether was removed by fractionation using a Podbielniak column. The remaining colorless liquid was fractionated, using a short Fenske column: Fraction 1, b.p. 78.5–81°, n_D^{20} 1.4321, 3.0 g.; Fraction 2, b.p. 81–82°, n_D^{20} 1.4344, 6.8 g.; Fraction 3, b.p. 82–83.5°, n_D^{20} 1.4365, 3.7 g.; Fraction 4, b.p. 124–126°/25 mm., n_D^{20} 1.4788, 2.4 g.

Fractions 1, 2, and 3 gave a negative test for halogen but all readily decolorized potassium permanganate solution and a solution of bromine in carbon tetrachloride. These fractions were assumed to be mixtures of cyclohexane and cyclohexene.[17]

Fractions 1, 2, and 3 were combined (13.5 g.) and a portion was hydrogenated. From the uptake of hydrogen gas, it was calculated that 41% of the mixture was cyclohexene. Thus, the yield of cyclohexene was 5.5 g., 34% of calculated, and that of cyclohexane was 8.0 g., 48% of calculated amount. The value for cyclohexene may be too low since alcohol (instead of acetic acid) was used as a medium in the hydrogenation experiments.

Fraction 4 did not decolorize potassium permanganate solution or a solution of bromine in carbon tetrachloride. This fraction was assumed to be cyclohexylcyclohexane. It was distilled over sodium, b.p. 121–122°/21 mm., n_D^{20} 1.4794, 2.1 g. (13%).[18]

Anal. Calc'd for $C_{12}H_{22}$: C, 86.55; H, 13.44; Mol. wt., 166. Found: C, 86.16; H, 13.45; Mol. wt., 159.

The reaction between benzylmagnesium bromide and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to benzylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise with stirring. No gas was evolved but the reaction mixture slowly turned black. Upon completion of addition, the mixture was heated under reflux for two hours.

Water (excess) was slowly added when a vigorous reaction occurred. The organic material was isolated in the usual way. Ether and ethyl bromide were removed by fractionation and the remaining colorless liquid was distilled: Fractions 1 and 2, b.p. 109–111°, n_D^{20} 1.4961, 14.5 g.; Fraction 3, b.p. 146–149°/21 mm., 2.1 g., solidified.

Fractions 1 and 2 did not decolorize potassium permanganate solution or a solution of bromine in carbon tetrachloride. These fractions were assumed to be toluene (14.5 g.), indicating that 80% of the benzylmagnesium bromide remained unreacted at the end of the experiment.

Fraction 3 was recrystallized from aqueous ethanol. White crystals, which melted at 52°, were obtained (2.1 g., 12% of calculated amount on the basis of Grignard used. Some dibenzyl, however, was present in the original Grignard reagent). The melting point of this material was not depressed when mixed with an authentic specimen of dibenzyl.

On repeating the experiment, but adding the benzylmagnesium bromide to ethyl bromide and manganous chloride, a similar result was obtained.

The reaction between β-phenethylmagnesium bromide and ethyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to β-phenethylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred and the reaction mixture turned black. Ethyl bromide (21.8 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (4.2 liters at S.T.P.). Upon completion of addition, the mixture was heated under reflux for one hour.

Water (excess) was added and the organic material was isolated in the usual way. Ether was removed by fractionation using a Podbielniak column. The remaining cloudy liquid was distilled: Fraction 1, b.p. 40–43°/20 mm., n_D^{20} 1.4980, 6.0 g.; Fraction 2, b.p. 43–46°/20 mm., n_D^{20} 1.5060, 3.5 g. Residue, hard white solid, 10.5 g.

Fractions 1 and 2 gave a negative test for halogen but all readily decolorized potassium permanganate solution and a solution of bromine in carbon tetrachloride. These fractions were assumed to be a mixture of ethylbenzene and styrene. From the refractive indices of pure ethylbenzene and styrene, it was calculated that Fractions 1 and 2 contained 8.5 g. of ethylbenzene (40% of calculated amount on the basis of the Grignard used) and 1.0 g. of styrene.

The residue, a hard white solid (probably polystyrene; 10.5 g.), was insoluble in ether and ethanol but dissolved with difficulty in benzene.

The polystyrene, together with the styrene, account for 55% of the phenethylmagnesium bromide used in this reaction.

The reaction between ethylmagnesium bromide and tert-butyl bromide in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to ethylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred, the reaction mixture turned black and gas was evolved (0.6 liter). *tert*-Butyl bromide (27.4 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (6.8 liters at S.T.P.) and magnesium bromide was formed. Upon completion of addition, the mixture was heated under reflux for one hour.

Water (excess) was added and the organic material was isolated in the usual way. Ether was removed by fractionation and the residue was distilled (b.p. 104–105.5°/740 mm.). The distillate solidified and was crystallized from ether. White crystals of strong camphoraceous odor, which melted at 100.5–101°, were thus obtained (4.4 g., 40% of hexamethylethane, calculated on the basis of the *tert*-butyl bromide used).

The reaction between ethylmagnesium bromide and benzyl chloride in the presence of manganous chloride. Anhydrous manganous chloride (1.26 g.) was added to ethylmagnesium bromide (200 ml. of a 1 *molar* solution) in the usual apparatus. An exothermic reaction occurred, the reaction mixture turned black and gas was evolved (0.5 liter). Benzyl chloride (25.3 g.), dissolved in ether (60 ml.), was added dropwise with stirring. A steady evolution of gas occurred (4.3 liters at S.T.P.). The reaction mixture became thick due to precipitation of magnesium salts. Upon completion of addition, the mixture was heated under reflux for one hour.

Water (excess) was added and the organic material isolated in the usual way. Ether was removed by fractionation. The solid residue was recrystallized from aqueous ethanol. White crystals, which melted at 51.5–52°, thus were obtained (17.3 g.; 95% on the basis of the benzyl chloride used). No depression in melting point was noted when the material was mixed with an authentic sample of dibenzyl.

The reaction between cyclopentylmagnesium bromide and isophorone in the presence of manganous chloride. A 2-liter three-necked flask, equipped with stirrer, dropping-funnel, and condenser, was flushed with dry nitrogen. Cyclopentylmagnesium bromide (530 ml. of a 1 *molar* solution) was introduced, followed by anhydrous manganous chloride (3.15 g.). The reaction mixture turned black. Isophorone (69 g.), dissolved in ether (150 ml.), was added dropwise with stirring. Upon completion of the addition, the reaction mixture was heated under reflux for one hour and then was allowed to stand overnight. A semi-solid white material separated.

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(17) The physical constants for cyclohexane [Forziati, Glasgow, Willingham, and Rossini, *J. Research Natl. Bur. Standards*, **36**, 129 (1946)] are as follows: b.p. 80.738°/760 mm., n_D^{20} 1.42623. The physical constants for cyclohexene [Vogel, *J. Chem. Soc.*, 1323 (1936)] are as follows: b.p. 83°/777 mm., n_D^{20} 1.4465.

(18) Zelinsky, Titz, and Fatejew [*Ber.*, **59**, 2590 (1926)] state that cyclohexylcyclohexane has the following physical constants: b.p. 239.5–240°, n_D^{20} 1.4800.

The reaction mixture was poured on to a mixture of crushed ice (1 kilo.) and acetic acid. The ether layer was separated and the aqueous layer was extracted with ether (3 × 75 ml.). The combined ethereal solutions were washed with sodium bicarbonate solution (4 × 100 ml.) and water, dried (sodium sulphate) and the ether was removed by fractionation.

The residue consisted almost entirely of a pale yellow solid, together with a very small amount of yellow oil. The oil was decanted from the solid, and the latter was washed with cold ligroin (60°). The ligroin washings were combined with the yellow oil and the ligroin was removed by fractionation. The remaining oil was distilled (b.p. 96–104°/25 mm., n_D^{20} 1.4760, 3.3 g.). This was accepted as being unreacted isophorone.

The solid product when crystallized from a mixture of absolute ethanol and ligroin was obtained in glistening white needles which melted at 166°. The product did not decolorize either a solution of potassium permanganate or a solution of bromine in carbon tetrachloride. The presence of carbonyl groups in the compound was confirmed by infrared analysis. This compound was accepted as 1,1′,3,3,3′,3′-hexamethyldicyclohexyl-5,5′-dione (62 g., 89%).

Anal. Calc'd for $C_{18}H_{30}O_2$: C, 77.66; H, 10.86; Mol. wt., 278. Found: C, 77.73; H, 10.92; Mol. wt., 291.

The *bis-semicarbazone* of this material, when crystallized from acetic acid, melted at 258–259°. Baker[19] states that the melting point of the dione is 162° and the bis-semicarbazone is 259–260°.

The action of benzylmagnesium chloride on ethyl bromide in the presence of 5 mole-% of cobaltous chloride. In a one-liter, round bottomed flask equipped with a reflux condenser, a mercury-sealed stirrer, and a dropping-funnel containing the Grignard reagent (and arranged so that any gases evolved could be collected) was placed ethyl bromide (64.8 g.) dissolved in ether (156 ml.) and anhydrous cobaltous chloride (3.8 g.).

With vigorous agitation benzylmagnesium chloride (487 ml. of 1.2 *molar* solution) was added slowly. It took 1.5 hours for the addition of the Grignard reagent. The temperature of the reaction mixture was held at 26–28° by means of an external water-bath. At first the only signs of reaction were a slight rise in temperature and a change in color of the mixture from blue to deep reddish-brown. After approximately 330 ml. of Grignard reagent were added, a slight gas evolution was noted.

After all of the Grignard reagent was introduced, the reaction mixture was stirred 18 minutes longer at 25°, then raised to the boiling point of ether, and maintained at that temperature for one hour. A total of 9.2 liters (S.T.P.) of gas was collected.

The reaction mixture was rather thick. Therefore it was diluted with 180 ml. of ether. Titration of an aliquot indicated that 94% of the Grignard reagent had reacted. The reaction mixture was decomposed with 300 g. of ice and 50 g. of glacial acetic acid and worked up in the usual manner. The ether layer was dried over sodium sulfate. The water layer from the decomposition of all of the aqueous washings were combined and made up to 1250 ml. A volumetric halogen analysis indicated the presence of 1.182 moles of halide ion. After the halogen from the Grignard solution (shown to be 0.595 mole volumetrically) and that derived from the cobaltous chloride (0.0595 mole) were deducted, 0.528 mole of halide ion due to ethyl bromide remained; in other words, at least 89% of the ethyl bromide had reacted.

The ether layer was filtered and the ether was removed on a water-bath through a 40-cm. Vigreaux column. Fractionation of the residue gave: (a) toluene (29 g., 53%). The toluene was identified by its boiling point (110–111°), and the preparation of 2,4-dinitrotoluene which melted at 71–72°. (b) *n*-propylbenzene (20%). This was identified by the boiling point 157–158° (uncorr.), by oxidation to benzoic acid with alkaline permanganate, and by conversion through treatment with phthalic anhydride and aluminum chloride in CS_2 to *o*-(4′-*n*-propylbenzoyl)benzoic acid which melted at 123–124°. (c) benzyl alcohol (1.5%). This was identified by preparation of benzyl *p*-nitrobenzoate which melted at 84–85°. (d) dibenzyl (10%) which melted at 51–52° and which did not depress the melting point of an authentic sample. (e) stilbene (7%) which melted at 122–123° and which did not depress the melting point of an authentic sample. (f) There was less than 1.0 g. of an undistillable oil which was not identified.

The above products account for 92% of the Grignard reagent used.

The gas (9.2 liters at S.T.P.) collected during the reaction was passed through bromine and 41 g. of 1,2-dibromoethane was obtained; b.p. 129–131°, d_{20}^{20} 2.158, n_D^{20} 1.5358. This quantity was equivalent to 0.218 mole of ethylene and, hence, also to 0.218 mole of ethane. Within the limits of error, the evolved gases comprised equivalent amounts of ethane and of ethylene and the total of 0.436 mole of gas plus 0.120 mole of propylbenzene accounted for 94% of the ethyl bromide used.

Treatment of reaction mixture at conclusion of reaction with mercuric chloride. The above experiment was repeated on a smaller scale to demonstrate that the large quantity of toluene arose from an attack of "benzyl" radicals on the ether.

Benzylmagnesium chloride (0.212 mole) and an equivalent amount of ethyl bromide and 5 mole-% of $CoCl_2$ were used. At the conclusion of the reaction, the viscous mass was diluted to 540 ml. with dry ether. A heavy material settled out and a clear green top ether layer remained. A titration using a sample of the green ether layer showed the solution to be neutral and that no unreacted Grignard reagent was present. Two more titrations using samples drawn from the precipitated reaction complex, however, indicated that at the most there was 0.024 mole of unreacted Grignard reagent present, or that 89% of the Grignard reagent had reacted.

Anhydrous mercuric chloride (18 g.) was added and refluxing and stirring were carried on for 2.3 hours. The reaction mixture was decomposed with ice containing 5 ml. of 50% acetic acid and worked up in the usual way.

Only traces of organomercury compounds were obtained and the products corresponded to those described in the previous experiment. Significantly, 8 g. (41%) of pure toluene was again isolated.

Addition of ethyl bromide to benzylmagnesium chloride in the presence of cobaltous chloride (5 mole-%). An experiment was carried out similar to those previously described except that in this case the cobaltous chloride was added to the benzylmagnesium chloride and the ethereal solution of ethyl bromide then was added to the Grignard reagent. The course of the reaction and the products were essentially unchanged by the reversal of addition procedures. The only difference noted was that in the present experiment gas evolution commenced shortly after the first few drops of ethyl bromide were introduced and persisted vigorously as long as the ethyl bromide was added but rapidly decreased as soon as the addition of ethyl bromide was completed.

Reaction of ethyl bromide and benzylmagnesium chloride. No reaction occurred between ethyl bromide and benzylmagnesium chloride in the absence of catalyst. Titration at the conclusion of refluxing showed that less than 2.5% of the Grignard reagent had reacted and total halogen analysis on the aqueous decomposition layer demonstrated that no ethyl bromide had reacted.

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[19] Baker, *J. Chem. Soc.*, 663 (1926).