$-7.5°$ to $-5.0°$ during five days, indicating very little reversibility toward the equilibrium value obtained from *d*-arabinose.

3. In contrast to the very small reversibility in the pentose systems, *d*-α-glucoheptose and *d*-glucoheptulose are mutually interconvertible by the action of saturated calcium hydroxide solution to give a common equilibrium value of $[\alpha]_D^{20-35}$ of approximately 45.0°.

CHICAGO, ILLINOIS

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CERTAIN FACTORS INFLUENCING THE YIELD OF GRIGNARD REAGENTS AND THE RATIO OF R_2Mg TO RMgX

BY GEORGE O. JOHNSON AND HOMER ADKINS

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The ratio of Grignard reagent to hydrocarbon formed in the reaction of magnesium with alkyl halides is in part determined by the presence of compounds other than the two essential components of the reaction mixture. Metallic chlorides have long been known to modify this ratio of Grignard to Wurtz reactions and more recently copper has been shown to exert a similar influence.[1,2] It has sometimes been assumed that the hydrocarbon formation was dependent upon the reaction of the Grignard reagent with some of the alkyl halide which had not yet reacted with magnesium as illustrated in equation 1.

$$RMgX + RX \longrightarrow R_2 + MgX_2 \qquad (1)$$

Equation 1 represents a reaction known to occur, for example, between allylmagnesium bromide and allyl bromide.[3]

It has become increasingly evident that the Grignard reagent in many cases is not exclusively or even predominantly in the form RMgX but rather as R_2Mg, these compounds being in more or less stable combination with MgX_2 and the solvent.[4,5,6,7] Therefore, a possible explanation of the effect of copper in modifying the ratio of the Grignard and Wurtz reactions is that it modifies the ratio of RMgX and R_2Mg, thus increasing the amount of the former available for the reaction represented in equation 1. This explanation of the effect of copper upon the proportion of products would rest on the further assumption that R_2Mg does not react as rapidly, if at all, with RX. The foregoing hypothesis has now been tested.

[1] Johnson and Adkins, THIS JOURNAL, **53**, 1520 (1931).
[2] Gilman and Zoellner, *ibid.*, **53**, 1581 (1931).
[3] Späth, *Monatsh.*, **34**, 1965 (1913).
[4] Schlenk and Schlenk, *Ber.*, **62B**, 920 (1929).
[5] Gilman and Fothergill, THIS JOURNAL, **51**, 3149 (1929).
[6] Noller, *ibid.*, **53**, 635 (1931).
[7] Schlenk, *Ber.*, **64B**, 734 (1931).

The yields of active Grignard reagent and of R_2Mg for sixteen alkyl halides with pure magnesium and with magnesium–copper alloy have been determined. It has been ascertained previously that the only reactions of any consequence occurring under the experimental conditions used in this work are the Grignard reagent formation and the Wurtz reaction, so that the extent of the latter is given by the difference between 100% and the figures given for the yield of Grignard reagent, except in the case of the more inactive chlorides. The determination of the effect of various experimental conditions upon the ratio of the Grignard and Wurtz reactions was made as previously described.[1] The amount of R_2Mg in the Grignard reagent was determined in general according to the method of Schlenk as modified by Noller. A summary of the experimental data is presented in Table I. The alkyl halides have been arranged in the order of the magnitude of the effect of copper in modifying the yield of Grignard reagent.

TABLE I

THE EFFECT OF COPPER UPON THE FORMATION OF THE GRIGNARD REAGENT

Alkyl halide	Yield of Grignard reagent, % Mg (pure)	Mg–Cu	Grignard reagent as R_2Mg, % Mg (pure)	Mg–Cu	Effect of Cu Upon total	Upon R_2Mg
Allyl bromide	72.3 ± 0.2 (2)	5.7 ± 2.0 (6)	49.4 ± 3.6 (2)	.....	−67	...
Benzyl bromide	83.8 ± 0.2 (2)	49.4 ± 1.9 (3)	70.5 ± 2.5 (3)	49.2 ± 6.6 (4)	−34	−21
Ethyl bromide	93.1 ± 0.8 (2)	62.4 ± 1.0 (2)	42.2 ± 1.8 (3)	30.2 ± 0.4 (2)	−31	−12
β-Phenylethyl bromide	91.6 ± 0.1 (2)	73.4 ± 1.0 (2)	76.0 ± 2.2 (4)	75.4 ± 2.8 (4)	−18	0
Cyclohexyl bromide	79.8 ± 0.4 (2)	64.4 ± 3.2 (2)	81.6 ± 1.7 (2)	72.9 ± 1.2 (2)	−15	− 8
Isobutyl bromide	87.5 ± 0.9 (5)	73.6 ± 2.1 (2)	79.7 ± 1.8 (6)	76.0 ± 3.3 (2)	−14	− 4
n-Butyl bromide	91.8 ± 0.4 (2)	74.9 (1)	81.6 ± 1.7 (2)	76.9 (1)	−17	− 5
Benzyl chloride	93.6 ± 0.7 (2)	76.5 ± 4.0 (3)	73.4 ± 2.5 (2)	72.8 ± 6.1 (3)	−17	0
Ethyl iodide	86.6 ± 2.3 (3)	72.5 ± 1.7 (2)	6.9 ± 2.7 (3)	5.9 ± 1.9 (2)	−14	− 1
n-Butyl chloride	91.3 ± 1.0 (2)	79.5 ± 0.5 (2)	84.2 ± 1.5 (2)	81.6 ± 1.6 (3)	−12	− 2
n-Butyl iodide	82.1 ± 0 (2)	74.3 ± 1.1 (2)	76.7 ± 1.4 (3)	62.6 ± 7.9 (2)	− 8	−14
n-Heptyl bromide	80.6 ± 1.0 (2)	72.8 ± 1.3 (2)	66.8 ± 9.1 (2)	72.8 ± 6.8 (2)	− 8	+ 6
Phenyl bromide	94.7 ± 0.5 (3)	92.3 ± 1.5 (2)	75.8 ± 2.7 (3)	81.5 ± 3.2 (2)	− 2	+ 6
Tert.-butyl bromide	23.7 ± 1.5 (2)	27.1 ± 1.1 (2)	39.4 ± 2.6 (2)	39.3 ± 2.8 (3)	+ 3	0
Tert.-butyl chloride	28.1 ± 0.5 (2)	43.4 ± 1.7 (2)	62.2 ± 2.8 (3)	74.9 ± 0.5 (2)	+15	+13
Tert.-amyl chloride	25.3 ± 0.3 (2)	38.6 ± 0 (2)	67.7 ± 1.2 (3)	71.1 ± 1.1 (2)	+13	+ 3

The effect of copper upon the course of the reaction of magnesium with the halides may be summarized as follows. The presence of copper in the magnesium decreased the yield of the Grignard reagent in the case of all of the primary and secondary halides, the depression of the yield varying from 66.6% in the case of allyl bromide to 2.4% in the case of phenyl bromide. The depressing effect of the copper was more marked with the bromides than for the chlorides, and more for the chlorides than for the iodides. Copper very definitely raised the yield of Grignard reagent from the three tertiary halides, the effect being more in the case of tertiary butyl chloride than it was in the case of the bromide. The potency of copper in depressing the Grignard reaction decreased with increasing length of chain in the alkyl halide.

The proportion of active Grignard reagent existing as R_2Mg was in nine cases very definitely modified when copper was added to the magnesium. The magnitude of the effect of copper upon the proportion of R_2Mg (column 7 of table) was in general less than it was upon the yield of Grignard reagent (column 6 of table). However, the sign of the effect, except for heptyl and phenyl bromide, was the same for both phenomena, *i. e.*, when copper brought about a considerable decrease in the yield of Grignard reagent it also brought about a decrease in the proportion of R_2Mg, and when copper increased the Grignard reaction it also increased the proportion of R_2Mg.[8]

The question now arises as to the rate at which alkyl halides react with the Grignard reagents prepared from them, and also with the corresponding solution of R_2Mg. In order to test this point Grignard reagents were prepared from twelve halides. Four aliquots were removed from each reaction mixture. The first two were analyzed for total Grignard reagent and R_2Mg, respectively. The third aliquot was treated with a small excess of the corresponding alkyl halide. An excess of alkyl halide was also added to the solution of R_2Mg from the fourth aliquot, from which the RMgX had been precipitated with dioxane. The two solutions containing the allyl halide were then refluxed for ten minutes and the residual active Grignard reagent in each determined in the usual manner, *i. e.*, by hydrolyzing and titrating the basicity so developed.

TABLE II

THE EFFECT OF ADDED RX ON SOLUTIONS OF GRIGNARD REAGENTS AND OF DIALKYL MAGNESIUM

Halide	Change in amount Of Grignard reagent	Of R_2Mg
Allyl bromide	−50.0±3.5 (2)	−7.8 (1)
Allyl bromide[a]	−31.9±3.1 (3)	−8.0±1.4 (3)
Ethyl bromide	− 0.7±0.7 (2)	−3.9 (1)
Ethyl iodide	+ 2.0±3.0 (3)	+3.5±3.0 (3)
n-Butyl bromide	− 0.2 (1)	+1.5 (1)
Isobutyl bromide	+ 1.3±1.0 (6)	+1.7±1.6 (4)
n-Butyl chloride	0	−4.3 (1)
n-Butyl iodide	+1.8±2.0 (4)	+5.0±5.0 (4)
n-Heptyl bromide	−1.0 (1)	...
Cyclohexyl bromide	−2.5±2.0 (5)	−2.8±2.2 (3)
Phenyl bromide	−0.4±0.1 (2)	−3.5±3.1 (2)
Benzyl bromide	− 0.4±0.6 (2)	...
Benzyl chloride	− 5.5±2.0 (6)	−3.5±6.5 (5)

[a] Zinc dust was added to the reaction mixture.

The data so obtained are summarized in Table II. These data show: (1) that allyl bromide reacted to a considerable extent with the Grignard

[8] Data are not available to show what effect, if any, the concentration of the Grignard reagent in the ether has upon the ratio of R_2Mg to RMgX.

reagent prepared from it under the conditions under which the latter is formed; (2) that diallyl magnesium reacted very slowly, if at all, with allyl bromide; (3) that in the case of the other halides there was little if any reaction of either the Grignard reagent or R_2Mg with the corresponding alkyl halide. It is true that for certain pairs of reactants there was a decrease in the amount of R_2Mg or Grignard reagent. However, the magnitude of the changes and the variations in duplicate analyses rob these changes of any significance.

There are recorded in Table III data which indicate the effect of zinc and mercuric chloride upon the yield of Grignard reagent and the proportion of it which is in the form R_2Mg. These data show that the addition of zinc to the reaction mixture increased the yield of the Grignard reagent in the case of allyl bromide, but was without effect upon the other halides. Mer-

TABLE III

EFFECT OF VARIOUS METALLIC CHLORIDES AND ZINC UPON THE FORMATION OF THE GRIGNARD REAGENT[a]

Alkyl halide	Yield of reagent, %	Reagent as R_2Mg, %	Change in yield of reagent,[b] %	Change in R_2Mg,[b] %
Allyl bromide[d]	80+2.1 (8)	46+1.2 (3)	+ 8	− 3
Ethyl iodide[d]	90	...	− 1	..
Isobutyl bromide[e]	88+0.6 (2)	76+1.0 (2)	+ 1	− 4
n-Butyl iodide[e]	83	61	+ 1	−15
Cyclohexyl bromide[f]	82+0.1 (2)	68	− 1	..
Cyclohexyl bromide[g]	41	53	−37	−28
Cyclohexyl bromide[h]	44	...	−20	..
Tert.-butyl bromide[g]	15	20	− 9	−19
Benzyl bromide[g]	90	70	+ 6	0
Benzyl bromide[h]	64	63	+14	+13
Benzyl chloride[g]	94	70[c]	+ 1	+ 5
Benzyl chloride[h]	91+0.5 (4)	81	+12	+ 9

[a] The following changes in the yield of Grignard reagents were obtained by adding approximately 0.01 g. of various chlorides to a reaction mixture containing 0.06 mole of the alkyl halide and 1.7 g. of a 12% copper–magnesium alloy: cyclohexyl bromide with ferric chloride, −29%; with aluminum chloride, −13%; with mercuric bromide, −17%; with zinc chloride, −32%; benzyl chloride with ferric chloride, −25%; *n*-butyl bromide with aluminum chloride, −1%; with magnesium bromide, +1%; with zinc chloride, −21%. [b] These figures represent the differences in percentage between the values given in columns 2 and 3 of this table, and the values given in Table I for the yield of Grignard reagent and R_2Mg obtained in the absence of mercuric chloride or zinc. [c] There is a change of several per cent. in the value when the solution is allowed to stand for from one to twenty-three hours. The percentage of R_2Mg increases and the amount of halogen in the solution decreases, due no doubt to the precipitation of $MgCl_2$. This is in agreement with Schlenk, *Ber.*, **64**, 734 (1931). [d] 0.2–0.4 g. of zinc, 6.5 g. of magnesium, 0.06 mole of alkyl halide. [e] 0.2 g. of zinc, 1.53 g. of magnesium and 0.06 mole of alkyl halide. [f] 0.2 g. of zinc, 4.0 g. of magnesium, 0.06 mole of alkyl halide. [g] 0.04 g. of mercuric chloride, 1.53 g. of magnesium and 0.06 mole of alkyl halide. [h] 0.04 g. of mercuric chloride, 1.53 g. of magnesium in an 88% magnesium–12% copper alloy, and 0.06 mole of alkyl halide.

curic chloride in some cases markedly increased the yield of Grignard reagent while with other halides the effect was the more normal one for metallic chlorides, *i. e.*, it decreased the yield. Both copper and mercuric chloride affected the proportion of Grignard reagent existing as R_2Mg. With mercuric chloride the effect upon the yield of Grignard reagent for a given alkyl halide was the same as it was upon the proportion of R_2Mg, *i. e.*, both were increased or both were decreased.

Conclusions and Summary

The yields of Grignard reagent and the proportion of dialkyl magnesium (R_2Mg) contained in each of them, as conditioned by the presence of copper, mercuric chloride, etc., have been ascertained for sixteen alkyl halides. The results so obtained and other data on certain related reactions seem to lead to the following conclusions.

1. The proportion of Wurtz and Grignard reactions which occur when an alkyl halide reacts with magnesium varies with the particular alkyl group and the halogen involved. It is also modified by the presence in the reaction mixture of small amounts of the metals copper and zinc and of mercuric and other metallic halides. The effect of copper, for example, upon the proportion of the two competitive reactions is not fixed but varies both in amount and in direction of change. For example, copper *decreased* the Grignard reaction from 72 to 6% for allyl bromide and *increased* the same reaction with *tert.*-butyl chloride from 28 to 43%.

2. The proportion of the active Grignard reagent existing as R_2Mg varies with the alkyl halide from which it is prepared, the variation being from 6% for ethyl iodide to 84% with *n*-butyl chloride. The proportion of R_2Mg is also modified by the presence of copper, mercuric chloride, etc., the variation being from a decrease of 21% in R_2Mg for benzyl bromide to an increase of 13% of R_2Mg from *tert.*-butyl chloride.

3. Those added reagents which for a given alkyl halide decrease the yield of Grignard reagent also in general decrease the proportion of the reagent existing as R_2Mg, and those reagents which for a given alkyl halide increase the yield of Grignard reagent also increase the proportion of R_2Mg in that reagent.

4. The alkyl halides except allyl bromide were quite inactive toward the Grignard reagent made from them (and also toward the R_2Mg component of that reagent) under the conditions under which the reagent is formed. It seems very improbable, therefore, that the formation of hydrocarbons (Wurtz reaction) during the reaction of magnesium with alkyl halides is dependent upon the reaction of the Grignard reagent with the alkyl halide.

MADISON, WISCONSIN