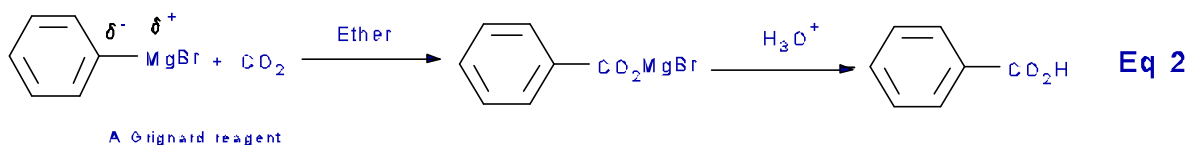
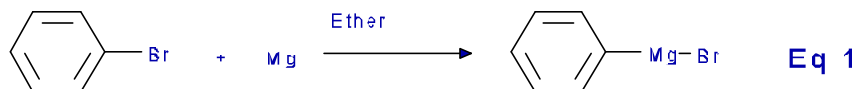


THE GRIGNARD REACTION. PREPARATION OF BENZOIC ACID



THE PROBLEM TO BE INVESTIGATED: Benzoic acid is synthesized by the use of an organometallic reagent, $C_6H_5-Mg-Br$, with CO_2 in a **Grignard reaction**.

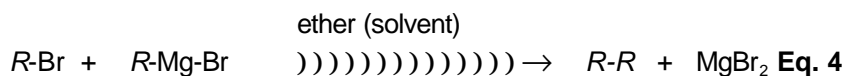
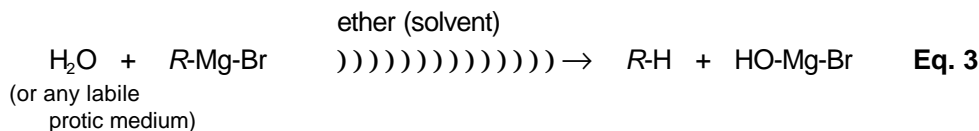


BACKGROUND INFORMATION: Organometallic compounds are important in life processes. One of the significant discoveries in organic chemistry is a series of reactions involving the **Grignard reaction**. Much research elucidating the structures, mechanisms, and general application in organic synthesis has been expended. Classified as an **addition reaction**, a Grignard reagent and methanal (formaldehyde) produces - after workup - a **primary alcohol**. With any other aldehyde, the Grignard reaction yields a **secondary alcohol**, while a ketone or ester will afford a **tertiary alcohol**:

| CARBONYL REACTANT (electrophile) | PRODUCT |
|----------------------------------|-------------------|
| formaldehyde | primary alcohol |
| aldehyde | secondary alcohol |
| ketone | tertiary alcohol |
| ester | tertiary alcohol |
| carbon dioxide | carboxylic acid |

While benzoic acid may be obtained by alternative methods; e.g., permanganate or dichromate oxidation of benzyl alcohol or an alkyl-substituted benzene, or hydrolysis of benzonitrile, the Grignard reaction is a non-oxidative process.

THE NATURE OF THIS INVESTIGATION: Grignard reagents must be produced under anhydrous conditions and used immediately after preparation. The presence of **protic media** such as water or alcohol will decompose the Grignard reagent resulting in the formation of the corresponding hydrocarbon (**Eq. 3**). Addition of the nucleophilic R- (or, in this case, **Ar-**) group to the electrophilic carbonyl group ($O=C=O$) also requires anhydrous conditions. The importance of a protic-free (anhydrous) environment can not be overemphasized; for, failure in generating the Grignard reagent is often associated with the presence of protic material (**Eq. 3**). As in this experiment, a common impurity, biphenyl ($R-R = C_6H_5-C_6H_5$) may also result from a coupling reaction to form a different hydrocarbon (**Eq. 4**).



PROCEDURE

Caution. All ethers are extremely flammable. Observe caution in handling chemicals. Until the Grignard reagent is reacted with the electrophile, all apparatus and chemicals must be absolutely dried!! **Anhydrous diethyl ether** must be used in preparation of the Grignard reagent. After the addition reaction, t-butyl methyl ether is employed in extraction.

Preparation of phenylmagnesiumbromide: Provisions for heating and cooling the reaction flask are necessary in this experiment. Set up your apparatus according to the model provided in the laboratory. The 100 mL RBF must be secured by a clamp (center neck) to the ring stand. Place the addition funnel and a stopper onto the side arms. A condenser -- equipped with a CaCl₂ tube and set up for refluxing conditions (circulating water) -- is fitted to the center neck. Allow sufficient space below the reaction flask to permit positioning of the heating well or water bath while controlling the reaction progress.

Weigh 0.5 g **magnesium** turnings. Before placing into the RBF, use a spatula or scissors and cut into four to six pieces of magnesium turnings to provide a "fresh" (unoxidized) surface. Measure and pour 2 mL of **bromobenzene** into the addition funnel. Using the same 10 mL graduate cylinder, measure and add 20 mL (in portions, 2 x 10 mL) **anhydrous diethyl ether** to the addition funnel. Using caution, the ring stand may be "rocked" to cause mixing of the bromobenzene/ether mixture. Through the stopcock, release about half of the mixture into the flask. Allow the mixture to stand and observe over a ten minute period whether the reaction is occurring. (**NOTE:** See **Helpful Hints** regarding the use of a "**starter solution**") After an induction period (3-5 mins), signs of a darkening solution (brownish color) with cloudiness and bubbling indicate an exothermic reaction. When the reaction is proceeding smoothly, add the remaining bromobenzene/ether solution dropwise.

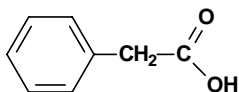
In some cases where the reaction may be "sluggish", the side-arm stopper may be removed and a dry stirring rod inserted to "nudge" several of the magnesium turning. Care should be exercised to prevent breakage of the flask (a common mistake which requires repeating the painful and time-consuming procedure!!). Heating the reaction flask initially may help, but prolonged heating is unnecessary. At times, the reaction flask may have to be cooled with ice water (briefly) to moderate the exothermic reaction. As the reaction subsides (some Mg residue may remain), reflux the mixture for an additional 15 minutes.

Nucleophilic addition of the Grignard reagent to CO₂: Immediately before this reaction, weigh out ca. 10 g Dry Ice on several paper towels (tared). Fold the towels, crush and place the Dry Ice in a 100 or 200 mL beaker. Under the fume hood, pour with stirring (caution!!) the Grignard reagent solution (contents of the reaction flask) over the Dry Ice. An additional 5-10 mL **anhydrous diethyl ether** may be required since the resulting addition salt becomes viscous. Cover the beaker with a watch glass, and allow the reaction to proceed (sublimation of excess CO₂ will occur).

After completion of the Grignard reaction, hydrolysis with acid is required to convert the salt to the free acid which will be extracted into the ether layer. Add ca. 10 g crushed ice followed by 3 mL of concentrated HCl and check for acidity with pH paper. Stir the mixture until two layers are evident. If more ether is required, add ca. 10 mL **t-butyl methyl ether**. Transfer the contents into a separatory funnel, remove and discard the lower layer. Wash the remaining ether layer in the separatory funnel with ca. 10 mL tap water.

SYNTHESIS OF BENZOIC ACID - HOMEWORK QUESTIONS

(1) Consider the synthesis of **phenylacetic acid** (shown below) via the Grignard reagent starting with the required **alkyl bromide** by a sequence similar to that used in the synthesis of benzoic acid.



- (a) Preparation of the Grignard Reagent from the appropriate alkyl bromide
- (b) Reaction of the Grignard Reagent with carbon dioxide to form the intermediate salt.
- (c) Treatment of the salt obtained in (b) with hydrochloric acid to free the **phenylacetic** acid.
- (d) The “COUPLING” side-reaction between the Grignard reagent in (a) and the alkyl bromide.
- (e) The side reaction of the Grignard Reagent in (a) with water.
- (f) The reaction of **phenylacetic** acid with sodium hydroxide
- (2) Considering your experience from this investigation, write the equation for the reaction of the Grignard reagent you prepared in the lab, C₅H₅-MgBr, with benzoic acid dissolved in diethyl ether.