NEW APPLICATIONS OF METAL CARBONYLS AS REAGENTS AND CATALYSTS IN SYNTHESIS

Howard Alper

Department of Chemistry, University of Ottawa, Ottawa, K1N 9B4, Canada

ABSTRACT - Recent results are described concerning the employment of metal carbonyls as reagents and catalysts in synthetic organic chemistry. Desulfurization of mercaptans and heterocyclic sulfur compounds (e.g., dibenzothiophene) can be achieved by the use of molybdenum hexacarbonyl in acetic acid, or adsorbed on silica gel. Epoxides, and alcohols capable of forming stable carbanions, can be efficiently deoxygenated by iron pentacarbonyl. A novel, and versatile, synthesis of mesoionic compounds and α-amino acid derivatives was realized by treatment of imidoyl halides with acyltetra-carbonylferrates. Azirines undergo interesting coupling (to heterocycles) and carbonylation (to isocyanates) reactions on exposure to metal carbonyls at room temperature. Phase transfer catalysis is a remarkably simple technique for effecting cobalt carbonyl catalyzed conversion of halides to acids [double carbonylation was observed in several instances], alkynes to butenolides, and dienes or trienes to acylated products. The latter two reactions are regiospecific.

Investigations during the past ten years have demonstrated the utility of metal carbonyls as reagents and catalysts in synthesis (Ref. 1). Among the most useful processes are those involving reduction, coupling, and carbonylation of organic substrates. This paper is concerned with recent developments in these three areas.
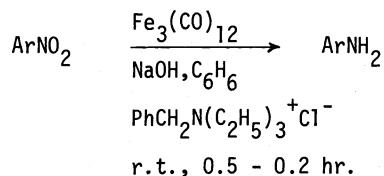
I. REDUCTION (DESULFURIZATION, DEOXYGENATION)

Desulfurization reactions are of considerable current interest, particularly with reference to applications for the removal of sulfur from fuel oil and flue gases. Thiocarbonyl compounds can be converted to olefins and/or hydrocarbons by a variety of metal carbonyls including dicobalt octacarbonyl, cyclopentadienyliron dicarbonyl dimer (Ref. 2), and molybdenum hexacarbonyl (Ref. 3). The latter Group VI metal carbonyl is a very useful reagent, not only for extracting sulfur from thioketones, but from organic compounds containing carbon-sulfur single bonds. The metal carbonyl is active, either in acetic acid [where molybdenum(II) is generated] or by adsorbance onto silica gel (Ref. 4). Examples include the formation of naphthalene from 2-naphthalenethiol, and the desulfurization of dibenzothiophene to biphenyl.
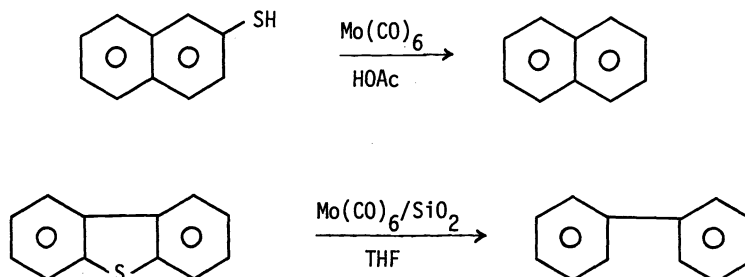

Iron pentacarbonyl is a fine reagent for deoxygenating N-oxides, nitrones, nitrile oxides, azoxy compounds, and sulfoxides (Ref. 5). Deoxygenation and coupling occurs with nitro compounds, while amines are efficiently produced by the use of triiron dodecacarbonyl

under phase transfer catalysis conditions (Ref. 6).

$$ArNO_2 \quad \xrightarrow[\substack{NaOH,C_6H_6 \\ PhCH_2N(C_2H_5)_3{}^+Cl^- \\ r.t., 0.5 - 0.2 \ hr.}]{Fe_3(CO)_{12}} \quad ArNH_2$$

The deoxygenation of epoxides by $Fe(CO)_5$ in dipolar aprotic solvents such as tetramethylurea (TMU) or N,N-dimethylacetamide is useful, both because good yields of olefins can be attained and a variety of functionalities can be tolerated [e.g., sulfone, ester, ketone, alcohol, olefin](Ref. 7). Even alcohols can be deoxygenated by $Fe(CO)_5$. The latter process is effected by initial _in situ_ generation of the alkoxide ion, and then reacting it with the metal carbonyl. Acid work-up affords the deoxygenated product, and destroys any metal
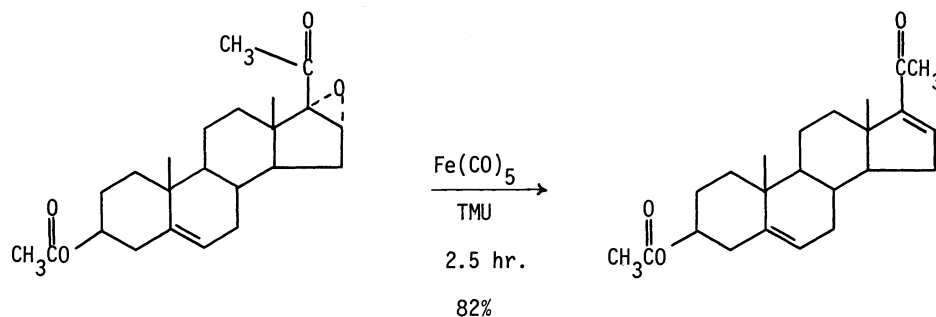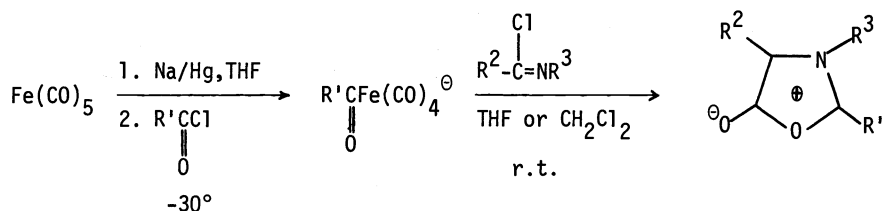

carbonyl residues. This deoxygenation procedure is applicable to alcohols capable of generating reasonably stable carbanions (Ref. 8).
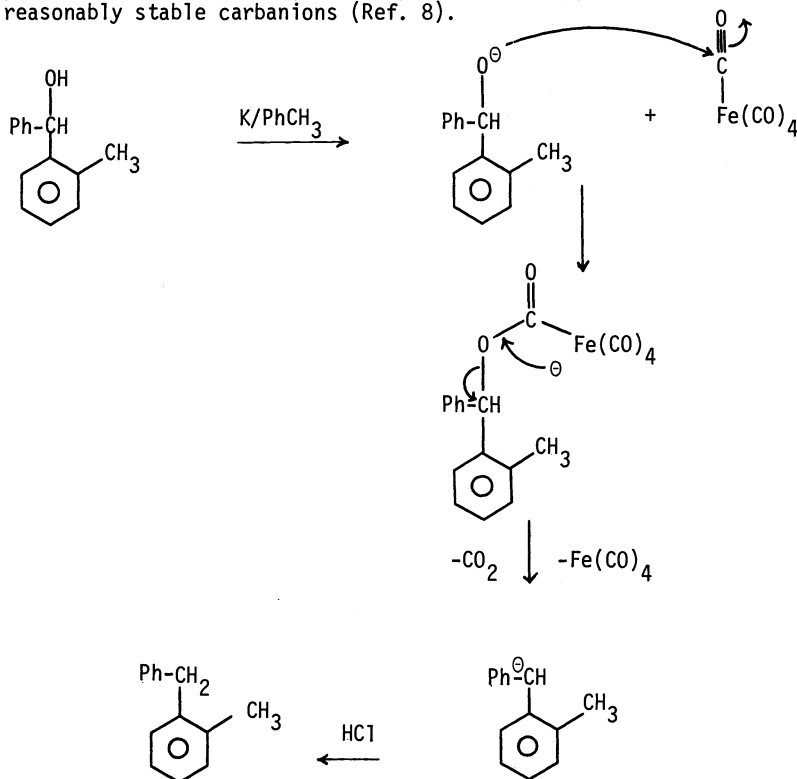
II. COUPLING REACTIONS

(a) Halide Derivatives

Much work has been done on coupling reactions of halides mediated by metal carbonyls (Ref. 1). Of particular note is the chemistry of tetracarbonylferrate(II), which has been reacted with saturated halides (or tosylate) to give ketones. There is solid evidence for the intermediacy of acyltetracarbonylferrates in these reactions. We have found acyltetracarbonylferrates [generated from $Fe(CO)_4^{-2}$ and an acid chloride at $-30°$] to be exceedingly useful reagents for the synthesis of 1,3-oxazol-5-ones, an important class of mesoionic compounds. This fascinating reaction occurs by exposure of imidoyl chlorides to the metal carbonyl anion. The location of substituent groups in the product suggests that a novel acyl

$$Fe(CO)_5 \xrightarrow[\substack{2.\ R'CCl \\ \\ O \\ -30°}]{1.\ Na/Hg,THF} R'CFe(CO)_4^{\ominus} \xrightarrow[\substack{THF\ or\ CH_2Cl_2 \\ r.t.}]{\substack{Cl \\ | \\ R^2-C=NR^3}} \text{(mesoionic product)}$$

migration from iron to nitrogen is a key step in the reaction pathway. Ligand migration of the carbon-iron σ-bond to one of the terminal carbonyl carbons may occur simultaneously or in a subsequent step. An amido ketene, which is a known precursor to the 1,3-oxazol-5-one, would result from decomplexation (Ref. 9).
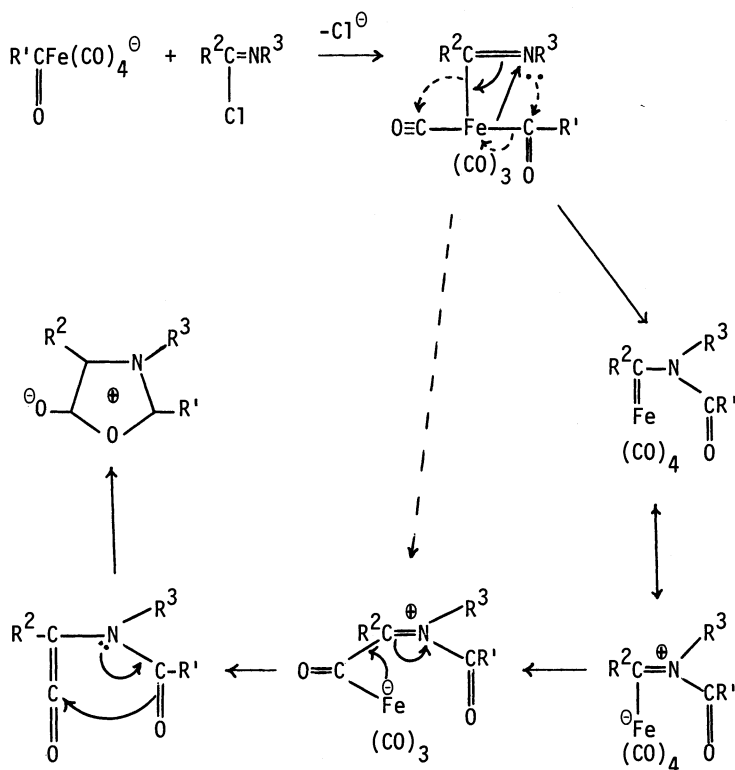

What is particularly valuable about this reaction is that it provides an entry to simple and polyfunctional α-amino acid derivatives, since the mesoionic compounds are readily ring-opened by water or alcohol.
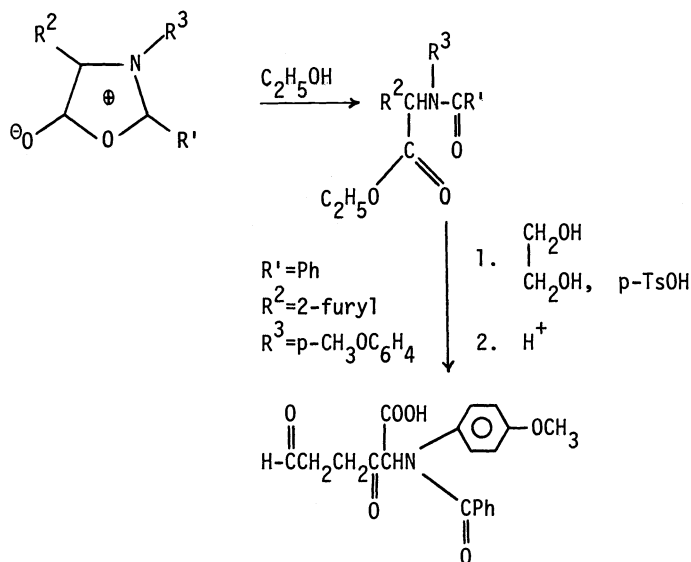
The reaction of imidoyl chlorides with acyltricarbonylnickelates appears to occur <u>via</u> an electron-transfer pathway, affording α-diketones and 1,4-diaza-1,3-butadienes as the principal products.

(b) Azirines

Metal carbonyls can induce a series of interesting cycloaddition reactions of azirines. Simple 2-arylazirines afford pyrazines and isomeric dihydropyrazines in the presence of Group VI metal hexacarbonyls. When the azirine possesses a substituent [aldehyde, Schiff base, α,β-unsaturated ester] at the saturated carbon of the three-membered ring which is capable of participating in intramolecular cycloaddition, then such a reaction will occur to give five membered ring heterocycles in high yield (Ref. 10). In the case of keto-vinylazirines, the stereochemistry about the double bond is an important factor as far as the reaction course is concerned (Ref. 11).
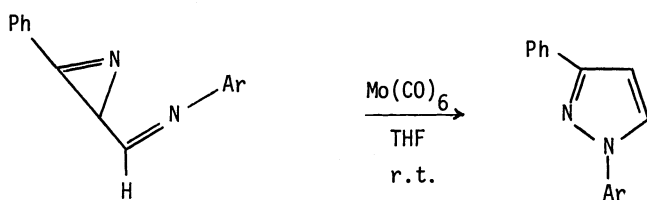
The cyclopentadienyliron dicarbonyl dimer can act in the same manner as Group VI metal carbonyls. An added feature, however, is the conversion of the metal carbonyl to the dimer of cyclopentadienone (Ref. 12).
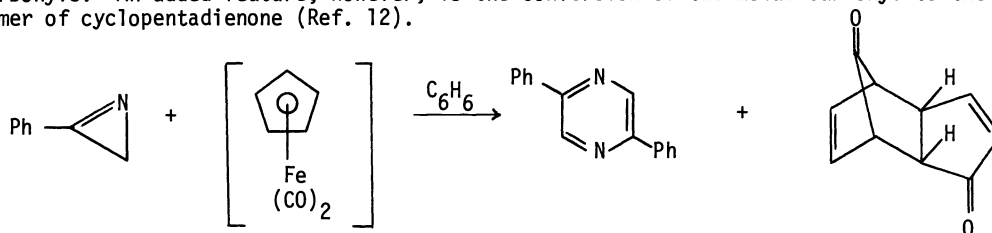
2-Styryl indoles can be synthesized in high yields by treatment of azirines with dicobalt octacarbonyl (Ref. 13) and chlorodicarbonylrhodium(I) dimer (Ref. 14). These heterocycles are precursors to a number of indole alkaloids.

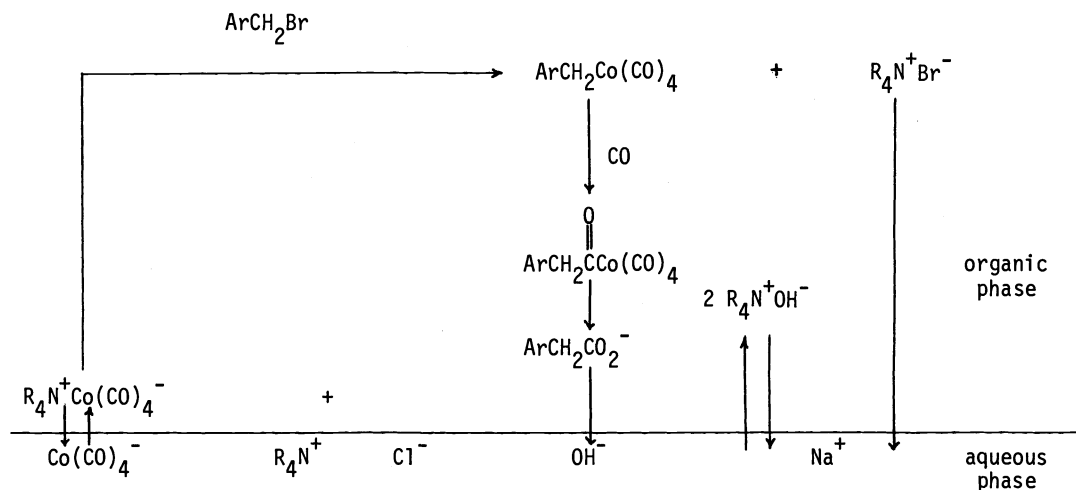### III. CARBONYLATION

(a) Azirines

We have initiated a study of the carbonylation of azirines in the presence of metal carbonyls. This study is directed towards the development of new synthetic methodology, and the entrapment of intermediates in the reactions described above. Initial results with rhodium are gratifying, since one can directly carbonylate azirines to vinyl isocyanates under very gentle conditions. The isocyanates were isolated as such or as urea or carbamate derivatives. The results can be interpreted in terms of nitrene or metallocycle intermediates (Ref. 15).
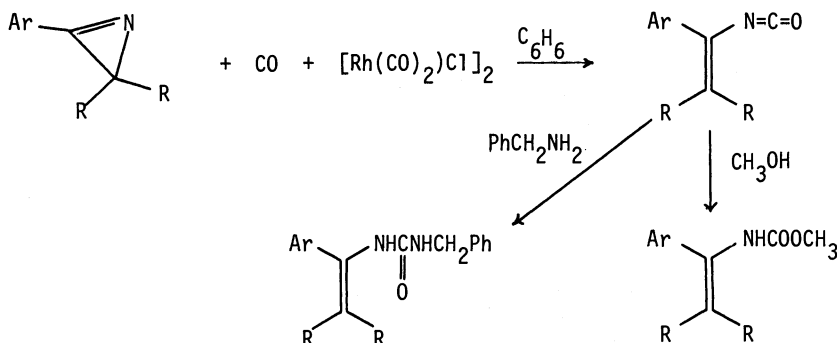

(b) Halides

Phase transfer catalysis is a technique of considerable potential in organometallic chemistry. Nowhere has it been more closely demonstrated than in the area of carbonylation reactions.

The cobalt carbonyl catalyzed carbonylation of halides to carboxylic acids is a reaction of considerable industrial importance. Some disadvantages of the reaction are that it requires elevated temperatures and pressures, long reaction times, excess base, and the product yields were usually modest (except for phenylacetic acid). We (Ref. 16), and Cassar (Ref. 17), found that the carbonylation reaction could be carried out under exceedingly mild conditions (r.t., 1 atm. pressure) by phase transfer catalysis. The reaction likely occurs _via_ alkyl and acylbobalt carbonyl intermediates.

In the case of o-methylbenzyl bromide, a novel double carbonylation occurred to give an
alkylated phenylpyruvic acid, in addition to o-methylphenylacetic acid. Such double
carbonylation reactions were observed (particularly under high-speed stirring) for other
benzylic bromides which contain electron-donating substituents on the benzene ring (Ref. 18).
The formation of pyruvic acid derivatives can be accounted for on the premise that enoli-
zation of the intermediate acylcobalt carbonyl takes place. Carbonylation of the vinyl-
cobalt species should be facile, and the resultant complex could then be converted to the
keto tautomer. The benzylic hydrogens of the pyruvoylcobalt carbonyl are more acidic than
those of the acylcobalt complex. Therefore, proton abstraction by base, followed by
alkylation and cobalt-carbon bond rupture, would afford the α-keto acid.
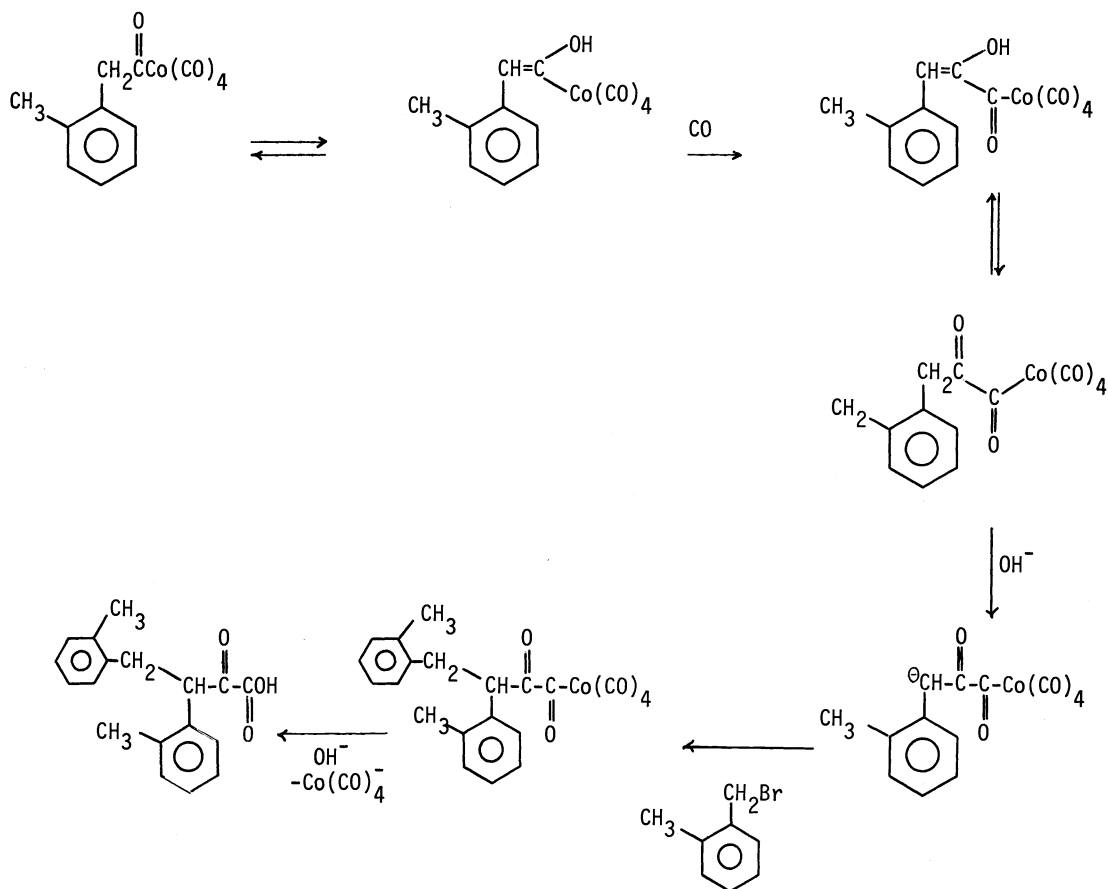
The acylcobalt tetracarbonyl was intercepted by a variety of unsaturated substrates. For
example, alkynes react with methyl iodide and carbon monoxide to form 2-butenolides in
good yields. This regiospecific reaction represents a simple, one-pot method for the
construction of an important class of pharmacological compounds. Mechanistically the
carbonylation of a vinylcobalt carbonyl intermediate is probably the key step in this
reaction (Ref. 19).
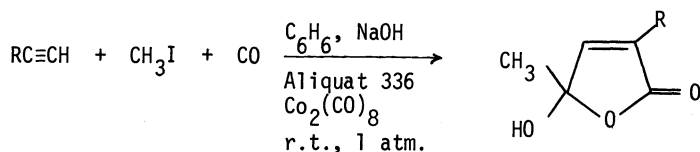
Dienes and trienes can be acylated by phase transfer catalyzed reaction with halides and carbon monoxide (Ref. 20). The reaction is regiospecific, with the acyl group becoming
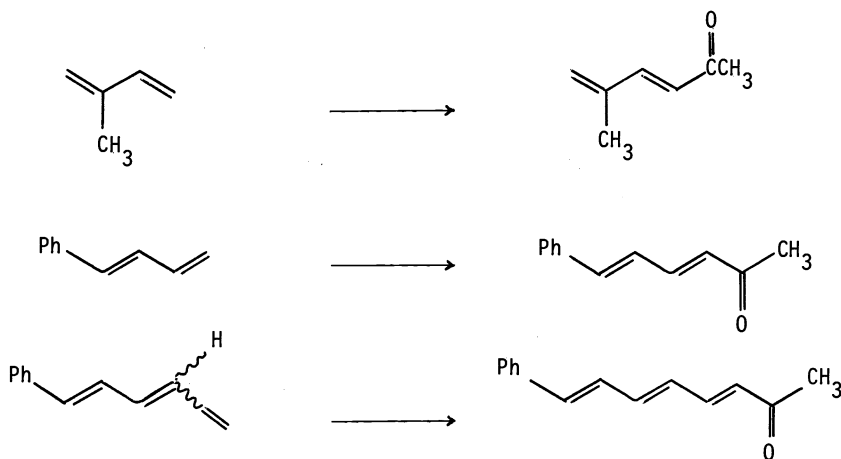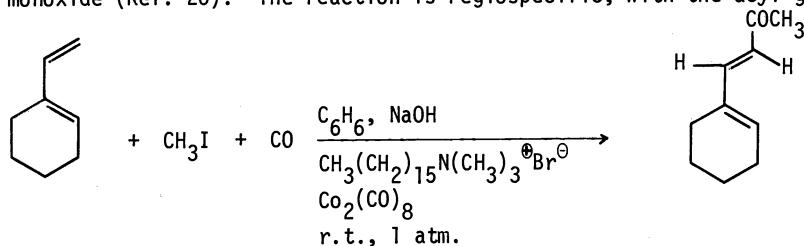
attached to the least substituted terminal carbon of the diene [and furthest removed from any substituent (if present) at an internal position].

ACKNOWLEDGEMENTS

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